Concept Development and Needs Identification for INFLO:

Functional and Performance Requirements, and High-Level Data and Communication Needs

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16. Abstract

The purpose of this project is to develop for the Intelligent Network Flow Optimization (INFLO), which is one collection (or bundle) of high-priority transformative applications identified by the United States Department of Transportation (USDOT) Mobility Program for development in 2011, the following:

- Concept of Operations (ConOps)
- Functional requirements and corresponding performance requirements
- High-level data and communication needs
- Test readiness Assessment Document

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1 Introduction

1.1 Purpose of the Document

The purpose of this document is to identify the functional requirements and high-level data and communication needs that must be accomplished in order to achieve the transformative goals identified in the Task 2.3 Intelligent Network Flow Optimization (INFLO) Concept of Operations (ConOps) document. This document is intended to communicate the requirements of the INFLO bundle of applications to the technical community who may develop and refine the applications or implement operational systems based on the concept.

1.2 Scope of the INFLO Project

In support of USDOT's Intelligent Transportation Systems' (ITS) Mobility Program, several of the Department's agencies are fully engaged in exploiting active interaction between fixed and mobile transportation system entities both in the way new forms of data are being exchanged and in the opportunities that are afforded to extend the geographic scope, precision and control of our Nation's surface transportation system. An important initiative within the framework of this strategic effort is the Dynamic Mobility Applications (DMA) program which, in part, seeks to create applications that fully leverage frequently collected and rapidly disseminated multi-source data gathered from connected travelers, vehicles and infrastructure, and that increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks. Under this program, the USDOT has identified a portfolio of ten high-priority mobility applications, including a common bundle collectively identified as Intelligent Network Flow Optimization, or INFLO.

The purpose of the INFLO project is to facilitate concept development and needs refinement for the INFLO applications and to assess their readiness for development and testing. The three applications under the INFLO bundle will ultimately help to maximize roadway system productivity, enhance roadway safety and capacity, and reduce overall fuel consumption. These three applications are:

- Queue Warning (Q-WARN);
- Dynamic Speed Harmonization (SPD-HARM); and
- Cooperative Adaptive Cruise Control (CACC).

In selecting these applications, the USDOT sought applications that have the potential to be transformative (i.e., that they result in substantial roadway mobility and safety improvements), that are achievable in the near-term, and that leverage the opportunities provided through connected entities. This philosophy of identifying applications that can be deployed in the near-term is in keeping with the USDOT's goals of quickly moving these applications from the research stage to adoption in the field.

Other considerations that will promote this widespread implementation include carefully considering user needs and requirements, ensuring the availability of required data sources, identifying potential barriers to implementation, and (wherever possible) using non-proprietary and/or open source approaches that can readily be adopted by a wide variety of potential end users in both the public and private sector.

The first task of this project was to conduct an assessment of the current state of practice and relevant prior and ongoing research for INFLO (see *Report on Assessment of Relevant Prior and Ongoing Research for INFLO*). The purpose of this assessment was to provide a clear understanding of relevant research in the area of network flow optimization that might impact the development and eventual deployment of an INFLO system. Relevant research and practices identified in the assessment formed the basis for the current state definition of this ConOps document.

The next task of this project was to conduct a face-to-face stakeholder workshop to solicit input on goals, performance measures, transformative performance targets, and high-level user needs for the INFLO bundle of applications (see *Report on Stakeholder Input on Goals, Performance Measures, Transformative Performance Targets, and High-Level User Needs for INFLO*). This workshop was conducted on February 8, 2012 at the Hall of States in Washington D.C. In total, 56 stakeholders participated in the workshop, representing a wide variety of backgrounds and expertise relevant to the analysis of the INFLO applications. Stakeholder input was crucial in defining the key goals, performance measures, and user needs described in this ConOps and in identifying key operational scenarios for each application.

The following task was to develop the INFLO Concept of Operations in order to define the concepts for the three INFLO applications, develop relevant operational scenarios that demonstrate the capabilities of the applications, identify the transformative goals (with respect to mobility, environment, and safety impacts) that the applications can realize, and develop corresponding qualitative and quantitative measures for estimating the performance of the applications in achieving these transformative goals. (See *INFLO Concept of Operations*.)

The current task, and the subject of this document, is to identify and assess the functional and performance requirements and data and communication needs of the INFLO system. The requirements specify what the INFLO bundle of applications must accomplish in order to meet the goals and objectives identified in the Concept of Operations. The requirements are organized by user need and sub-system in order to ensure that they can be traced back to the needs and issues identified in the ConOps.

The final phase of this project is to conduct a test-readiness assessment for the INFLO applications, which entails identifying the technical and non-technical issues related to field testing the applications.

1.3 Document Overview

This document is organized and will be presented following the guidelines of IEEE 1362-1998 - IEEE *Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document*.

The sections are as follows:

- Chapter 1 – Introduction
- Chapter 2 – General Description of INFLO

- Chapter 3 – Requirements
- Chapter 4 – Data and Communication Needs

2 General Description of INFLO

This section describes the operational concepts for the three INFLO applications and provides justification for their selection. The operational concepts are not intended to be detailed designs of the applications, but high-level, conceptual descriptions of how the applications are expected to operate. The concepts provide only as much detail as is needed to be able to develop meaningful operational scenarios.

2.1 Dynamic Speed Harmonization (SPD-HARM)

2.1.1 Context

Speed harmonization of traffic flows in response to downstream congestion, incidents, and weather or road conditions can greatly help to maximize traffic throughput and reduce crashes. Research and experimental evidence have consistently demonstrated that by that reducing speed variability among vehicles, especially in near-onset flow breakdown conditions, traffic throughput is improved, flow breakdown formation is delayed or even eliminated, and collisions and severity of collisions are reduced.

The INFLO SPD-HARM application concept aims to realize these benefits by utilizing connected vehicle V2V and V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles. Figure 2-1 below provides a stylized depiction of how the SPD-HARM concept could work.

The SPD-HARM concept reflects an operational environment in which speed recommendation decisions are made at a TMC or other traffic management entity and then communicated to the affected traffic. In such an environment, the SPD-HARM application is considered to reside within the traffic management entity and be external to the vehicle. This approach was taken because it was agreed that effective speed harmonization requires the coordination of traffic across large portions of the road network, a task not well suited to ad-hoc vehicle-to-vehicle communication.

SPD-HARM driver communication will always give priority to crash avoidance/mitigation safety applications when such applications determine that a safety alert is necessary.

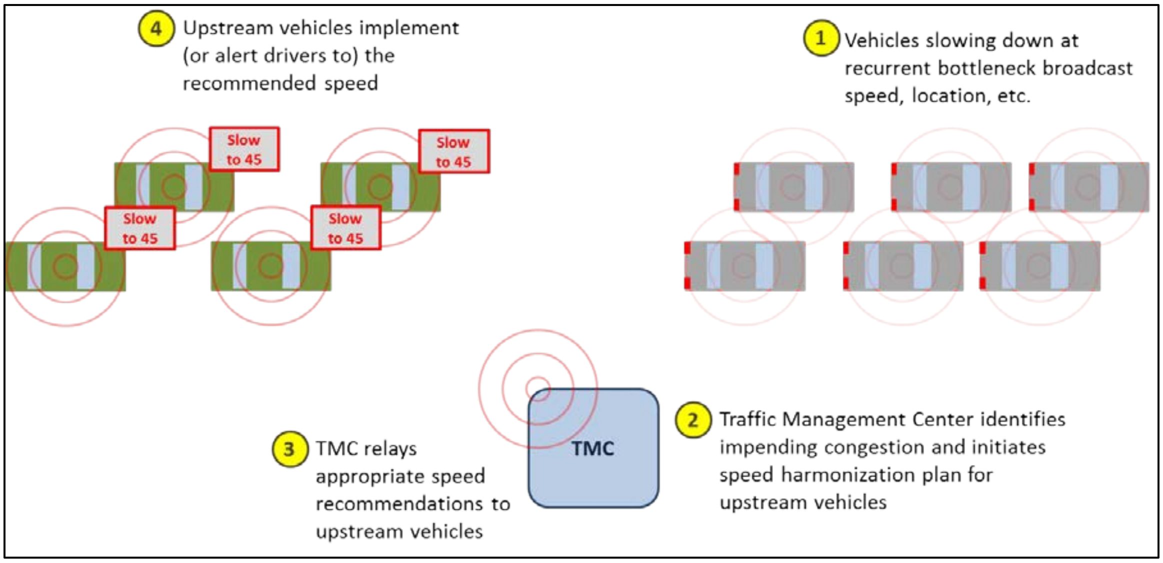

Figure 2-1. Stylized Depiction of a Connected Vehicle-Enabled SPD-HARM Application.

2.1.2 Modes and States

This section discusses the various modes of operation for the proposed SPD-HARM concept. The speed harmonization system should mostly activate during recurrent congestion periods (e.g., morning and evening peaks) and non-recurrent events (e.g., incidents and weather conditions).

The typical modes of operation for the SPD-HARM concept are:

Normal Mode: SPD-HARM in the normal operation mode should have all the designed functionality available. All systems and subsystems should work properly.

Degraded Mode: In this mode, some function(s) are not working properly and might go offline. Many different scenarios could result in operation in this mode, such as failed communication.

Training Mode: The control center should have the capability of operating in the training mode for the purpose of training the new operators. The mode allows new operators to train on simulations without interfering with the actual daily operations.

Maintenance Mode: During the maintenance of the system, some subsystems and their functionalities may go offline. This mode is very similar to the Degraded Mode but the system usually can go online if needed. This means that this mode would not affect the normal operation.

Failsafe Mode: The system should have the ability to perform normal operation (or at least some levels of normal operation) when there is no connection between the system and the control center.

2.1.3 Major System Capabilities

Traffic Information Collection Subsystem (Data Acquisition)

The purpose of this subsystem is to collect and transmit information about the current traffic condition and vehicle classifications to the control center. Two primary sources of data are available to collect traffic information:

1. Fixed-location sensor stations, providing an operator's perspective on facility condition and operational state
2. Mobile sources, namely the Connected Vehicles, providing individual-specific information on vehicle state and user-experienced traffic.

The traffic information subsystem compiles, fuses, and interprets data gathered from both sensors and vehicles and provides information about the traffic condition along the facility. The information is then used for the purpose of congestion alerts and speed selection, including personalized information when considered in conjunction with vehicle-specific conditions. This can be done on a reactive or predictive basis (depending on the underlying algorithms).

The information from these two sources is different in nature as well as in format, though similar indicators could be computed from both sources for basic versions speed harmonization strategies.

- For traffic sensors, the aggregated speed, flow, and occupancy data collected are specific to both line and link. Effective use of speed harmonization to improve traffic fluidity and avoid flow breakdown requires accurate measurement of vehicle speeds over a stretch of highway, and computation of the variance of these measurements over short intervals of no more than 1~2 minutes, and possibly 30 seconds if sufficient number of connected vehicles are sending information (and thus enabling calculation of a meaningful sample variance). Connected Vehicle architectures enable greater flexibility and possibilities in terms of local vs. central processing than fixed-location sensors, but in all cases the main monitoring and algorithmic functions are best executed centrally so as to consider facility-wide and system-wide perspectives rather than a purely local segment-level one.
- Unlike fixed-location traffic sensors, the Connected Vehicle subsystem provides information on individual vehicles and their unique experience. The Connected Vehicle Subsystem is capable of providing all the required information for decision-making for speed selection, incident detection, and breakdown formation identification. Depending on the degree of technological sophistication and user permissions, information could include vehicle mechanical status and driver preferences, as well as recent experience with the facility. In addition to providing the control center and/or the speed harmonization application with complementary information to that provided by fixed sensors, especially when aggregated over several vehicles in a given local neighborhood, information through the Connected Vehicle subsystem can also form the basis for customizing and personalizing user instructions, as well as monitoring the performance, effectiveness and gaps of the supplied control, and therefore provide essential information for improving and adapting the control logic over time.. In the case where connected vehicle penetration is low or the Connected Vehicle Subsystem is not fully functional, traffic sensors can be supplemental or backup source of data.

The SPD-HARM traffic information collection subsystem also requires a user interface where the users can change the configurations of the data collection (e.g., the aggregation interval for the traffic data). This interface will likely be a map-based interactive interface, in which link traffic conditions are easily distinguishable and information on data sources, average speeds, flow, and density (occupancy) is readily available. In addition, information about the speed variance is needed for speed harmonization applications.

Environmental Information Collection Subsystem

The purpose of this subsystem is to collect and transmit the current environmental condition to the control center. Four sources of data collection are available to collect environmental information:

1. Environmental sensor stations
2. Third-party data providers
3. Probe vehicles
4. Connected vehicles

Information from these sources is transmitted to the control center and used to generate weather responsive alerts and appropriate speed selections. The kinds of environmental information collected by connected vehicles are relatively limited and include traction status, outside temperature readings, and windshield wiper activation information. Environmental sensor stations (also known as Road Weather Information Systems (RWIS)), however, collect a great deal more environmental data from the field, including visibility, air temperature, road temperature, humidity, wind speed, pressure, and precipitation.

The SPD-HARM environmental information subsystem requires a user interface that allows for configuration of the environmental data collection, including modifying the schedule for data collection intervals. An interactive map is also useful for providing key information to the user, such as visibility, air temperature, road temperature, humidity, wind speed, and precipitation for specific locations and links.

Note that certain applications of speed harmonization may not be intended to address weather-related problems, or may be limited in application to “normal” weather conditions. In this case, the environmental data subsystem would not be essential. However, the ability to provide speed information for all applicable weather conditions would enhance the system’s effectiveness and the public’s confidence in the information provided. Accordingly, we include this subsystem in the essential category.

Speed Harmonization Response Generation Subsystem

The purpose of the speed harmonization subsystem is to use the data collected from the traffic and environmental information collection subsystems to select appropriate speed recommendations and generate other recommended actions for specific segments and road users of the facility. A speed selection algorithm should be used to determine the timing, locations, and values of speed adjustments. Note that the algorithm must be capable of predicting traffic conditions, identifying potential solutions, and evaluating these solutions in real-time. Traffic simulation capabilities, incorporating both real-time and historical data, form the basis of the estimation and prediction capability. These, as well as the traffic optimization models must be constantly evaluated, adjusted, and improved.

An interface should provide the speed harmonization subsystem user the ability to access SPD-HARM connected vehicle driver alerts and infrastructure-based VSLs for a given segment and modify configuration settings if necessary. Any action taken by the operator or system should be recorded in the Data Storage Subsystem (see Data Storage discussion below).

Information Dissemination Subsystem

The purpose of this subsystem is to send speed harmonization related information generated by the response generation subsystem to road users on specific segments of the road facility via in-vehicle alerts and/or traditional DMS and lane control signal (LCS) systems. The subsystem should allow for simultaneous control of message transmission to connected vehicles and infrastructure-based signs for a given road segment. It should also allow for the configuration of in-vehicle messages or lane control signals for portions of the traffic flow on a lane-by-lane basis.

Certain pre-defined thresholds are used for the determination of high risk situations for fog events, road freezing events, and high winds. When the measured values cross certain thresholds, specific responses, including speed reduction and weather advisory alerts, activate for the facility. Environmental information can also be collected from third-party data providers and portable environmental sensor stations.

Data Storage (Warehouse)

Major changes in facility management decisions and changes in system device status should be stored for a reasonable amount of time (e.g., the system could store data for 13 months so that to make one year of data always available). The system also should store the traffic and environmental data for the purpose of using as historical data in the speed selection algorithm as well as automatic incident detection. This will support the dual functionality of performance monitoring and assessment, as well as algorithm and knowledge-based enhancement.

Service Monitoring Subsystem

The role of this subsystem is to alert operators to system issues and to provide operators with information on how to address or isolate the issues. In addition, the service monitor subsystem notifies the maintenance and support team. When a part of a subsystem is malfunctioning or requires maintenance, the information may come to the operator in the control center to send a work order to the maintenance and support team. Note that this subsystem does not integrate all the functionality of the maintenance system, but rather provides alerts to operators to help facilitate the required maintenance.

Automated Incident Detection Subsystem

This capability falls under the general system management category—not directly essential to speed harmonization, but beneficial as part of the overall package of interventions that include speed harmonization. The purpose of this subsystem is to automatically alert users of potential incidents or events (e.g., congestion occurrence) by controlling and analyzing connected vehicle system, sensors, and video data. The subsystem monitors traffic data and video and compares them with historical data to determine any anomalies in the traffic flow pattern.

Note that the use of connected vehicle technology makes the incident detection algorithms much simpler as the output of the conventional algorithm can be directly transmitted to the control center through the V2I protocols. Furthermore, experience over the past 10 years has shown that the widespread availability of cell phones all but guarantees that authorities are alerted of any incident long before it can be detected by any algorithm.

Compliance Monitoring Subsystem
The purpose of this system is to automatically identify speed recommendation violations and to alert the control entity of such events. Violator identification can occur either by conventional automated speed detection methods (e.g., overhead radar) or by connected vehicle-based detection and identification (e.g., Electronic Vehicle Identification and Intelligent Speed Assistance).

Automated enforcement is not considered a part of the compliance monitoring system due to its associated challenges, particularly in the U.S., relating to data privacy concerns, data ownership, legal authority questions, OEM participation, and user acceptance. While international experience in speed harmonization indicates that automated enforcement generally promotes increased speed compliance (see *Report on Assessment of Relevant Prior and Ongoing Research for INFLO*), it is unlikely that any SPD-HARM deployment in the U.S. will utilize mandatory speed limits or automated enforcement of speed recommendations.

However, as discussed previously, there is evidence that speed harmonization can be largely self-enforcing, as limited compliance in the kind of high-volume, high-density situations where speed harmonization is generally called for would be sufficient to bring the entire traffic stream into compliance as passing opportunities become virtually non-existent. Greater user acceptance and compliance could also be encouraged through incentive-based systems, discussed previously.

2.1.4 Major System Conditions

This document is intended to define system requirements for a typical SPD-HARM deployment. Within this framework, there are certain system conditions which should be met in order for a deployment to occur. These conditions will vary depending on the precise deployment location and stakeholder desires, but these are specific conditions that are deemed important to any SPD-HARM deployment.

ITS staffing
It is not necessary to recruit new staff to deploy SPD-HARM applications, especially as the algorithms become more intelligent and more adaptive. However some investment in time and effort is required for initial training, and monitoring and tracking. This may increase the workload to some degree on TMC operators after initial implementation.

Data provision and ownership policies
Inter-agency, inter-jurisdictional, and public-private data sharing agreements—in particular with respect to connected vehicle data—must be well defined in order for the SPD-HARM concept to operate. This means that the current day issues related to privacy protection and liability concerns as well as the institutional barriers that have frequently impeded the ability of transportation agencies to share operational data must be overcome. Specifically with regard to speed harmonization applications, different implementation architectures will have different implications for data availability, use and ownership. Strategies based on sensor-derived data are least controversial from an agency standpoint; strategies using information provided by individual vehicles may require further elaboration.

System performance management
Effectiveness of speed harmonization, like most online dynamic control strategies, requires continual monitoring and adaptation to reflect changes in the external environment, as well as the behavioral adjustment displayed by system users. Policies should be set for renewing the devices and algorithms that fall outside of the predefined standards in the policy. Note that the policies related to SPD-HARM should be consistent with the policies for the other INFLO applications and systems, as they will likely use the same devices and facilities.

Software and hardware development process
Development and validation of the SPD-HARM application and communication system must follow a structured product development process for hardware and software.

Software distribution
Based on analysis of the performance of the speed harmonization system, software and algorithm updates must be transmitted wirelessly to the connected vehicles/devices in the field. This will reduce the amount of required coordination between the operators and OEMs and provides a less vehicle-dependent environment in which to operate the system.

Accident liability
Policies must be developed that cover liability and litigation issues that may arise due to accidents and malfunctions with SPD-HARM systems. Vehicle manufacturers in particular are concerned about the risks and liability potential associated with vehicle systems that rely on externally generated information.

2.1.5 Major System Constraints

Minimum interval for posted speed adjustments
The minimum interval before changing displayed or disseminated speed recommendations is an important parameter of speed harmonization logic, and reflects a trade-off between driver expectation and operational effectiveness. Absent CACC (or a similar autonomous car following environment), connected vehicle drivers can be expected to acknowledge and adjust to only so many varying speed target recommendations before they stop attending to SPD-HARM recommendations completely.

Compliance
Speed harmonization systems would only require a small percentage of complying drivers to achieve much of their intended benefit. However, attaining this level of compliance would still require a combination of driver education and incentive-based approaches, including devising opt-in participatory programs. (See *INFLO Concept of Operations*, Section 5.3.1 for a fuller discussion of the benefits of an opt-in program for INFLO-enabled vehicles on managed lanes.)

Algorithm effectiveness
Algorithms currently utilized for speed harmonization applications vary in terms of sophistication and effectiveness and research remains incomplete in this regard. The success of a connected vehicle based SPD-HARM application will depend on how effective the underlying speed harmonization algorithm is at interpreting traffic and weather conditions data and generating speed recommendation

plans in response. Effective strategies are likely to require local calibration, testing and adaptation over time, which are best undertaken within an open framework.

System architecture design flexibility
The degree of flexibility in system architecture design and operational deployment affects the ability of the system to respond to changing conditions, improved technology, and other developments in this rapidly evolving field. The new design should also consider backward compatibility and be able to read and receive data based on older standards including data formats and communication protocols.

2.1.6 Operational Scenarios

SPD-HARM operational scenarios were developed as part of the INFLO Concept of Operations in order to provide a system definition that could be implemented in a variety of locations. Thus, they were made to be generic and not location-specific. The operational scenarios that were identified are as follows:

1. *Fixed Point Breakdown Formation (external-to-vehicle processing and I2V speed recommendation dissemination)* – A flow breakdown starts to form at a known flow breakdown point. Applicable situations include known bottlenecks on the facility (e.g., bridges, tunnels, on- and off-ramps, and positive grades). Because the boundaries of the breakdown formation point are known, roadside equipment (RSE) and infrastructure-based systems have been installed to monitor traffic flow conditions and generate speed recommendations for approaching vehicles. Appropriate speed and lane usage recommendations are disseminated to upstream vehicles via infrastructure-to-vehicle (I2V) communication as well as dynamic message signs (DMS).
2. *Non-Location Specific Breakdown Formation (external-to-vehicle processing and I2V speed recommendation dissemination)* – Flow breakdown occurs at a location that is not closely monitored as a known fixed flow breakdown point. As a result, high detail infrastructure-based detection and segment-specific predictive models of flow breakdown are not available. The primary means of traffic conditions detection and speed recommendation dissemination is via connected vehicle-based communication. Traffic flow analysis and speed recommendation determination occurs external to the vehicle (i.e., by the Traffic Management Entity's SPD-HARM application).
3. *Weather-Related Speed Harmonization (external-to-vehicle processing and I2V speed recommendation dissemination)* – Utilizing extensive real-time modeling of weather impacts on traffic to choose the safe speed for the prevailing weather condition. The Traffic Management Entity's SPD-HARM application uses traffic and weather data collected from connected vehicles throughout the transportation network, environmental sensors, and other third party agencies to provide appropriate speed guidance to maximize traffic flow and reduce safety risks.

See Section 6.1 of the *INFLO Concept of Operations* document for a more detailed discussion of these scenarios.

2.2 Queue Warning (Q-WARN)

2.2.1 Context

Queuing conditions present significant safety concerns, particularly with the increased potential for rear-end collisions. They also present disruptions to traffic throughput by introducing shockwaves into the upstream traffic flow. The INFLO Q-WARN application concept aims to minimize the occurrence and impact of traffic queues by utilizing connected vehicle technologies, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications, to enable vehicles within the queue event to automatically broadcast their queued status information (e.g., rapid deceleration, disabled status, lane location) to nearby upstream vehicles and to infrastructure-based central entities (such as the TMC) in order to minimize or prevent rear-end or other secondary collisions.

It is important to note that the Q-WARN application concept is not intended to operate as a crash avoidance system (e.g., like the forward collision warning [FCW] safety application). In contrast to such systems, Q-WARN will engage well in advance of any potential crash situation, providing messages and information to the driver in order to minimize the likelihood of his needing to take crash avoidance or mitigation actions later. As such, Q-WARN-related driver communication will always give priority to crash avoidance/mitigation safety applications when such applications determine that a safety-related alert is necessary.

Figure 2-2 below provides a stylized depiction of how the Q-WARN concept could work.

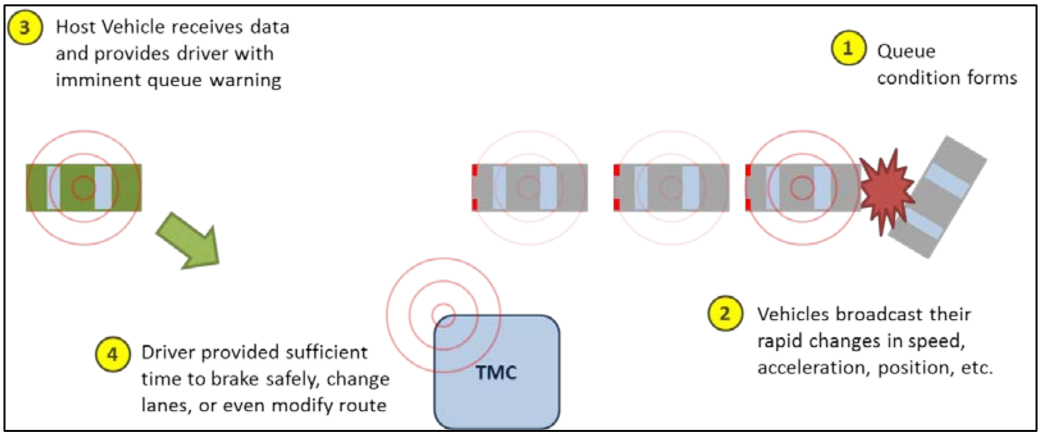

Figure 2-2. Stylized Depiction of a Connected Vehicle-Enabled Q-WARN Application.

2.2.2 Modes and States

This section discusses the various modes of operation for the proposed Q-WARN concept. The queue warning system should mostly activate at fixed queue generation points and during recurrent congestion periods (e.g., morning and evening peaks) and non-recurrent events (e.g., incidents and weather conditions).

The typical modes of operation for the Q-WARN concept are:

Normal Mode: Q-WARN in the normal operation mode should have all the designed functionality available. All systems and subsystems should work properly.

Degraded Mode: In this mode, some function(s) are not working properly and might go offline. Many different scenarios could result in operation in this mode, such as failed communication.

Training Mode: The control center should have the capability of operating in the training mode for the purpose of training the new operators. The mode allows new operators to train on simulations without interfering with the actual daily operations.

Maintenance Mode: During the maintenance of the system, some subsystems and their functionalities may go offline. This mode is very similar to the Degraded Mode but the system usually can go online if needed. This means that this mode would not affect the normal operation.

Backup Mode: The system should have the ability to perform normal operation (or at least some levels of normal operation) when there is no connection between the system and the control center.

2.2.3 Major System Capabilities

The conceptual Q-WARN application performs two essential tasks: queue determination (detection and/or prediction) and queue information dissemination. In order to perform these tasks, Q-WARN solutions can be vehicle-based or infrastructure-based or utilize a combination of each. See Table 2-1 for a summary of the capabilities and advantages of these approaches for essential Q-WARN tasks.

Table 2-1. Comparison of Vehicle- and Infrastruture-based Q-WARN Capabilities.

Task	Vehicle-based Q-WARN	Infrastructure-based Q-WARN
Queue determination – *detection*	Yes (less precise, wider range)	Yes (more precise, limited range)
Queue determination – *prediction*	No (insufficient visibility into traffic state)	Yes (able to monitor traffic state for given locations)
Queue information dissemination	Yes (V2V)	Yes (I2V)

Queue determination (detection and/or prediction):
A strictly vehicle-based Q-WARN application is necessarily *reactive*, in that it can only detect and respond to an already-formed queue because it has visibility only into the immediate local traffic. Vehicle-based Q-WARN is not capable of predicting potential queue formation because it does not have a comprehensive picture of the traffic state, in terms of historical patterns and the wider traffic conditions. Additionally, limited visibility into the traffic state is likely to reduce the precision and reliability of vehicle-based queue detection. Despite these limitations and given high enough levels of

connected vehicle penetration (likely only in the long term), vehicle-based Q-WARN has the advantage of being immediately deployable on nearly any roadway without the need for the construction, operation, or maintenance of queue warning related infrastructure.

An infrastructure-based Q-WARN application, on the other hand, can be *proactive*—utilizing its broader visibility into the traffic state to predict likely queue formations. A central entity (such as a Traffic Management Center) can predict, using data collected over a period of time and over a geographical area, the location, length, duration, and likelihood of a queue forming. This allows for preemptive actions to be taken to either minimize the impact or prevent the formation of a vehicle queue. Thus, an infrastructure-based component for the Q-WARN application is necessary for queue prediction even in the long-term.

Queue information dissemination:
A strictly vehicle-based queue information dissemination approach (i.e., without external intervention from infrastructure systems or traffic management entities) would provide adequate upstream traffic queue warning, given sufficient levels of connected vehicle-equipped market penetration. Vehicle-based queue information dissemination would also be viable for queue warnings and related information generated by infrastructure-based entities. However, due to the need for high connected vehicle penetration levels, the vehicle-based information dissemination approach is likely to be more applicable in the mid-to-long term.

An infrastructure-based queue information dissemination approach, on the other hand, will be more effective in the near-term at providing sufficient queue warning when there are fewer equipped vehicles on the road. Additionally, in cases where vehicle-based communication may not be feasible (for example, at a tunnel entrance where line-of-sight obstructions may prevent direct communication between vehicles), infrastructure-based information dissemination will be required in order to provide a queue warning capability.

2.2.4 Major System Conditions

This document is intended to define system requirements for a typical Q-WARN deployment. Within this framework, there are certain system conditions which should be met in order for a deployment to occur. These conditions will vary depending on the precise deployment location and stakeholder desires, but these are specific conditions that are deemed important to any Q-WARN deployment.

ITS staffing
There is also limited ability (from both time and budget points of view) for hiring and training the new staff. As a result, the current staff might have more duties compare to their current duties after implementing the new Q-WARN system.

Data provision and ownership policies
Inter-agency, inter-jurisdictional, and public-private data sharing agreements—in particular with respect to connected vehicle data—must be well defined in order for the Q-WARN concept to operate. This means that the current day issues related to privacy protection and liability concerns as well as the institutional barriers that have frequently impeded the ability of transportation agencies to share operational data must be overcome.

System performance management
Policies should be set for renewing the devices and algorithms that fall outside of the predefined standards in the policy. Note that the policies related to Q-WARN should be consistent with the policies for the other INFLO applications and systems, as they will likely use the same devices and facilities.

Accident liability
Policies must be developed that cover liability and litigation issues that may arise due to accidents and malfunctions with Q-WARN systems. Vehicle manufacturers in particular are concerned about the risks and liability potential associated with vehicle systems that rely on externally generated information.

Software and hardware development process
Development and validation of the Q-WARN application and communication system must follow a structured product development process for hardware and software.

Software distribution
Based on analysis of the performance of the Q-WARN system, software and algorithm updates must be transmitted wirelessly to the connected vehicles/devices in the field. This will reduce the amount of required coordination between the operators and OEMs and provides a less vehicle-dependent environment in which to operate the system.

2.2.5 Major System Constraints

Algorithm effectiveness
Algorithms currently utilized for queue warning and queue detection vary in terms of sophistication and effectiveness and research remains incomplete in this regard. The success of a connected vehicle based Q-WARN application will depend on how effective the underlying queue detection algorithm is at interpreting streaming connected vehicle data and reliably identifying formed or impending queues. Producing too many false positive queue warnings may result in drivers taking the warnings less seriously or even ignoring them completely.

System architecture design flexibility
The degree of flexibility in system architecture design and operational deployment affects the ability of the system to respond to changing conditions, improved technology, and other developments in this rapidly evolving field.

2.2.6 Operational Scenarios

Q-WARN operational scenarios were developed as part of the INFLO Concept of Operations in order to provide a system definition that could be implemented in a variety of locations. Thus, they were made to be generic and not location-specific. The operational scenarios that were identified are as follows:

1. *Fixed Queue Generation Point Queue Warning (external-to-vehicle processing and I2V queue warning dissemination)* – A queue forms at a known queue

generation point. Applicable situations include spillover at exit ramps, border crossings, lane merges, bridges, and tunnels. Because the queue generation point is known, roadside equipment (RSE) and infrastructure-based systems have been installed to monitor queue conditions and generate warnings and response strategies for approaching vehicles. V2V communication is supplemented by externally-originated queue warnings and response strategies, which are disseminated to upstream vehicles via infrastructure-to-vehicle (I2V) communication as well as dynamic message signs (DMS).

2. *Non-Location Specific Queue Warning (vehicle-based processing and V2V queue warning dissemination)* – A queue forms on a roadway with sparse roadside equipment (RSE) coverage. Queue detection will be done in-vehicle, alerts will be propagated upstream solely via V2V communication, and response strategies will be devised in-vehicle on the fly. Because this scenario relies wholly on connected vehicle-based detection, communication, and response development, non-connected vehicles will be unable to participate. Therefore, this scenario should be considered representative of the long-term state of the connected vehicle environment.

3. *Weather-Related Queue Prediction and Warning (external-to-vehicle processing and I2V dissemination)* – Traffic Management Entity conducts extensive real-time modeling of weather impacts on traffic to predict impending queue formation. The Traffic Management Entity's Q-WARN application draws extensively from traffic and weather data from the data environment collected from connected vehicles throughout the transportation network. By anticipating imminent queue formation, the Traffic Management Entity will provide proactive warnings and recommendations to affected vehicles in order to minimize the impact of or even eliminate completely the predicted queue.

See Section 6.2 of the *INFLO Concept of Operations* document for a more detailed discussion of these scenarios.

2.3 Cooperative Adaptive Cruise Control (CACC)

2.3.1 Context

Cooperative adaptive cruise control (CACC) can significantly increase traffic throughput by tightly coordinating in-platoon vehicle movements to reduce headways between vehicles, resulting in a smoothing of traffic flow and an improvement in traffic flow stability. Additionally, by reducing drag, shorter headways can result in improved fuel economy and provides the environmental benefits of lowered energy consumption and reduced greenhouse gas emissions.

The CACC operational concept represents an evolutionary advancement of conventional cruise control (CCC) systems and adaptive cruise control (ACC) systems by utilizing V2V and V2I communication to automatically synchronize the movements of many vehicles within a platoon.

As with SPD-HARM and Q-WARN, CACC-related driver communication will always give priority to crash avoidance/mitigation safety applications when such applications determine that a safety-related alert is necessary.

Figure 2-3 below provides a stylized depiction of how the flow of a traffic lane could be improved by the utilization of connected vehicle CACC-enabled V2V communications and strategies.

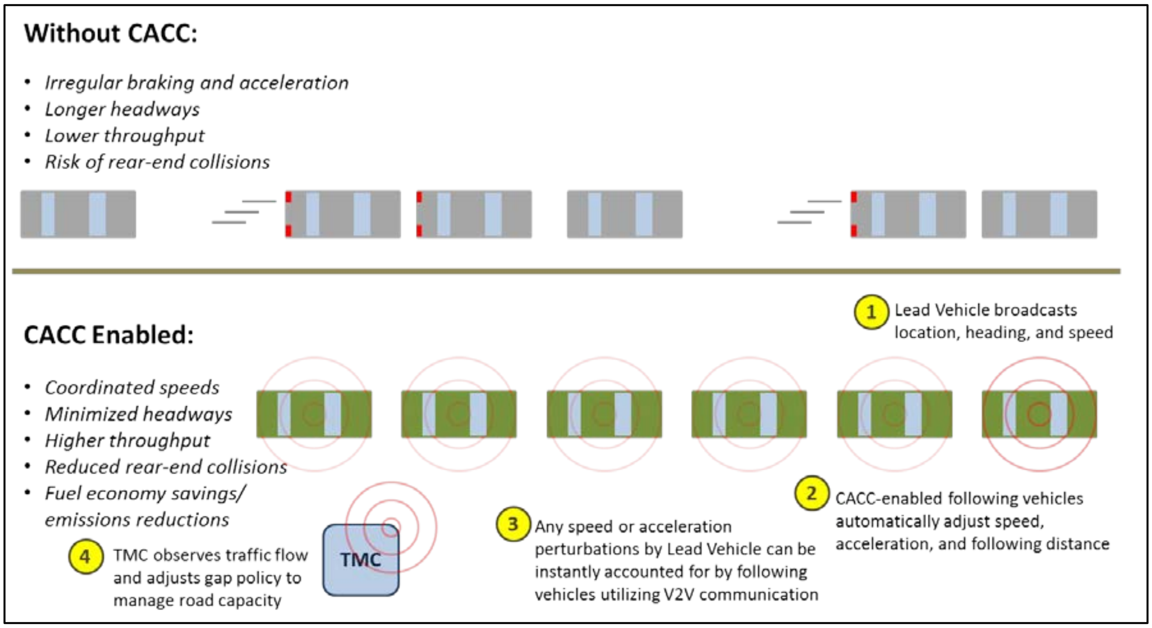

Figure 2-3. Stylized Depiction of Connected Vehicle-Enabled CACC.

2.3.2 Modes and States

This section discusses the various modes of operation for the proposed CACC concept. The CACC system should mostly activate during recurrent congestion periods (e.g., activated upstream of congestion points and bottlenecks during morning and evening peaks) and non-recurrent events (e.g., activated upstream of incidents).

The typical modes of operation for CACC concept are:

Normal Mode: CACC in the normal operation mode should have all the designed functionality available. All systems and subsystems should work properly.

Degraded Mode: In this mode, some function(s) are not working properly and might go offline. Many different scenarios could result in operation in this mode, such as failed communication. In such cases, vehicles in CACC-specific and other lanes would revert to manual control.

Training Mode: The control center should have the capability of operating in the training mode for the purpose of training the new operators. The mode allows new operators to train on simulations without interfering with the actual daily operations.

Maintenance Mode: During the maintenance of the system, some subsystems and their functionalities may go offline. This mode is very similar to the Degraded Mode but the system usually can go online if needed. This means that this mode would not affect the normal operation.

Backup Mode: The system should have the ability to perform normal operation (or at least some levels of normal operation) when there is no connection between the system and the control center.

2.3.3 Major System Capabilities

The CACC concept reflects an operational environment in which CACC-related decisions are made within the vehicles themselves and supplemented by external information (for example, from a TMC providing reduced speed recommendations due to downstream congestion). This approach was taken because it was agreed that vehicle-based decision-making would be sufficient to organize and coordinate vehicles effectively within a local platoon, but that platoon-level speed recommendations should come from an external entity (such as a TMC) that has visibility into the conditions of the entire road network. Micro-level decisions based on vehicle location and class within and between individual vehicles, however, can be made utilizing strictly V2V and multi-hop communication.

Platoons are not strictly required, however, for the CACC system to provide benefit. For instance, the CACC platform can be utilized to implement automated speed harmonization for vehicles traveling in mixed technology environments.

The CACC concept as described in this section will most likely be realized as an opt-in program, in which dedicated lanes or even entire facilities are made available to connected vehicle drivers who have signed up for the program and agree to abide by CACC speed, gap, and other recommendations and policies in order to receive the benefits (in terms of improved travel times, safety, and comfort) of the CACC facilities. Frequent violators could be banned from the facility much in the same way that frequent toll road violators today are identified and then excluded from the toll facilities.

An opt-in approach, as opposed to a mandatory program, would mitigate the inherent regulatory, enforcement, privacy, and liability related burdens on system implementers, transportation agencies, and industry partners. Such issues are discussed in more detail in the *INFLO Concept of Operations,* Section 5.3.

2.3.4 Major System Conditions

Available vehicle bus data for subject vehicle
These data may include the vehicle speed, fuel consumption, engine speed, brake pedal level, throttle level, turn signal indicator, anti-lock braking system (ABS) status, etc.

Brake and throttle actuation
CACC requires that the vehicle systems be automatically actuated to achieve the longitudinal performance needed. This hardware (or software in the case of drive-by-wire) is typically not included in today's vehicles and as such must be integrated with CACC systems.

Vehicle location solutions
Accurate vehicle locating is an important component of CACC as well as the other INFLO applications. One approach to providing enhanced vehicle locating is the use of Wide Area Augmented System (WAAS) Global Positioning Systems (GPS), which utilizes ground-based reference stations to supplement GPS signals. Dead reckoning is another approach that may be part of the vehicle locating solution to provide back-up vehicle tracking in the event that the GPS signal is lost. Vehicle-mounted sensor systems and infrastructure-based detection may also play a role in Connected Vehicle locating and positioning. These and other solutions should be examined during detailed design and testing phases of the mobility applications programs.

On-board data fusion and algorithm processing
An on-board central processing unit (CPU) is necessary to fuse the various data sources and compute the optimal longitudinal motion decisions. This algorithm will develop tactical CACC recommendations that will be use the strategic recommendations made by the TMC together with the data gathered from the subject vehicle and the other equipped vehicles in its vicinity.

Collision avoidance systems
CACC vehicles should also be equipped with forward collision avoidance systems to ensure that the vehicle is able to avoid collisions with surrounding vehicles in the event that communication between the subject vehicle and surrounding vehicles is lost. The system should also have some in-vehicle warning system to communicate to the driver in the event that the system loses communication with surrounding vehicles and manual intervention is required.

DSRC (or similar) communication systems
DSRC or a similar hardware technology is necessary to enable communication between other vehicles and infrastructure (e.g., traffic signal controller) in the vicinity of the subject vehicle. Cellular communication hardware is also necessary to communicate with the TMC to send and receive platoon-level speed recommendations (also known as strategic CACC decisions).

Combining strategic TMC and local tactical car-following speed recommendations to compute a final vehicle speed decision
The system will need to deal with contradicting speed recommendations. For example the TMC might recommend a speed reduction based on downstream conditions, however local conditions dictate a speed increase. The system will need to derive a final decision that is some compromise between the two recommendations.

CACC-dedicated lane transitions
The system will need to deal with transitions from dedicated to non-dedicated lanes and transitions from automated to semi-automated or manual control.

2.3.5 Major System Constraints

The critical constraints related to the CACC concept relate to hardware, technical, institutional, and data-related issues. These constraints are discussed below.

Digital map availability
A digital map of high resolution would provide a means for CACC and all INFLO-enabled vehicles to perform lane identification and to operate more efficiently, by recognizing changes in the roadway horizontal and vertical profiles to adjust speed as necessary. Furthermore, high resolution maps can also provide the system with information on location of various traffic control devices including stop and traffic signalized intersections.

On-vehicle radar system availability
A radar system is required to measure the spacing and headway between the subject and surrounding vehicles. This is important especially in the event that V2V communication is lost by allowing the vehicle to track surrounding vehicles without the need for V2V communication.

Data accuracy
The system will need to incorporate safety measures to deal with errors in vehicle speed measurements, vehicle spacing and headway measurement errors, and vehicle location errors. The system will also need to consider fail-safe or defaults to revert to normal driving. Research is required to identify the optimum transition from automated to manual control and how the driver should be informed of the switch in mode of operation.

Communication latency and lags in the provision of data
The system must be able to deal with latency and lags in the provision of data. Specifically, the system might consider longer headways to ensure that the system can respond to these latencies without resulting in vehicle collisions. The system should also include collision avoidance systems that use radar sensors to ensure that for longer than normal latencies the vehicle is able to avoid collisions.

Effects of automated vehicle control on driver behavior
The system will have to deal with long-term effects on driver behavior as a result of semi-autonomous longitudinal vehicle control. Although the driver will have control of the steering wheel the driver may become less attentive once he/she proceeds into the CACC lane. These issues will require further investigation and study.

Accommodating varying vehicle-specific limitations
CACC requires that engine and other components of the vehicles respond efficiently. For example, there will be a difference in response times of electric vehicles and internal combustion engine vehicles. The age and the characteristics of vehicles with CACC are also critical. Thus, vehicle fleet will be as important as the algorithms in each vehicle.

Data storage capability constraints
With regards to data storage constraints, it is important that the system can manage the data storage issues that have to be dealt with when these systems are widely implemented in the field.

Data cleansing capability constraints
The system should be able to deal with inconsistencies discrepancies across different data sources. Some form of fallback system should be developed when data sources demonstrate inconsistencies. The system should also be able to deal with noise in the data using filtering techniques.

Failure management constraints
The system should be able to deal with and identify errors in the various data sources. This can be achieved through some form of data redundancy within the system. The system should also be able to identify potential sources of error in one data source and assign weights to the data depending on the level of trust in the data source. The system design might use some particle filtering techniques to update the weights using a Bayesian filtering framework.

2.3.6 Operational Scenarios

CACC operational scenarios were developed as part of the INFLO Concept of Operations in order to provide a system definition that could be implemented in a variety of locations. Thus, they were made to be generic and not location-specific. The operational scenarios that were identified are as follows:

1. *Joining and Exiting a CACC Platoon (Vehicle-Based Processing; V2V-Dissemination)* – The subject vehicle joins a platoon of CACC-equipped vehicles, travels with the platoon for some distance, and then finally exits the platoon.
2. *Traveling in a CACC Platoon with Non-Homogenous Vehicles (Vehicle-Based Processing; V2V-Dissemination)* – A platoon of CACC-equipped vehicles includes a heavy-duty truck or a low powered light duty vehicle traveling along a mountainous terrain. As a result of the steep terrain, the truck is unable to maintain the platoon speed, resulting in a large gap ahead of the truck and the formation of a moving bottleneck.
3. *Traveling in a Platoon with V2V Communication Failure (Vehicle-Based Processing; V2V-Dissemination)* – The subject vehicle traveling within a CACC platoon experiences a V2V communication failure. The subject vehicle and trailing CACC platoon vehicles must revert to manual or ACC control. The driver of the subject vehicle attempts to exit the platoon as safely as possible.
4. *Non-Equipped Vehicle Enters CACC Platoon (Vehicle-Based Processing; V2V-Dissemination)* – A non-CACC equipped vehicle merges into a CACC platoon.

The connected vehicles within the CACC platoon detect the entry of the non-equipped vehicle and adapt gap and speed policies accordingly: in this case, by splitting the platoon into two and maintaining appropriate speed and gap between the trailing platoon and the non-equipped vehicle.

5. *Traveling in a Platoon in Inclement Weather (V2V and TMC Communication)* – Inclement weather begins to form that will affect the roadway on which a CACC platoon is traveling. The Traffic Management Entity generates new speed and gap recommendations for the platoon based on weather data received from downstream infrastructure-based detectors and connected vehicles.

6. *Combined INFLO Operational Scenario: Congestion on the INFLO Managed Lane* – This scenario takes place in an integrated corridor that includes dedicated INFLO/CACC managed lanes. Drivers of connected vehicles who have opted into the INFLO program are granted exclusive use of the special managed lane.

See Sections 6.3 and 6.4 of the *INFLO Concept of Operations* document for a more detailed discussion of these scenarios.

3 Functional Requirements

This section provides a discussion of the functional and performance requirements that must be met in order to achieve the operational concepts described in the previous section. Note that criteria specified by the performance requirements were developed based on discussions with and feedback received from INFLO stakeholders and represent the consensus best estimation of how well the given requirements must perform to achieve the desired operational concept. It should be understood that additional research, prototyping, and testing of the proposed systems is still necessary and that the performance criteria identified in this section may change as a result.

3.1 Functional Requirements Properties

The requirements detailed in this section were developed based on the following guiding principles:

1. *Abstract* – Each requirement should be implementation independent.
2. *Unambiguous* – Each requirement should be stated in such a way so that it can be interpreted in only one way.
3. *Traceable* – For each requirement it should be feasible to determine a relationship between a specific documented user need and the requirement, itself.
4. *Validatable* – Each requirement should have the means to prove that the system satisfies the requirement.

In addition, the requirements share the following properties:

- Unique set – Each requirement should be stated only once.
- Normalized – Requirements should not overlap (i.e., they shall not refer to other requirements or the capabilities of other requirements).
- Linked set – Explicit relationships should be defined among individual requirements to show how the requirements are related to form a complete system.
- Complete – A Requirements Specification should include all the requirements identified by the customer, as well as those needed for the definition of the system.
- Consistent – Requirements Specification content should be consistent and non-contradictory in the level of detail, style of requirement statements, and in the presentation of material.
- Bounded – The boundaries, scope, and context for the set of requirements should be identified.
- Modifiable – The Requirements Specification should be modifiable. Clarity and non-overlapping requirements contribute to this.
- Configurable – Versions should be maintained across time and across instances of the SyRS.

3.2 Conformance with Connected Vehicle "Core System" Requirements

While the following sections present the key functional and performance requirements specific to the INFLO applications, it should be emphasized that these application-specific requirements are intended to work in concert with the concept of operations and published requirements of the Connected Vehicle Core System Initiative. The Core System Concept specifies the network and data distribution services to enable DMA applications such as INFLO to send and receive data securely. Key requirements specified by the Core System Concept that are relevant to INFLO are in the areas of data distribution, network services, and user permissions.

3.3 SPD-HARM

3.3.1 SPD-HARM Requirements Development

The SPD-HARM high-level system user needs listed in Table 3-1 were developed as part of the Concept of Operations and agreed upon by the INFLO stakeholders. They served as the starting point for the development of the SPD-HARM requirements, which are discussed in this section. Each requirement is mapped to one of the following 14 SPD-HARM high-level user needs.

Table 3-1. SPD-HARM System User Needs.

User	High-Level User Need	Discussion
Vehicle operator	1. Needs to know the recommended speed to travel	In the case where the vehicle operator is making the decision to comply with speed recommendations (i.e., not in a semi-autonomous vehicle environment, as with CACC), the driver must be made aware of the appropriate speed to travel so that he or she can adjust the throttle accordingly. Such information must be provided succinctly and in such a way that it is not overly distracting to the driver.
Vehicle operator	2. Needs to know which lane to be in	A robust dynamic speed harmonization system will be able to optimize not only vehicle speeds but also lane utilization to achieve efficient flow of traffic. This includes recommendations based on vehicle weight or class. Therefore, in addition to knowing the recommended speed, the vehicle operator must also know the appropriate lane to be in. Such information must be provided succinctly and in such a way that it is not overly distracting to the driver.

User	High-Level User Need	Discussion
Vehicle operator	3. Needs to know why the given speed change is being recommended	To be effective, a SPD-HARM system must be proactive in providing speed change recommendations, which often means slowing down traffic far upstream to the source of the traffic disturbance. For drivers to feel compelled to comply with the recommended speed changes when the immediate traffic conditions appear to be free flowing (for example), it is psychologically important for them to know why they are being asked to change their behavior. Examples of information that may be beneficial to drivers include alerts and location of upcoming incidents, weather, or other road conditions, or even estimates of fuel cost savings and emissions reductions that could be achieved by complying with the speed change recommendations. Such information must be provided succinctly and in such a way that it is not overly distracting to the driver.
Vehicle operator	4. Needs personal data to remain private and secure	The privacy of individuals in the traffic stream must be maintained as data about their behavior is anonymized and shared across multiple jurisdictions.
Connected Vehicle/Device	5. Needs to collect relevant vehicle data	The connected vehicle, aftermarket device, or other interacting application must be able to obtain relevant vehicle data (including position, movement, actions, and road conditions/weather) so that it can be communicated to and processed by other vehicles and systems.
Connected Vehicle/Device	6. Needs to disseminate relevant vehicle data to other vehicles or systems	The connected vehicle/device must have a dissemination capability so that the vehicle data it has obtained can be accessed by other vehicles and systems.
Connected Vehicle/Device	7. Needs to receive relevant information from other vehicles or systems	In order to be able to provide useful information to the driver, the connected vehicle/device must be able to receive such information from other vehicles and systems.

User	High-Level User Need	Discussion
Connected Vehicle/Device	8. Needs to communicate relevant information to vehicle operator	Speed recommendations and other instructions and information must ultimately be conveyed to the driver. Therefore, the connected vehicle/device, which receives such information externally, must be able to communicate it to the driver in such a way that it is accepted and can be acted upon. Examples of this communication to the driver include auditory, visual, or haptic alerts and on-screen messages.
Traffic Management Entity	9. Needs to receive multi-source data	The traffic management entity, which includes TMCs or other entity responsible for traffic management functions, must be able to receive relevant data from connected vehicles/devices, roadway traffic detection systems, weather systems, and third party systems in order to process it and make speed recommendations.
Traffic Management Entity	10. Needs to process multi-source data	The traffic management entity must be able to aggregate, organize, and clean the received transportation and weather data in order to develop speed recommendations from it.
Traffic Management Entity	11. Needs to generate speed harmonization strategies	The critical function of the SPD-HARM system is to use algorithms and modeling to generate optimal speed recommendations based on the information received on the conditions (traffic, incidents, weather, etc.) of the transportation network.
Traffic Management Entity	12. Needs to disseminate speed harmonization recommendations and information to connected vehicles/devices	Once speed harmonization strategies and recommendations have been developed, the traffic management entity must be able to communicate this information to the appropriate affected connected vehicles/devices.
Traffic Management Entity	13. Needs to analyze performance of SPD-HARM system	Based on data received from the field, the traffic management entity must be able to validate the reliability of data, analyze the performance of the SPD-HARM system overall, and make changes to the algorithm or software to improve performance.
Data Capture and Management Environment	14. Needs to collect SPD-HARM data and disseminate relevant information to other dynamic mobility applications	In order to maximize the benefit of the co-deployment of different DMAs, relevant SPD-HARM data should be shared with the other DMAs. The interface for such sharing is the Data Capture and Management environment.

3.3.2 SPD-HARM Requirements Organization

SPD-HARM requirements are identified in the following tables, organized by user need addressed as summarized in Section 3.2.1, above. Column descriptions of the requirements table are given below.

Application Evolution

The Application Evolution State columns indicate with an “x” whether the given requirement is applicable in the near-term (corresponding to the SPD-HARM operational concept achievable within 1-10 years), mid-term (10-20 year horizon), or long-term (20+ year horizon).

The requirements identified as “near-term” represent the core set of requirements necessary to achieve a baseline level of performance of the SPD-HARM system as described in the near-term operational concept—see Operational Scenarios 1 and 3 (Section 6.1.1 and 6.1.3) of the INFLO Concept of Operations (ConOps). The near-term operational concept envisions the optimization of vehicle speeds in response to weather, congestion, and incidents along known fixed-point bottleneck locations (e.g., bridges, tunnels, on- and off-ramps, and positive grades). Essential connected vehicle-generated data elements include the current location, speed, acceleration/deceleration, and lane information of the vehicle. Other crucial data—including weather, road surface conditions, and facility-wide traffic conditions—will be supplemented by roadside sensors and third party sources. System-generated speed and lane usage recommendations will be disseminated to vehicles via infrastructure-to-vehicle (I2V) communication as well as traditional dynamic message signs (DMS).

The mid- and long-term operational concepts extend the near-term concept by relying more heavily on connected vehicle-based data collection and processing (as opposed to infrastructure-based systems) to make speed harmonization determinations, as detailed in SPD-HARM Operational Scenarios 2 and 3 (Sections 6.1.2 and 6.1.3) of the INFLO ConOps. They also assume a more complete penetration of connected vehicles and an ability of the SPD-HARM systems to accommodate more data elements and increased data volumes in order to conduct more refined analysis, make reliable predictions about future traffic conditions, and interact with other mobility and safety applications.

Priority

In addition to a requirement’s near-, mid-, and long-term applicability, its relative priority in terms of implementation impact is given using a priority rating (high/medium/low). This rating is indicated in the adjacent column.

Key Systems and Subsystems

Key systems and subsystems involved in the given requirement are indicated in the next column. The systems and subsystems that will be referenced by the SPD-HARM requirements include:

- **Connected Vehicle-based SPD-HARM Application** – the core in-vehicle application that processes real-time data and makes speed harmonization decisions for the vehicle
- **Connected Vehicle Driver Interface System** – the in-vehicle system that displays system output and receives user input
- **Connected Vehicle Communication System** – the in-vehicle system that communicates wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions (may include DSRC, cellular communication, or WiFi)
- **Integrated Vehicle Network Access System/Integrated Vehicle Network Access System** – the in-vehicle systems that read real-time vehicle data (speed, heading, temperature, etc.) to make available to the SPD-HARM Application

- **Traffic Management Entity (TME)** – the generalized system (which could refer to a TMC) that is responsible for making segment-specific and network-wide target speed recommendations for SPD-HARM-enabled Connected Vehicles and communicating these recommendations via I2V communications
- **TME-based SPD-HARM Application** – the core infrastructure-based application that processes real-time and historical transportation network data to determine network efficient speed harmonization recommendations
- **V2I/I2V Roadside Equipment** – the infrastructure-based communication systems that receive and send information between SPD-HARM-enabled Connected Vehicles and the TME (may include DSRC, cellular communication, or WiFi)
- **TME Performance Monitoring Subsystem** – the subsystem of the TME-based SPD-HARM Application that monitors the effectiveness of speed harmonization recommendations and policies on the transportation network using safety and mobility measures
- **Data Environments** – the systems that receive, store, and summarize real-time data gathered from Connected Vehicles and Infrastructure to be made available to various Dynamic Mobility Applications

Requirement Type

Finally, the type of requirement (whether functional, performance, system-to-system interface, security, or privacy) is indicated in the last column.

3.3.3 SPD-HARM Functional, System, and Data Requirements

1. Need to know the recommended speed to travel, 8. Need to communicate relevant information to vehicle operator

1. Need to know the recommended speed to travel, 8. Need to communicate relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-1.1	**Near:**	x	High	Connected Vehicle-based SPD-HARM application, Connected Vehicle driver interface system	The Connected Vehicle-based SPD-HARM application shall pass target speed recommendations to the driver interface system.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RS-1.2	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate segment-specific target speed recommendations to the driver.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-1.2.1	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate segment-specific target speed recommendations to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			

2. Need to know which lane to be in, 8. Need to communicate relevant information to vehicle operator

2. Need to know which lane to be in, 8. Need to communicate relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-2.1	**Near:**			Connected Vehicle	The Connected Vehicle shall have the ability to detect the lane in which it is traveling.	Functional
	Mid:	x	Med			
	Long:	x	High			

2. Need to know which lane to be in, 8. Need to communicate relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-2.2	**Near:**			Connected Vehicle-based SPD-HARM application, Connected Vehicle driver interface system	The Connected Vehicle-based SPD-HARM application shall pass target lane recommendations to the driver interface system.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			
RS-2.3	**Near:**			Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate target lane recommendations to the driver.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RS-2.3.1	**Near:**			Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate target lane recommendations to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	Human-Machine Interface
	Mid:	x	Low			
	Long:	x	Med			

3. Need to know why the given speed is being recommended, 8. Need to communicate relevant information to vehicle operator

3. Need to know why the given speed is being recommended, 8. Need to communicate relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-3.1	**Near:**	x	Med	Connected Vehicle-based SPD-HARM application, Connected Vehicle driver interface system	The Connected Vehicle-based SPD-HARM application shall pass speed change justification information to the driver interface system.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

3. Need to know why the given speed is being recommended, 8. Need to communicate relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-3.2	**Near:**	x	Med	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RS-3.2.1	**Near:**	x	Med	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver utilizing auditory or visual (on-screen) messages.	Human-Machine Interface
	Mid:	x	Med			
	Long:	x	Med			

4. Need personal data to remain private and secure

4. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-4.1	**Near:**	x	High	Connected Vehicle-based SPD-HARM application	The Connected Vehicle-based SPD-HARM application shall utilize secure data transmission methods when disseminating any personally identifiable information.	Security
	Mid:	x	High			
	Long:	x	High			
RS-4.2	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	Privacy
	Mid:	x	High			
	Long:	x	High			
RS-4.3	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall use secure transmission methods for disseminating target speed and lane recommendations and justification for speed changes	Security
	Mid:	x	High			
	Long:	x	High			

4. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-4.4	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	Security
	Mid:	x	High			
	Long:	x	High			

5. Need to collect relevant vehicle data

5. Need to collect relevant vehicle data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-5.1	**Near:**	x	Med	Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-5.1.1a	**Near:**	x	Med	Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, heading, lateral and longitudinal acceleration) from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			

5. Need to collect relevant vehicle data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-5.1.1b	**Near:**			Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (yaw rate, rate of change of steering wheel, brake status, brake boost status, impact sensor status, anti-lock braking status) from the vehicle network.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-5.1.2	**Near:**			Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather weather data (time, location, external air temperature, barometric pressure, wiper status, headlight status) from the vehicle network.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RS-5.1.3	**Near:**			Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather road surface data (time, location, traction control status, stability control status, differential wheel speed) from the vehicle network.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RS-5.2	**Near:**	x	High	Connected Vehicle-based SPD-HARM application, Integrated Vehicle Network Access System	Communications between the Connected Vehicle-based SPD-HARM application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	Functional
	Mid:	x	High			
	Long:	x	High			

6. Need to disseminate relevant vehicle data to other vehicles or systems

6. Need to disseminate relevant vehicle data to other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-6.1	**Near:**			Connected Vehicle-based SPD-HARM application, Target Connected Vehicle communication system	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current lane, current speed, current location, current acceleration/deceleration, actions [acceleration, deceleration, compliance with target speed], road condition, and weather information) to other connected vehicles utilizing V2V communication.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	High			
RS-6.2a	**Near:**	x	Med	Connected Vehicle-based SPD-HARM application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current speed, current location, current acceleration/deceleration) to infrastructure systems utilizing V2I communication.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RS-6.2b	**Near:**			Connected Vehicle-based SPD-HARM application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current lane, actions [acceleration, deceleration, compliance with target speed], road condition, and weather information) to infrastructure systems utilizing V2I communication.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

7. Need to receive relevant information from other vehicles or systems

7. Need to receive relevant information from other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-7.1	**Near:**			Connected Vehicle-based SPD-HARM application, Target Connected Vehicle communication system	The Connected Vehicle-based SPD-HARM application shall have the ability to receive target vehicle-collected data (current lane, current speed, current location, current acceleration/deceleration, actions [acceleration, deceleration, compliance with target speed], road condition, and weather information) from other connected vehicles utilizing V2V communication.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	High			
RS-7.2	**Near:**	x	High	Connected Vehicle-based SPD-HARM application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based SPD-HARM application shall have the ability to receive target speed recommendations, target lane recommendations and justification for speed changes from infrastructure-based systems utilizing I2V communication.	System-to-system Interface
	Mid:	x	High			
	Long:	x	Med			

9. Need to receive multi-source data

9. Need to receive multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-9.1	**Near:**	x	High	Traffic Management Entity (TME)-based SPD-HARM application, Weather Data Environment, RSE, Connected Vehicles	The Traffic Management Entity (TME)-based SPD-HARM application shall have a data collection capability for receiving real-time data from multiple sources.	Functional
	Mid:	x	High			
	Long:	x	High			

9. Need to receive multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-9.1.1	**Near:**	x	High	Traffic Management Entity (TME)-based SPD-HARM application, Weather Data Environment, Roadside Equipment (RSE), Connected Vehicles	The TME-based SPD-HARM application shall have a data collection capability for receiving real-time traffic, road conditions, and weather data from infrastructure-based systems.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-9.1.2a	**Near:**	x	High	TME-based SPD-HARM application, Connected Vehicles	The TME-based SPD-HARM application shall have the capability to receive real-time traffic (including location and speed) from connected vehicles.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-9.1.2b	**Near:**			TME-based SPD-HARM application, Connected Vehicles	The TME-based SPD-HARM application shall have the capability to receive road conditions (e.g. ice, wet, etc.) and weather data (clear, rainy and snowy) from connected vehicles.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-9.2	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have the capability to access a data environment that includes historical traffic data (including speed, flow and density), road conditions data (e.g. ice, wet, etc.), and weather data (clear, rainy and snowy).	Functional
	Mid:	x	Med			
	Long:	x	High			

10. Need to process multi-source data

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.1	**Near:**	x	High	TME-based SPD-HARM application	The TME-based SPD-HARM application shall be capable of fusing and processing data from various sources to make target speed recommendations.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-10.1.1a	**Near:**	x	High	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize real-time traffic data when calculating the recommended target speed.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-10.1.1b	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize historical, and predicted traffic data when calculating the recommended target speed.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RS-10.1.2	**Near:**	x	Med	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize real-time and predicted weather data when calculating the recommended target speed.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-10.1.3	**Near:**	x	Med	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize real-time and predicted road surface data when calculating the recommended target speed.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-10.2	**Near:**	x	Med	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a shockwave detection capability for known fixed bottleneck locations.	Functional
	Mid:	x	High			
	Long:	x	High			

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.2.1	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a shockwave detection capability that identifies at least 95% of all shockwave occurrences for known fixed bottleneck locations.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.2	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a false positive identification rate of no more than 5% of all shockwave events at known fixed bottleneck locations.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.3	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall detect formed shockwaves within 5 seconds of formation at known fixed bottleneck locations.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.4	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.4.1	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave within 5 seconds of shockwave detection.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.5	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the length of the formed shockwave.	Functional
	Mid:	x	Med			
	Long:	x	High			

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.2.5.1	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the length of the formed shockwave to within 10 ft.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.5.2	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the length of the formed shockwave within 5 seconds of shockwave detection.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.5.3	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall update the current shockwave length estimation once per second.	Performance
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.6a	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize real-time traffic data in shockwave detection algorithms.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-10.2.6b	**Near:**	x	Low	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize road condition and weather data in shockwave detection algorithms.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-10.3	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a shockwave/breakdown prediction capability for known fixed bottleneck points.	Functional
	Mid:					
	Long:	x	High			

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.3.1	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a false positive prediction rate of no more than 5% of all shockwave/breakdown predictions at known fixed bottleneck locations.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.2	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a missed prediction rate of no more than 5% of all formed shockwaves/breakdowns at known fixed bottleneck locations.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.3	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall predict impending shockwaves/breakdowns within 5 seconds of availability of relevant real-time data at known fixed bottleneck locations.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.4	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected time of formation of the predicted shockwaves/breakdowns.	Functional
	Mid:					
	Long:	x	High			
RS-10.3.4.1	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the time of formation of the predicted shockwave/breakdown to within 5 seconds of actual shockwave/breakdown formation.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.4.2	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall update the shockwave/breakdown time of formation prediction once per second.	Performance
	Mid:					
	Long:	x	Med			

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.3.5	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected lane(s) impacted by the predicted shockwave/breakdown.	Functional
	Mid:					
	Long:	x	High			
RS-10.3.5.1	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected lane(s) impacted by the predicted shockwave/breakdown within 5 seconds of shockwave/breakdown determination.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.5.2	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall update the shockwave/breakdown impacted lane(s) prediction once per second.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.6	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected length of the predicted shockwave/breakdown.	Functional
	Mid:					
	Long:	x	High			
RS-10.3.6.1	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected length of the predicted shockwave/breakdown accurate to within 20 ft of actual formed shockwave length.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.6.2	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected length of the formed shockwave/breakdown within 5 seconds of shockwave/breakdown determination.	Performance
	Mid:					
	Long:	x	Med			

10. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-10.3.6.3	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall update the shockwave/breakdown length prediction once per second.	Performance
	Mid:					
	Long:	x	Med			
RS-10.3.7	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall determine the expected duration of the predicted shockwave/breakdown.	Functional
	Mid:					
	Long:	x	Med			
RS-10.3.8	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize real-time and historical data in shockwave/breakdown prediction algorithms.	Functional
	Mid:					
	Long:	x	High			
RS-10.3.9	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize online and offline modeling for shockwave/breakdown prediction.	Functional
	Mid:					
	Long:	x	Med			

11. Need to generate speed harmonization strategies

11. Need to generate speed harmonization strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-11.1	**Near:**	x	High	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a target speed generation capability.	Functional
	Mid:	x	High			
	Long:	x	High			

11. Need to generate speed harmonization strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-11.1.1	**Near:**	x	High	TME-based SPD-HARM application	The TME-based SPD-HARM application shall generate target speed strategies for different segments of the roadway.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-11.1.2a	**Near:**	x	High	TME-based SPD-HARM application, Weather Data Environment, RSE, Connected Vehicles	The TME-based SPD-HARM application shall generate target speed strategies that consider downstream traffic conditions, weather, and local roadway surface conditions.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-11.1.2b	**Near:**			TME-based SPD-HARM application, Weather Data Environment, RSE, Connected Vehicles	The TME-based SPD-HARM application shall generate target speed strategies that consider predicted future traffic conditions.	Functional
	Mid:	x	Med			
	Long:	x	High			
RS-11.1.3	**Near:**		Med	TME-based SPD-HARM application	The TME-based SPD-HARM application shall utilize online or offline modeling to generate target speed strategies.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-11.1.4	**Near:**			TME-based SPD-HARM application	The TME-based SPD-HARM application shall take into account the anticipated levels of driver compliance when generating specific target speed strategies.	Functional
	Mid:	x	High			
	Long:	x	Med			
RS-11.2	**Near:**			Traffic Management Entity	The Traffic Management Entity shall provide user education on the need to comply with recommended speed targets.	Policy
	Mid:	x	Med			
	Long:	x	Med			

12. Need to disseminate speed harmonization recommendations and information to connected vehicles/devices

12. Need to disseminate speed harmonization recommendations and information to connected vehicles/devices						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-12.1	**Near:**	x	High	TME-based SPD-HARM application	The TME-based SPD-HARM application shall have a target speed recommendation dissemination capability.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-12.1.1	**Near:**	x	High	TME-based SPD-HARM application, Connected Vehicles	The TME-based SPD-HARM application shall disseminate target speed recommendations to SPD-HARM enabled connected vehicles on the facility via I2V communications.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-12.1.2	**Near:**	x	High	TME-based SPD-HARM application, RSE	The TME-based SPD-HARM application shall disseminate target speed recommendations to DMS locations.	Functional
	Mid:	x	Med			
	Long:					

13. Need to analyze performance of SPD-HARM system

13. Need to analyze performance of SPD-HARM system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-13.1	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	Functional
	Mid:	x	High			
	Long:	x	High			

13. Need to analyze performance of SPD-HARM system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-13.1.1	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based SPD-HARM application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and capacity drop.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RS-13.1.2	**Near:**	x	Med	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RS-13.2	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RS-13.3	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	Functional
	Mid:	x	High			
	Long:	x	High			
RS-13.4	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based SPD-HARM application shall be modifiable such that algorithms and software performance can be improved.	Design
	Mid:	x	High			
	Long:	x	High			
RS-13.5	**Near:**	x	High	TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall continuously compare the actual performance of the system with the performance determined by the SPD-HARM application to determine recommended calibrations to the application.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			

13. Need to analyze performance of SPD-HARM system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-13.6	**Near:**			TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall provide a means to identify, track, and analyze unidentified or mis-identified shockwave/breakdown formation events.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RS-13.7	**Near:**			TME-based SPD-HARM application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall provide a means to compare predicted versus actual shockwave/breakdown occurrences and characteristics.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			

14. Need to collect SPD-HARM data and disseminate relevant information to other dynamic mobility applications

14. Need to collect SPD-HARM data and disseminate relevant information to other dynamic mobility applications						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-14.1	**Near:**	x	Low	SPD-HARM application, Traffic Management Entity	The SPD-HARM application shall make SPD-HARM-derived target speed information (impacted road segments, target speeds recommended, user messages provided) available for sharing with other dynamic mobility applications.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RS-14.2	**Near:**	x	Low	SPD-HARM application, Q-WARN application, Traffic Management Entity	The SPD-HARM application shall make SPD-HARM-derived shockwave/breakdown formation information ([predicted] time of formation, length, duration, lanes impacted, user messages provided) available for sharing with other dynamic mobility applications.	Functional
	Mid:	x	Low			
	Long:	x	Med			

14. Need to collect SPD-HARM data and disseminate relevant information to other dynamic mobility applications						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RS-14.3	**Near:**	x	Low	SPD-HARM application, Q-WARN application, CACC application, DMAs, Traffic Management Entity, Data Environment	SPD-HARM-derived target speed information and shockwave/breakdown formation information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			

3.4 Q-WARN

3.4.1 Q-WARN Requirements Development

The Q-WARN high-level system user needs listed in Table 3-2 were developed as part of the Concept of Operations and agreed upon by the INFLO stakeholders. They served as the starting point for the development of the Q-WARN requirements, which are discussed in this section. Each requirement is mapped to one of the following 19 Q-WARN high-level user needs.

Table 3-2. Q-WARN System User Needs.

User	High-Level User Need	Discussion
Vehicle operator	1. Needs to know of a downstream traffic queue in sufficient time to react safely	In the case where the driver must engage the brakes or throttle in order to change the vehicle speed (i.e., not as in a semi-autonomous vehicle environment, as with CACC), the driver must be made aware of the downstream queue with sufficient notice to take into account typical human reaction times. Additionally, such information must be provided succinctly and in such a way that it is not overly distracting to the driver.
Vehicle operator	2. Needs to know what actions to take to respond to the impending queue	In order to react appropriately, the driver must be provided sufficient information about the queue to make a decision. This information includes distance to end of queue, estimated duration of the queue (including alerting when the queue has cleared), and other descriptions of the queue condition. Additionally, such information must be provided succinctly and in such a way that it is not overly distracting to the driver.
Vehicle operator	3. Needs personal data to remain private and secure	The privacy of individuals in the traffic stream must be maintained as data about their behavior is anonymized and shared across multiple jurisdictions.
Connected Vehicle/Device (queued vehicle)	4. Needs to detect a queued state	The vehicle, aftermarket device, or other interacting application must be able to detect that the vehicle is in a queue state so that other vehicles and systems can be alerted to the lane and facility location of the queue.
Connected Vehicle/Device (queued vehicle)	5. Needs to disseminate queued status alert to upstream vehicles and other systems	The connected vehicle/device must have a dissemination capability so that the vehicle queued alert status can be received and interpreted by other vehicles and systems.

User	High-Level User Need	Discussion
Connected Vehicle/Device (upstream of queue)	6. Needs to receive relevant queue information from other vehicles or systems	In order to be able to provide useful information to the driver, the connected vehicle/device must be able to receive relevant information from other vehicles and systems.
Connected Vehicle/Device (upstream of queue)	7. Needs to generate queue warning response strategies	The critical function of the vehicle-based Q-WARN system is to generate optimal recommendations based on the detection of a downstream queue. (Strategies may include speed reduction, lane change, or diversion.) In addition, pertinent queue-related information, including distance to end of queue, estimated duration of the queue, and other descriptions of the queue condition, should be generated.
Connected Vehicle/Device (upstream of queue)	8. Needs to communicate recommendations to vehicle operator	Braking, lane change, and other recommendations must ultimately be conveyed to the driver. Therefore, the connected vehicle/device must be able to communicate this information to the driver in such a way that it is accepted and can be acted upon. Examples of this communication to the driver include auditory, visual, or haptic alerts and on-screen messages. In the semi-autonomous vehicle environment (e.g., a Q-WARN/CACC co-deployment), braking or other throttle adjustment actions will occur automatically.
Traffic Management Entity	9. Needs to collect relevant traffic, road condition, and weather data	To supplement vehicle-generated traffic data, traffic management entities will utilize infrastructure-based detection systems to gather traffic, road condition, and weather data. Infrastructure-based detection plays an important role both in the near-term (where connected vehicle/device penetration rates are lower) and at known fixed queue generation points.
Traffic Management Entity	10. Needs to disseminate relevant traffic, road condition, and weather data to vehicles	To supplement gaps in vehicle-generated traffic data, infrastructure-based detection systems will disseminate traffic, road condition, and weather data to connected vehicles/devices. Infrastructure-based detection and information dissemination plays an important role both in the near-term (where connected vehicle/device penetration rates are lower) and at known fixed queue generation points.

User	High-Level User Need	Discussion
Traffic Management Entity	11. Needs to detect formed queues	One of the critical functions of the infrastructure-based Q-WARN system is to be able to quickly and reliably detect a formed queue, in particular at fixed queue generation points where vehicle-based communication and detection may not be feasible (for example, at a tunnel entrance where line-of-sight obstructions may prevent direct communication between vehicles).
Traffic Management Entity	12. Needs to predict impending queues	In addition to detecting formed queues, the infrastructure-based Q-WARN system should be able to predict impending queue formation based on the relevant traffic, road condition, and weather data collected for a given road segment or fixed queue generation point.
Traffic Management Entity	13. Needs to generate queue warning response strategies for upstream vehicles	The other critical function of the infrastructure-based Q-WARN system is to generate optimal recommendations for upstream vehicles based on the detection of a formed or impending queue, including speed reduction, lane change, or diversion recommendations. In addition, pertinent queue-related information, including distance to end of queue, estimated duration of the queue, and other descriptions of the queue condition, should be generated.
Traffic Management Entities	14. Need to disseminate recommended queue warning strategies to upstream vehicles	Queue response strategies and pertinent queue-related information generate traffic management entities must be disseminated to vehicles upstream of the queue. The information will be communicated to the vehicles via in-vehicle alerts and roadside signage. (Traditional roadside infrastructure will continue to play an important part in information dissemination in the near-term, where connected vehicle penetration is expected to be relatively low).
Traffic Management Entity	15. Needs to analyze performance of Q-WARN system	Based on data received from the field, the traffic management entity must be able to validate the reliability of data, analyze the performance of the Q-WARN system overall, and make changes to the algorithm or software to improve performance.

User	High-Level User Need	Discussion
Traffic Management Entity	16. Needs to push Q-WARN application updates and modifications to connected vehicles/devices	Based on analysis of the performance of the Q-WARN system, algorithm or software updates must be able to be pushed (wirelessly) to connected vehicles/devices in the field.
Arterial Signal Systems	17. Need to disseminate signal phasing information to approaching vehicles	In the arterial environment, queues generate around traffic signals. By providing approaching connected vehicles/devices information about impending signal changes, sudden vehicle stops and rear-end collisions and shockwave propagation can be limited.
Data Capture and Management Environment	18. Needs to collect Q-WARN data and disseminate relevant information to other dynamic mobility applications	In order to maximize the benefit of the co-deployment of different DMAs, relevant Q-WARN data should be shared with the other DMAs. The interface for such sharing is the Data Capture and Management environment.
Data Capture and Management Environment	19. Needs to collect and aggregate Q-WARN related data and disseminate to freeway and arterial traffic management entities	In order for aggregate Q-WARN performance to be evaluated by traffic management entities, the data must first be collected and disseminated.

3.4.2 Q-WARN Requirements Organization

Q-WARN requirements are identified in the following tables, organized by user need addressed as summarized in Section 3.3.1, above. Column descriptions of the requirements table are given below.

Application Evolution
The Application Evolution State columns indicate whether the given requirement is applicable in the near-term (corresponding to the Q-WARN operational concept achievable within 1-10 years), mid-term (10-20 year horizon), or long-term (20+ year horizon).

The requirements identified as “near-term” represent the core set of requirements necessary to achieve a baseline level of performance of the Q-WARN system as described in the near-term operational concept—see Q-WARN Operational Scenarios 1 and 3 (Section 6.2.1 and 6.2.3) of the INFLO Concept of Operations (ConOps). The near-term operational concept envisions the generation of queue warnings along known fixed-point queue generation locations (e.g., exit ramps, border crossings, lane merges, bridges, and tunnels) using a combination of in-vehicle alerts and traditional infrastructure message signs. Essential connected vehicle-generated data elements include the current location, speed, acceleration/deceleration, and lane information of the vehicle. Other crucial data—including weather, road surface conditions, and facility-wide traffic conditions—will be supplemented by roadside sensors and third party sources.

The mid- and long-term Q-WARN operational concepts extend the near-term concept by relying more heavily on connected vehicle-based data collection and processing (as opposed to infrastructure-based systems) to facilitate accurate queue determination and prediction and to propagate queue warnings to other vehicles, as detailed in Q-WARN Operational Scenarios 2 and 3 (Sections 6.2.2 and 6.2.3) of the INFLO ConOps. They also assume a more complete penetration of connected vehicles and an ability of the Q-WARN systems to accommodate more data elements and increased data volumes in order to conduct more refined analysis, make reliable predictions about future traffic conditions and likely queue formations, and interact with other mobility and safety applications.

Priority
In addition to a requirement’s near-, mid-, and long-term applicability, its relative priority in terms of implementation impact is given using a priority rating (high/medium/low). This rating is indicated in the adjacent column.

Key Systems and Subsystems
Key systems and subsystems involved in the given requirement are indicated in the next column. The systems and subsystems that will be referenced by the Q-WARN requirements include:

- **Connected Vehicle-based Q-WARN Application** – the core in-vehicle application that processes real-time data and makes individual queue warning determinations
- **Connected Vehicle Driver Interface System** – the in-vehicle system that displays system output and receives user input
- **Connected Vehicle Communication System** – the in-vehicle system that communicates wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions (may include DSRC, cellular communication, or WiFi)
- **Integrated Vehicle Network Access System**– the in-vehicle systems that read real-time vehicle data (speed, heading, temperature, etc.) to make available to the Q-WARN Application

- **Traffic Management Entity (TME)** – the generalized system (which could refer to a TMC) that is responsible for making segment-specific queue warning alerts and recommendations for Q-WARN-enabled Connected Vehicles and communicating this information via I2V communications
- **TME-based Q-WARN Application** – the core infrastructure-based application that processes real-time and historical transportation network data to generate queue warnings for a given road segment
- **V2I/I2V Roadside Equipment** – the infrastructure-based communication systems that receive and send information between Q-WARN-enabled Connected Vehicles and the TME (may include DSRC, cellular communication, or WiFi)
- **TME Performance Monitoring Subsystem** – the subsystem of the TME-based Q-WARN Application that monitors the effectiveness of Q-WARN recommendations and policies on the transportation network using safety and mobility measures
- **Data Environments** – the systems that receive, store, and summarize real-time data gathered from Connected Vehicles and Infrastructure to be made available to various Dynamic Mobility Applications

Requirement Type

Finally, the type of requirement (whether functional, performance, system-to-system interface, security, or privacy) is indicated in the last column.

3.4.3 Q-WARN Functional, System, and Data Requirements

1. Need to know of a downstream traffic queue in sufficient time to react safely, 8. Need to communicate queue warning information to vehicle operator

1. Need to know of a downstream traffic queue in sufficient time to react safely, 8. Need to communicate queue warning to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-1.1a	**Near:**	x	High	Connected Vehicle-based Q-WARN application, Connected Vehicle driver interface system	The Connected Vehicle-based Q-WARN application shall pass individualized queue warnings and queue characteristic information (based on vehicle's distance to end of queue) to the driver interface system.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RQ-1.1b	**Near:**			Connected Vehicle-based Q-WARN application, Connected Vehicle driver interface system	The Connected Vehicle-based Q-WARN application shall pass queue warnings and queue characteristic information (length of queue, lane(s) impacted, other descriptions of the queue condition) to the driver interface system.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			
RQ-1.2a	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate queue warnings and queue characteristic information (based on vehicle's distance to end of queue) to the driver.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-1.2b	**Near:**			Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate queue warnings and queue characteristic information (length of queue, lane(s) impacted, other descriptions of the queue condition) to the driver.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RQ-1.2.1	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate queue warnings and queue information to the driver utilizing auditory, visual, or haptic alerts and auditory or visual (on-screen) messages.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			

2. Need to know what actions to take to respond to an impending queue, 8. Need to communicate queue warning information to vehicle operator

2. Need to know what actions to take to respond to an impending queue, 8. Need to communicate queue warning to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-2.1	**Near:**			Connected Vehicle-based Q-WARN application, Connected Vehicle driver interface system	The Connected Vehicle-based Q-WARN application shall pass individualized queue response strategies (based on vehicle's distance to end of queue) to the driver interface system (speed reduction, lane change, diversion recommendations).	System-to-system Interface
	Mid:	x	Med			
	Long:	x	High			
RQ-2.2	**Near:**			Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate queue response strategies (speed reduction, lane change, diversion recommendations) to the driver.	Functional
	Mid:	x	Med			
	Long:	x	High			
RQ-2.2.1	**Near:**			Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate queue response strategies to the driver utilizing auditory or visual (on-screen) messages.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			

3. Need personal data to remain private and secure

3. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-3.1	**Near:**	x	High	Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall utilize secure data transmission methods when disseminating any personally identifiable information.	Security
	Mid:	x	High			
	Long:	x	High			

3. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-3.2	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	Privacy
	Mid:	x	High			
	Long:	x	High			
RQ-3.3	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall use secure transmission methods for disseminating queue warnings, queue characteristic information, and response strategies.	Security
	Mid:	x	High			
	Long:	x	High			
RQ-3.4	**Near:**	x	High	Traffic Management Entity	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	Security
	Mid:	x	High			
	Long:	x	High			

4. Need to detect a queued state

4. Need to detect a queued state						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-4.1	**Near:**	x	Med	Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall have the ability to detect when the vehicle is in a queued state.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-4.2	**Near:**	x	Med	Connected Vehicle-based Q-WARN application, Integrated Vehicle Network Access System	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			

4. Need to detect a queued state						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-4.2.1a	**Near:**	x	Med	Connected Vehicle-based Q-WARN application, Integrated Vehicle Network Access System	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, heading, lateral and longitudinal acceleration) from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-4.2.1b	**Near:**			Connected Vehicle-based Q-WARN application, Integrated Vehicle Network Access System	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (yaw rate, rate of change of steering wheel, brake status, brake boost status, impact sensor status, anti-lock braking status) from the vehicle network.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RQ-4.2.2	**Near:**			Connected Vehicle-based Q-WARN application, Integrated Vehicle Network Access System	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather weather data (time, location, external air temperature, barometric pressure, wiper status, headlight status) from the vehicle network.	Functional
	Mid:	x	Low			
	Long:	x	Low			
RQ-4.2.3	**Near:**			Connected Vehicle-based Q-WARN application, Integrated Vehicle Network Access System	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather road surface data (time, location, traction control status, stability control status, differential wheel speed) from the vehicle network.	Functional
	Mid:	x	Low			
	Long:	x	Low			
RQ-4.3	**Near:**	x	High	Connected Vehicle-based Q-WARN application, ntegrated	Communications between the Connected Vehicle-based Q-WARN application and the Integrated	Functional
	Mid:	x	High			

4. Need to detect a queued state						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
	Long:	x	High	Vehicle Network Access System	Vehicle Network Access System shall utilize standardized data sets and communications protocols.	

5. Need to disseminate queued status alert to upstream vehicles and other systems

5. Need to disseminate queued status alert to upstream vehicles and other systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-5.1	**Near:**			Connected Vehicle-based Q-WARN application, Target Connected Vehicle communication system	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.	Functional
	Mid:	x	Med			
	Long:	x	High			
RQ-5.2	**Near:**	x	Med	Connected Vehicle-based Q-WARN application, RSE	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to infrastructure systems via V2I communication.	Functional
	Mid:	x	High			
	Long:	x	High			

6. Need to receive relevant queue information from other vehicles or systems

6. Need to receive relevant queue information from other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-6.1	**Near:**	x	High	Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via I2V communication channels.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-6.2	**Near:**			Connected Vehicle-based Q-WARN application, Target Connected Vehicle communication system	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via V2V communication channels.	Functional
	Mid:	x	Med			
	Long:	x	High			

7. Need to generate queue response strategies

7. Need to generate queue response strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-7.1	**Near:**	x	High	Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall individualize generic queue warning message based on vehicle's position and distance to the end of the queue.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-7.2	**Near:**			Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies based on distance to end of queue.	Functional
	Mid:	x	High			
	Long:	x	High			

7. Need to generate queue response strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-7.2	**Near:**			Connected Vehicle-based Q-WARN application	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies based on local traffic, weather, and roadway conditions.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RQ-7.3	**Near:**			Connected Vehicle-based Q-WARN application, SPD-HARM application, EnableATIS application, FRATIS application	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies that include speed reduction, lane change, or diversion recommendations.	Functional
	Mid:					
	Long:	x	Med			
RQ-7.3.1	**Near:**			Connected Vehicle-based Q-WARN application, SPD-HARM application	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based SPD-HARM application to generate appropriate speed reduction targets.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			
RQ-7.3.2	**Near:**			Connected Vehicle-based Q-WARN application, SPD-HARM application	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based SPD-HARM application to generate appropriate lane change recommendations.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			
RQ-7.3.3	**Near:**			Connected Vehicle-based Q-WARN application, EnableATIS application, FRATIS application	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based EnableATIS and/or FRATIS applications to generate appropriate route diversion recommendations.	System-to-system Interface
	Mid:					
	Long:	x	Med			

9. Need to collect relevant traffic, road conditions, and weather data

9. Need to collect relevant traffic, road conditions, and weather data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-9.1	**Near:**			Traffic Management Entity (TME)-based Q-WARN application, Weather Data Environment, RSE, Connected Vehicles	The Traffic Management Entity (TME)-based Q-WARN application shall have a data collection capability for receiving real-time traffic, road conditions, and weather data from multiple sources.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-9.1.1	**Near:**	x	High	Traffic Management Entity (TME)-based Q-WARN application, Weather Data Environment, RSE, Connected Vehicles	The Traffic Management Entity (TME)-based Q-WARN application shall have a data collection capability for receiving real-time traffic, road conditions, and weather data from infrastructure-based systems.	Functional
	Mid:	x	Med			
	Long:	x	Low			
RQ-9.1.2	**Near:**			TME-based Q-WARN application, Connected Vehicles	The TME-based Q-WARN application shall have the capability to receive real-time traffic (including location and speed), road conditions (e.g. ice, wet, etc.), and weather data (clear, rainy and snowy) from connected vehicles.	Functional
	Mid:	x	Med			
	Long:	x	High			
RQ-9.2	**Near:**	x	Low	TME-based Q-WARN application	The TME-based Q-WARN application shall have the capability to access a data environment that includes historical traffic data (including speed, flow and density), road conditions data (e.g. ice, wet, etc.), and weather data (clear, rainy and snowy).	Functional
	Mid:	x	Med			
	Long:	x	High			

10. Need to disseminate relevant traffic, road condition, and weather data to vehicles

10. Need to disseminate relevant traffic, road condition, and weather data to vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-10.1	**Near:**	x	Med	Traffic Management Entity, Connected Vehicles	The Traffic Management Entity shall communicate traffic, road condition, and weather data to connected vehicles/devices via I2V communications systems.	Functional
	Mid:	x	High			
	Long:	x	High			

11. Need to detect a formed queue

11. Need to detect a formed queue						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-11.1	**Near:**	x	High	TME-based Q-WARN application	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue detection.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-11.1.1a	**Near:**	x	High	TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time data in queue detection algorithms.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-11.1.1b	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize predicted and historical traffic data in queue detection algorithms.	Functional
	Mid:	x	Med			
	Long:	x	High			

11. Need to detect a formed queue						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-11.1.2a	**Near:**	x	Low	TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time weather data in queue detection algorithms.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RQ-11.1.2b	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize predicted weather data in queue detection algorithms.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RQ-11.1.3a	**Near:**	x	Low	TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time road surface data in queue detection algorithms.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RQ-11.1.3b	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize predicted road surface data in queue detection algorithms.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RQ-11.2	**Near:**	x	High	Traffic Mgmt Entity-based Q-WARN application	The TME-based Q-WARN application shall have a queue detection capability for known fixed queue generation locations.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-11.2.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall have a false positive identification rate of no more than 1% of all queue detection events at known fixed queue generation locations.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.2.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall have a missed detection rate no more than 1% of all	Performance
	Mid:	x	Med			

11. Need to detect a formed queue						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
	Long:	x	High		formed queues at known fixed queue generation locations.	
RQ-11.2.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall detect formed queues within 5 seconds of formation at known fixed queue generation locations.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.3	**Near:**	x	Med	TME-based Q-WARN application	The TME-based Q-WARN application shall determine the lane(s) impacted by the formed queue.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-11.3.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the lane(s) impacted by the formed queue within 5 seconds of queue detection.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.4	**Near:**	x	Med	TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the formed queue.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-11.4.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the formed queue to within 10 ft.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.4.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the formed queue within 5 seconds of queue detection.	Performance
	Mid:	x	Med			
	Long:	x	High			

11. Need to detect a formed queue						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-11.4.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the current queue length estimation once per second.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.5	**Near:**	x	Med	TME-based Q-WARN application	The TME-based Q-WARN application shall determine the number of vehicles in the formed queue.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-11.5.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the number of vehicles in the formed queue within 5 seconds of queue detection.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.5.1.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the current car count estimation once per second.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.6	**Near:**	x	Med	TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed and direction of the formed queue.	Functional
	Mid:	x	Med			
	Long:	x	High			
RQ-11.6.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed of the formed queue within 5 seconds of queue detection.	Performance
	Mid:	x	Med			
	Long:	x	High			
RQ-11.6.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the estimation of the traveling speed of the queue	Performance
	Mid:	x	Med			

11. Need to detect a formed queue						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
	Long:	x	High		once per second.	
RQ-11.6.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed of the formed queue to within 5 mph.	Performance
	Mid:	x	Med			
	Long:	x	High			

12. Need to predict impending queue formation

12. Need to predict impending queue formation						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-12.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue prediction.	Functional
	Mid:					
	Long:	x	High			
RQ-12.1.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time, predicted, and historical traffic data in queue prediction algorithms.	Functional
	Mid:					
	Long:	x	High			
RQ-12.1.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time and predicted weather data in queue prediction algorithms.	Functional
	Mid:					
	Long:	x	Med			

12. Need to predict impending queue formation						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-12.1.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize real-time and predicted road surface data in queue prediction algorithms.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.1.4	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize online or offline modeling in queue prediction algorithms.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.2	**Near:**			Traffic Mgmt Entity-based Q-WARN application	The TME-based Q-WARN application shall have a queue prediction capability for known fixed queue generation locations.	Functional
	Mid:					
	Long:	x	High			
RQ-12.2.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall have a false positive identification rate of no more than 5% of all queue detection events at known fixed queue generation locations.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.2.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall have a missed prediction rate no more than 5% of all formed queues at known fixed queue generation locations.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the time of formation of the predicted queue.	Functional
	Mid:					
	Long:	x	High			
RQ-12.3.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the time of formation of the predicted	Performance
	Mid:					

12. Need to predict impending queue formation						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
	Long:	x	Med		queue to within 5 seconds of actual queue formation.	
RQ-12.4	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the lane(s) impacted by the predicted queue.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.4.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the lane(s) impacted by the predicted queue within 5 seconds of queue determination.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.5	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the predicted queue.	Functional
	Mid:					
	Long:	x	High			
RQ-12.5.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the predicted queue to within 20 ft of actual formed queue length.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.5.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the length of the predicted queue within 5 seconds of queue determination.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.5.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the current queue length prediction once per second.	Performance
	Mid:					
	Long:	x	Med			

12. Need to predict impending queue formation						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-12.6	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the expected duration of the predicted queue.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.6.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the expected duration of the predicted queue once per second.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.7	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the number of vehicles in the predicted queue.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.7.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the number of vehicles in the predicted queue within 5 seconds of queue determination.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.7.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the car count estimation for the predicted queue once per second.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.8	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed and direction of the predicted queue.	Functional
	Mid:					
	Long:	x	Med			
RQ-12.8.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed of the predicted	Performance
	Mid:					

12. Need to predict impending queue formation						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
	Long:	x	Med		queue within 5 seconds of queue determination.	
RQ-12.8.2	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall update the estimated traveling speed of the predicted queue once per second.	Performance
	Mid:					
	Long:	x	Med			
RQ-12.8.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall determine the traveling speed of the predicted queue to within 10 mph of the speed of the actual formed queue.	Performance
	Mid:					
	Long:	x	Med			

13. Need to generate queue warning response strategies for upstream vehicles

13. Need to generate queue warning response strategies for upstream vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-13.1	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall have a queue warning response strategy generation capability.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-13.1.1	**Near:**			TME-based Q-WARN application, SPD-HARM application, EnableATIS application, FRATIS application	The TME-based Q-WARN application shall generate queue warning response strategies that include speed reduction, lane change, and diversion recommendations.	Functional
	Mid:	x	High			
	Long:	x	Med			

13. Need to generate queue warning response strategies for upstream vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-13.1.1.1	**Near:**			TME-based Q-WARN application, SPD-HARM application	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate speed reduction targets.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			
RQ-13.1.1.2	**Near:**			TME-based Q-WARN application, SPD-HARM application	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate lane change recommendations.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			
RQ-13.1.1.3	**Near:**			TME-based Q-WARN application, EnableATIS application, FRATIS application	The TME-based Q-WARN application shall interface with the TME-based EnableATIS and/or FRATIS applications to generate appropriate route diversion recommendations.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Low			
RQ-13.1.2a	**Near:**			TME-based Q-WARN application, Weather Data Environment, RSE, Connected Vehicles	The TME-based Q-WARN application shall generate target speed strategies that consider distance to end of queue.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-13.1.2b	**Near:**			TME-based Q-WARN application, Weather Data Environment, RSE, Connected Vehicles	The TME-based Q-WARN application shall generate target speed strategies that consider estimated duration of the queue, other descriptions of the queue condition, downstream traffic conditions, predicted future traffic conditions, weather, and local roadway surface conditions.	Functional
	Mid:					
	Long:	x	Med			
RQ-13.1.3	**Near:**			TME-based Q-WARN application	The TME-based Q-WARN application shall utilize online or offline modeling to generate queue warning response recommendations.	Functional
	Mid:	x	Med			
	Long:	x	Med			

13. Need to generate queue warning response strategies for upstream vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-13.3	**Near:**	x	Med	Traffic Management Entity	The Traffic Management Entity shall provide user education on the need to comply with queue warning response recommendations.	Policy
	Mid:	x	Med			
	Long:	x	Med			

14. Need to disseminate queue warnings

14. Need to disseminate queue warnings						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-14.1	**Near:**	x	High	TME-based Q-WARN application	The TME-based Q-WARN application shall have a queue warning and queue information dissemination capability.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-14.1.1	**Near:**	x	High	TME-based Q-WARN application, RSE	The TME-based Q-WARN application shall disseminate queue warnings and queue information to DMS locations.	Functional
	Mid:	x	Med			
	Long:					
RQ-14.1.2	**Near:**	x	High	TME-based Q-WARN application, Connected Vehicles	The TME-based Q-WARN application shall disseminate queue warnings and queue information to connected vehicles.	Functional
	Mid:	x	High			
	Long:	x	Med			
RQ-14.1.3	**Near:**	x	Low	TME-based Q-WARN application, Traveler Information Systems	The TME-based Q-WARN application shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	Functional
	Mid:	x	Med			
	Long:	x	Med			

15. Need to analyze performance of the Q-WARN system

15. Need to analyze performance of the Q-WARN system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-15.1	**Near:**	x	High	TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-15.1.1	**Near:**			TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Q-WARN application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and capacity drop.	Functional/ Performance
	Mid:	x	High			
	Long:	x	High			
RQ-15.1.2	**Near:**			TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	Functional/ Performance
	Mid:	x	Med			
	Long:	x	Med			
RQ-15.2	**Near:**	x	High	TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Q-WARN application shall provide a means to identify, track, and analyze unidentified or mis-identified queue formation events.	Functional/ Performance
	Mid:	x	High			
	Long:	x	High			
RQ-15.3	**Near:**			TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Q-WARN application shall provide a means to compare predicted versus actual queue occurrences and characteristics.	Functional/ Performance
	Mid:					
	Long:	x	High			
RQ-15.4	**Near:**	x	High	TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	Functional/ Performance
	Mid:	x	High			
	Long:	x	High			

15. Need to analyze performance of the Q-WARN system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-15.5	**Near:**	x	High	TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	Functional
	Mid:	x	High			
	Long:	x	High			
RQ-15.6	**Near:**	x	High	TME-based Q-WARN application, TME Performance Monitoring Subsystem	The TME-based Q-WARN application shall be modifiable such that algorithms and software performance can be improved.	Design
	Mid:	x	High			
	Long:	x	High			

17. Need to disseminate signal phasing information to approaching vehicles

17. Need to disseminate signal phasing information to approaching vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-17.1	**Near:**			Arterial Signal System, Connected Vehicles	The Arterial Signal System shall have a dissemination capability to provide approaching connected vehicles signal phasing information.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

18. Need to collect Q-WARN data and disseminate relevant information to other dynamic mobility applications

18. Need to collect Q-WARN data and disseminate relevant information to other dynamic mobility applications						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-18.1	**Near:**			Q-WARN application, Traffic Management Entity	The Q-WARN application shall make Q-WARN-derived queue warning information (queue location and characteristics, recommended responses provided, user messages provided) available for sharing with other dynamic mobility applications.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RQ-18.2	**Near:**			Q-WARN application, SPD-HARM application, CACC application, DMAs, Traffic Management Entity, Data Environment	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

19. Need to collect and aggregate Q-WARN related data and disseminate to freeway and arterial traffic management entities

19. Need to collect and aggregate Q-WARN related data and disseminate to freeway and arterial traffic management entities						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RQ-19.1	**Near:**			Data Capture and Management Environment	The Data Capture and Management Environment shall collect, aggregate, and disseminate queue warning related data to freeway and arterial traffic management entities.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

3.5 CACC

3.5.1 CACC Requirements Development

The CACC high-level system user needs listed in Table 3-3 were developed as part of the Concept of Operations and agreed upon by the INFLO stakeholders. They served as the starting point for the development of the CACC requirements, which are discussed in this section. Each requirement is mapped to one of the following 17 CACC high-level user needs.

Table 3-3. CACC System User Needs.

User	High-Level User Need	Discussion
Vehicle operator	1. Needs to join a CACC platoon	The driver must be made aware of how, when, and where to safely join a CACC platoon. Such information must be provided succinctly and in such a way that it is not overly distracting to the driver.
Vehicle operator	2. Needs to establish or accept a speed and gap policy	Once a driver has joined a platoon, he must be able to establish or accept a recommended speed and gap policy for his connected vehicle to implement. Such interaction must occur in such a way that it is not overly distracting to the driver.
Vehicle operator	3. Needs to exit a CACC platoon	When a driver decides to leave the platoon (for example, because she is exiting the freeway), she must be able to regain manual throttle control and change lanes safely.
Vehicle operator	4. Needs personal data to remain private and secure	The privacy of individuals in the traffic stream must be maintained as data about their behavior is anonymized and shared across multiple jurisdictions.
Connected Vehicle	5. Needs to collect relevant vehicle data	The connected vehicle must be able to obtain relevant vehicle data (including position, movement, actions, and road conditions/weather) so that it can be communicated to and processed by other vehicles and systems.
Connected Vehicle	6. Needs to disseminate relevant vehicle data to other vehicles or systems	The connected vehicle must have a dissemination capability so that the vehicle data it has obtained can be accessed by other vehicles and systems.
Connected Vehicle	7. Needs to receive relevant information from other vehicles or systems	In order to be able to provide useful information to the driver, the connected vehicle must be able to receive such information from other vehicles and systems.

User	High-Level User Need	Discussion
Connected Vehicle	8. Needs to communicate actions and other relevant information to vehicle operator	Speed and gap recommendations, platoon entry and exit points, and other information must ultimately be conveyed to the driver. Therefore, the connected vehicle must be able to communicate it to the driver in such a way that it can be acted upon. Examples of this communication to the driver include auditory, visual, or haptic alerts and on-screen messages.
Connected Vehicle	9. Needs to generate cruise control strategies	The critical function of the on-board CACC system is to quickly and reliably generate speed and gap decisions by interpreting the streams of internally collected and externally received data.
Connected Vehicle	10. Needs to automatically engage vehicle throttle and other equipment to enact cruise control strategies	The on-board CACC system must be able to translate strategies into actions by autonomously controlling vehicle throttle and other equipment.
Connected Vehicle	11. Needs to integrate external commands from traffic management entities with self- or platoon-generated cruise control strategies	The on-board CACC system must be able to receive and accept speed and other recommendations from external traffic management entities.
Traffic Management Entity	12. Needs to receive multi-source data	The traffic management entity, which includes TMCs or other entity responsible for traffic management functions, must be able to receive relevant data from connected vehicles/devices, roadway traffic detection systems, weather systems, and third party systems in order to process it and make gap and speed recommendations.
Traffic Management Entity	13. Needs to process multi-source data	The traffic management entity must be able to aggregate, organize, and clean the received traffic data in order to develop gap and speed recommendations from it.
Traffic Management Entity	14. Needs to generate speed or gap strategies	The traffic management entity must be able to use algorithms and modeling to generate optimal speed and gap recommendations for platoons based on the information received on the conditions (traffic, incidents, weather, etc.) of the transportation network.

User	High-Level User Need	Discussion
Traffic Management Entity	15. Needs to disseminate speed and gap recommendations and other information to connected vehicles	Once speed and gap recommendations have been developed, the traffic management entity must be able to communicate this information to the connected vehicles in the platoon.
Traffic Management Entity	16. Needs to analyze performance of CACC system	Based on data received from the field, the traffic management entity must be able to validate the reliability of data, analyze the performance of the CACC system overall, and make changes to the algorithm or software to improve performance.
Data Capture and Management Environment	17. Needs to collect CACC data and disseminate relevant information to other dynamic mobility applications	In order to maximize the benefit of the co-deployment of different DMAs, relevant CACC data should be shared with the other DMAs. The interface for such sharing is the Data Capture and Management environment.

3.5.2 CACC Requirements Organization

CACC requirements are identified in the following tables, organized by user need addressed as summarized in Section 3.4.1, above. Column descriptions of the requirements table are given below.

Application Evolution
The Application Evolution State columns indicate whether the given requirement is applicable in the near-term (corresponding to the CACC operational concept achievable within 1-10 years), mid-term (10-20 year horizon), or long-term (20+ year horizon).

The requirements identified as “near-term” represent the core set of requirements necessary to achieve a baseline level of performance of the CACC system as described in the near-term operational concept—see CACC Operational Scenario discussion (Section 6.4) in the INFLO Concept of Operations (ConOps). The near-term operational concept envisions an integrated corridor that utilizes dedicated CACC managed lanes, in which CACC-enabled vehicles form and travel in ad-hoc platoons. Drivers establish their own following gaps, which are automatically maintained between vehicles utilizing V2V DSRC communications supplemented by traditional adaptive cruise control vehicle sensor systems (e.g., radar, cameras). While in the CACC managed lanes, longitudinal control is maintained autonomously by the vehicle but latitudinal control is always under the control of the driver.

The mid- and long-term CACC operational concepts extend the near-term concept by introducing more advanced car-following models (for example, differentiating platoons based on vehicle performance characteristics) to achieve shorter gaps between cars and to optimize platoon efficiency—see CACC Operational Scenario discussion (Section 6.3) in the INFLO ConOps. They also employ increased autonomous decision-making, utilizing vehicle-based processing to identify optimal platoons for a driver to join, establish appropriate locations to enter and exit formed platoons, and reduce vehicle following distances in order to maximize throughput. It should be noted that because the driver is always responsible for the safe operation of his vehicle, he will always have the ability to override any system-generated speed or gap policy. Similarly, the driver will always have the option not to join a CACC platoon or managed lane that requires specific performance criteria, in terms of participating vehicle speed and following gap.

Priority
In addition to a requirement’s near-, mid-, and long-term applicability, its relative priority in terms of implementation impact is given using a priority rating (high/medium/low). This rating is indicated in the adjacent column.

Key Systems and Subsystems
Key systems and subsystems involved in the given requirement are indicated in the next column. The systems and subsystems that will be referenced by the CACC requirements include:

- **Connected Vehicle-based CACC Application** – the core in-vehicle application that processes real-time data and makes individual gap, speed, and other CACC decisions
- **Connected Vehicle Driver Interface System** – the in-vehicle system that displays system output and receives user input
- **Connected Vehicle Communication System** – the in-vehicle system that communicates wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions (may include DSRC, cellular communication, or WiFi)

- **Integrated Vehicle Network Access System/Integrated Vehicle Network Access System** – the in-vehicle systems that read real-time vehicle data (speed, heading, temperature, etc.) to make available to the CACC Application
- **Traffic Management Entity (TME)** – the generalized system (which could refer to a TMC) that is responsible for making segment-specific and network-wide platoon speed and gap recommendations for CACC-enabled Connected Vehicles and communicating these recommendations via I2V communications
- **TME-based CACC Application** – the core infrastructure-based application that processes real-time and historical transportation network data to determine network efficient CACC gap and speed recommendations
- **V2I/I2V Roadside Equipment** – the infrastructure-based communication systems that receive and send information between CACC-enabled Connected Vehicles and the TME (may include DSRC, cellular communication, or WiFi)
- **TME Performance Monitoring Subsystem** – the subsystem of the TME-based CACC Application that monitors the effectiveness of CACC recommendations and policies on the transportation network using safety and mobility measures
- **Data Environments** – the systems that receive, store, and summarize real-time data gathered from Connected Vehicles and Infrastructure to be made available to various Dynamic Mobility Applications

Requirement Type

Finally, the type of requirement (whether functional, performance, system-to-system interface, security, or privacy) is indicated in the last column.

3.5.3 CACC Functional, System, and Data Requirements

1. Need to join a CACC platoon

1. Need to join a CACC platoon						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-1.1	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine recommended platoon entry location and timing for vehicle entering a platoon.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-1.1.1	**Near:**			Connected Vehicle driver interface system	The driver interface system shall provide the driver the means to initiate a CACC platoon entry request.	Human-Machine Interface
	Mid:	x	Med			
	Long:	x	Med			
RC-1.1.2	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine the appropriate time to transfer longitudinal vehicle control from the driver to the vehicle upon entry into the CACC platoon or CACC-enabled managed lane.	Functional
	Mid:	x	Med			
	Long:	x	High			
RC-1.1.3	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The driver interface system shall alert the driver of the transfer of longitudinal control when entering a CACC platoon or CACC-enabled managed lane.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			
RC-1.2.1	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall identify potential platoons to join based on established vehicle-based criteria for acceptable platoon speed and gap policies, performance characteristics, and platoon sizes.	Functional
	Mid:					
	Long:	x	Med			

1. Need to join a CACC platoon						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-1.2.2	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall be capable of identifying the platoon in which it is joining or traveling.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-1.2.3	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall be capable of identifying the number of vehicles in the platoon, the lane location of the platoon, the spatial location of start and end points of the platoon, and the performance characteristics of vehicles within a platoon in which it is joining or traveling.	Functional
	Mid:	x	High			
	Long:	x	High			

It should be noted that the performance characteristics of the vehicles include various vehicle parameters that allow for the estimation of the vehicle acceleration capabilities. This includes the estimation of the vehicle tractive force and various resistance forces including the aerodynamic, rolling, and grade resistance forces. These parameters include the following: (a) vehicle power; (b) vehicle mass; (c) tractive axle(s) and percent mass on the tractive axle(s); (d) drag coefficient; and (e) frontal area.

2. Need to establish or accept a speed and gap policy

2. Need to establish or accept a speed and gap policy						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-2.1	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The Connected Vehicle-based CACC application shall communicate the current speed and gap policy to the driver interface system for display to the driver.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			
RC-2.2	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall provide a means for the driver to accept, reject, and modify a given speed and gap policy.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			
RC-2.3	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The Connected Vehicle-based CACC application shall modify the current speed and gap policy based on instructions received by the driver via the driver interface system.	Functional
	Mid:	x	High			
	Long:	x	High			

3. Need to exit a CACC platoon

3. Need to exit a CACC platoon						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-3.1	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine recommended platoon exit location and timing for vehicle exiting a platoon.	Functional
	Mid:	x	Med			
	Long:	x	Med			

3. Need to exit a CACC platoon						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-3.2	**Near:**			Connected Vehicle driver interface system	The driver interface system shall provide the driver the means to initiate a CACC platoon exit request.	Human-Machine Interface
	Mid:	x	Med			
	Long:	x	Med			
RC-3.3	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine the appropriate time to restore longitudinal vehicle control to the driver upon CACC platoon exit.	Functional
	Mid:	x	Med			
	Long:	x	High			
RC-3.4	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The driver interface system shall alert the driver of the restoration of longitudinal control when exiting a CACC platoon.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			

4. Need personal data to remain private and secure

4. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-4.1	**Near:**	x	High	Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall utilize secure data transmission methods when disseminating any personally identifiable information.	Security
	Mid:	x	High			
	Long:	x	High			

4. Need personal data to remain private and secure						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-4.2	**Near:**	x	High	Traffic Management Entity (TME)	The TME shall ensure that all personally identifiable information obtained from Connected Vehicles are anonymous.	Privacy
	Mid:	x	High			
	Long:	x	High			
RC-4.3	**Near:**	x	High	Traffic Management Entity (TME)	The TME shall protect systems and data from unauthorized access.	Security
	Mid:	x	High			
	Long:	x	High			
RC-4.4	**Near:**	x	High	Traffic Management Entity (TME)	The TME shall use secure transmission methods for disseminating target speed and gap policies.	Security
	Mid:	x	High			
	Long:	x	High			

5. Need to collect relevant vehicle data

5. Need to collect relevant vehicle data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-5.1	**Near:**	x	High	Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			

5. Need to collect relevant vehicle data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-5.1.1a	**Near:**	x	High	Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, forward gap, heading, acceleration) from the vehicle network.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-5.1.1b	**Near:**			Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (lateral acceleration, yaw rate, rate of change of steering wheel, brake status, brake boost status, impact sensor status, anti-lock braking status) from the vehicle network.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RC-5.1.2	**Near:**			Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather weather data (time, location, external air temperature, barometric pressure, wiper status, headlight status) from the vehicle network.	Functional
	Mid:	x	Low			
	Long:	x	Med			
RC-5.1.3	**Near:**			Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather road surface data (time, location, traction control status, stability control status, differential wheel speed) from the vehicle network.	Functional
	Mid:	x	Low			
	Long:	x	Med			

5. Need to collect relevant vehicle data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-5.2	**Near:**	x	High	Connected Vehicle-based CACC application, Integrated Vehicle Network Access System	Communications between the Connected Vehicle-based CACC application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	Functional
	Mid:	x	High			
	Long:	x	High			

6. Need to disseminate relevant vehicle data to other vehicles or systems

6. Need to disseminate relevant vehicle data to other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-6.1a	**Near:**	x	High	Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall disseminate position and movement data to other connected vehicles.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RC-6.1b	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall disseminate actions, road conditions, and weather information data to other connected vehicles.	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			
RC-6.1.1	**Near:**	x	High	Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall disseminate relevant vehicle data to other connected vehicles utilizing V2V communication.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			

6. Need to disseminate relevant vehicle data to other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-6.2	**Near:**	x	Med	Connected Vehicle-based CACC application, Roadside Equipment (RSE)	The Connected Vehicle-based CACC application shall disseminate relevant vehicle data to infrastructure systems utilizing V2I communication.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			

7. Need to receive relevant information from other vehicles or systems

7. Need to receive relevant information from other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-7.1a	**Near:**	x	High	Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall have the ability to receive position and movement data from other connected vehicles	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RC-7.1b	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall have the ability to receive actions, road conditions, and weather information from other connected vehicles	System-to-system Interface
	Mid:	x	Low			
	Long:	x	Med			
7.1.1	**Near:**	x	High	Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall receive relevant vehicle data from other connected vehicles utilizing V2V communication.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			

7. Need to receive relevant information from other vehicles or systems						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-7.2	**Near:**			Connected Vehicle-based CACC application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based CACC application shall have the ability to receive platoon-level gap and speed policy recommendations from infrastructure-based systems.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	High			
RC-7.2.1	**Near:**			Connected Vehicle-based CACC application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based CACC application shall have the ability to receive relevant platoon-level information from infrastructure-based systems utilizing I2V communication.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			

8. Need to communicate actions and other relevant information to vehicle operator

8. Need to communicate actions and other relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-8.1a	**Near:**			Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The Connected Vehicle-based CACC application shall pass platoon-level speed and gap recommendations to the driver interface system.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			
RC-8.1b	**Near:**			Connected Vehicle-based CACC application, Connected Vehicle driver interface system	The Connected Vehicle-based CACC application shall pass platoon entry and exit point recommendations to the driver interface system.	System-to-system Interface
	Mid:					
	Long:	x	Med			

8. Need to communicate actions and other relevant information to vehicle operator						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-8.2	**Near:**	x	High	Connected Vehicle driver interface system	The Connected Vehicle driver interface system shall communicate individualized CACC information to the driver in an appropriate manner utilizing auditory, visual, or haptic alerts and on-screen messages.	Human-Machine Interface
	Mid:	x	High			
	Long:	x	High			

9. Need to generate cruise control strategies

9. Need to generate cruise control strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-9.1	**Near:**	x	High	Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall fuse internally collected and externally received data to make speed and gap decisions.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-9.1.1	**Near:**			Connected Vehicle-based CACC application, RSE, Transportation Mgmt Entity	The Connected Vehicle-based CACC application shall consider system-wide speed harmonization recommendations generated by and received from infrastructure systems when determining appropriate speed and gap.	Functional
	Mid:	x	Med			
	Long:	x	High			
RC-9.1.2	**Near:**	x	High	Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall consider inter-vehicle movements and actions when determining appropriate speed and gap.	Functional
	Mid:	x	High			
	Long:	x	High			

9. Need to generate cruise control strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-9.2	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine recommended platoon entry position, location, and timing for vehicle entering a platoon.	Functional
	Mid:					
	Long:	x	Med			
RC-9.3	**Near:**			Connected Vehicle-based CACC application	The Connected Vehicle-based CACC application shall determine recommended platoon exit location and timing for vehicle exiting a platoon.	Functional
	Mid:					
	Long:	x	Med			

10. Need to automatically engage vehicle throttle and other equipment to enact cruise control strategies

10. Need to automatically engage vehicle throttle and other equipment to enact cruise control strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-10.1	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle	The Connected Vehicle shall provide an interface to the CACC application to enable and control throttle level and gear selection.	Hardware
	Mid:	x	High			
	Long:	x	High			
RC-10.2	**Near:**	x	High	Connected Vehicle-based CACC application, Connected Vehicle	The Connected Vehicle shall provide an interface to the CACC application to receive in-vehicle radar, camera, and sensor data.	Functional
	Mid:	x	High			
	Long:	x	High			

11. Need to integrate external commands from traffic management entities with self- or platoon-generated cruise control strategies

11. Need to integrate external commands from traffic management entities with self- or platoon-generated cruise control strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-11.1	**Near:**			Connected Vehicle-based CACC application, RSE, TME-based CACC application	The Connected Vehicle-based CACC application shall be capable of receiving external cruise control commands.	Functional
	Mid:	x	Med			
	Long:	x	High			
RC-11.2	**Near:**			Connected Vehicle-based CACC application, RSE, TME-based CACC application	The Connected Vehicle-based CACC application shall be capable of rejecting external cruise control commands.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-11.3	**Near:**			Connected Vehicle-based CACC application, Target Connected Vehicle communication system	The Connected Vehicle-based CACC application shall confirm that all other platoon vehicles have received and accepted external cruise control commands before executing them.	Functional
	Mid:	x	High			
	Long:	x	High			

12. Need to receive multi-source data

12. Need to receive multi-source data							
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-12.1	**Near:**			TME-based CACC application, Weather Data Environment, RSE, Connected Vehicles	The TME-based CACC application shall have a data collection capability for receiving real-time traffic (traffic stream flow and speed data), roadway surface condition (dry, wet, icy, or snowy), and weather data (precipitation type, precipitation intensity, wind direction and speed, and sight distance) from infrastructure-based systems.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			
RC-12.2	**Near:**			TME-based CACC application, Connected Vehicles	The TME-based CACC application shall have a data collection capability for receiving real-time traffic (traffic stream flow and speed data), roadway surface condition (dry, wet, icy, or snowy), and weather data (precipitation type, precipitation intensity, wind direction and speed, and sight distance) from connected vehicles.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-12.3	**Near:**			TME-based CACC application	The TME-based CACC application shall have a data storage capability for real-time and historical real-time traffic (traffic stream flow and speed data), roadway surface condition (dry, wet, icy, or snowy), and weather data (precipitation type, precipitation intensity, wind direction and speed, and sight distance).	Functional
	Mid:	x	Med			
	Long:	x	Med			

13. Need to process multi-source data

13. Need to process multi-source data						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-13.1	**Near:**			TME-based CACC application	The TME-based CACC application shall fuse and process the various data sources to make cruise control strategy recommendations.	Functional
	Mid:	x	Med			
	Long:	x	Med			

14. Need to generate speed or gap strategies

14. Need to generate speed or gap strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-14.1	**Near:**			TME-based CACC application	The TME-based CACC application shall have a speed and gap strategy generation capability.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-14.1.1	**Near:**			TME-based CACC application	The TME-based CACC application shall generate platoon-level speed and gap strategies for different segments of the roadway.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-14.1.2	**Near:**			TME-based CACC application, SPD-HARM application, Weather Data Environment, RSE, Connected Vehicles	The TME-based CACC application shall generate platoon-level speed and gap strategies that consider platoon vehicle characteristics, local roadway surface conditions, weather conditions, and system speed harmonization recommendations.	Functional
	Mid:	x	Med			
	Long:	x	Med			

14. Need to generate speed or gap strategies						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-14.1.3	**Near:**			TME-based CACC application, SPD-HARM application	The TME-based CACC application shall interface with the TME-based SPD-HARM application to generate appropriate speed harmonization targets.	System-to-system Interface
	Mid:	x	Med			
	Long:	x	Med			
RC-14.1.4	**Near:**			TME-based CACC application	The TME-based CACC application shall utilize online or offline modeling to generate platoon-level speed and gap strategies.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-14.2	**Near:**			TME-based CACC application	The TME-based CACC application shall take into account anticipated levels of driver compliance when generating specific target speed and gap strategies.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-14.3	**Near:**	x	Med	Traffic Management Entity	The Traffic Management Entity shall provide user education on the need to comply with recommended speed and gap targets.	Policy
	Mid:	x	Med			
	Long:	x	Med			

15. Need to disseminate speed and gap recommendations and other information to connected vehicles

15. Need to disseminate speed and gap recommendations and other information to connected vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-15.1	**Near:**			TME-based CACC application	The TME-based CACC application shall have a platoon-level speed and gap recommendation dissemination capability.	Functional
	Mid:	x	Med			
	Long:	x	Med			

15. Need to disseminate speed and gap recommendations and other information to connected vehicles						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-15.2	**Near:**			TME-based CACC application, Connected Vehicles	The TME-based CACC application shall disseminate platoon-level speed and gap recommendations to connected vehicle CACC platoons.	Functional
	Mid:	x	Med			
	Long:	x	Med			
RC-15.3	**Near:**			TME-based CACC application, Connected Vehicles	The TME-based CACC application shall disseminate platoon-level speed and gap recommendations to connected vehicle CACC platoons via I2V communications.	System-to-system Interface
	Mid:	x	High			
	Long:	x	High			

16. Need to analyze performance of CACC system

16. Need to analyze performance of CACC system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-16.1	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-16.1.1	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based CACC application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and throughput.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RC-16.1.2	**Near:**	x	Med	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	Functional/Performance
	Mid:	x	Med			
	Long:	x	Med			

16. Need to analyze performance of CACC system						
Req ID	**Application Evolution State**		**Priority**	**Systems/Subsystems Involved**	**Functional Requirement**	**Requirement Type**
RC-16.2	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			
RC-16.3	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	Functional
	Mid:	x	High			
	Long:	x	High			
RC-16.4	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based CACC application shall be modifiable such that algorithms and software performance can be improved.	Design
	Mid:	x	High			
	Long:	x	High			
RC-16.5	**Near:**	x	High	TME-based CACC application, TME Performance Monitoring Subsystem	The TME-based Performance Monitoring Subsystem shall continuously compare the actual performance of the system with the performance determined by the CACC application to determine recommended calibrations to the application.	Functional/Performance
	Mid:	x	High			
	Long:	x	High			

17. Need to collect CACC data and disseminate relevant information to other dynamic mobility applications

<table>
<tr><th colspan="7">17. Need to collect CACC data and disseminate relevant information to other dynamic mobility applications</th></tr>
<tr><th>Req ID</th><th colspan="2">Application Evolution State</th><th>Priority</th><th>Systems/Subsystems Involved</th><th>Functional Requirement</th><th>Requirement Type</th></tr>
<tr><td rowspan="3">RC-17.1</td><td>Near:</td><td></td><td></td><td rowspan="3">CACC application, SPD-HARM application, Q-WARN application, DMAs, Data Environment</td><td rowspan="3">The CACC application shall make relevant CACC-derived information (platoon locations and characteristics [size, vehicle capabilities, gap and speed policy]) available to other dynamic mobility applications via the Data Environment.</td><td rowspan="3">System-to-system Interface</td></tr>
<tr><td>Mid:</td><td>x</td><td>Low</td></tr>
<tr><td>Long:</td><td>x</td><td>Med</td></tr>
</table>

4 Data and Communication Needs

This section provides a discussion of the data and communication needs of the INFLO application systems and subsystems in order to meet the requirements detailed in Section 3. The tables below identify the data element(s), the originating system (source) and receiving system (sink) of the given data element, and the communication mode utilized to transfer the data.

4.1 SPD-HARM

ID	Data Element	Data Source	Data Sink	Communication Mode
DS-1	Link-based target speed recommendation and advisory message	Traffic Management Entity-Based SPD-HARM App	V2I Roadside Equipment	Hardline or Wireless LAN
DS-2	Target speed recommendation and advisory message	Traffic Management Entity-Based SPD-HARM App	Roadway Dynamic Message Sign	Hardline or Wireless LAN
DS-3	Target speed recommendation and advisory message	V2I Roadside Equipment	On-Board SPD-HARM App	I2V communication (DSRC, cellular, Wi-Fi)
DS-4	Target speed recommendation and advisory message	On-Board SPD-HARM App	Connected Vehicle Driver Interface System	In-vehicle communication
DS-5	Real-time CV weather data (external air temperature, barometric pressure, wiper status, headlight status	On-Board Connected Vehicle Sensor System	On-Board SPD-HARM App	In-vehicle communication

ID	Data Element	Data Source	Data Sink	Communication Mode
DS-6	Real-time CV performance data (location, heading, velocity, accelerometer [lateral, longitudinal], anti-lock braking system status, traction control, stability control, rate of change of steering wheel, yaw rate, differential wheel speed, brake status, brake boost, impact sensor)	On-Board Connected Vehicle Sensor System	On-Board SPD-HARM App	In-vehicle communication
DS-7	Real-time CV performance data	On-Board SPD-HARM App (Subject Vehicle)	On-Board SPD-HARM App (Remote Vehicle)	V2V communication (DSRC, cellular, Wi-Fi)
DS-8	Real-time CV weather data	On-Board SPD-HARM App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DS-9	Real-time CV performance data	On-Board SPD-HARM App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DS-10	Aggregated real-time CV-collected weather data	V2I Roadside Equipment	Traffic Management Entity-Based SPD-HARM App	Hardline (fiber, leased telco) or Wireless LAN
DS-11	Aggregated real-time CV performance data	V2I Roadside Equipment	Traffic Management Entity-Based SPD-HARM App	Hardline (fiber, leased telco) or Wireless LAN
DS-12	Real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature)	Roadway Weather Detection System	Traffic Management Entity-Based SPD-HARM App	Hardline (fiber, leased telco) or Wireless LAN
DS-13	Real-time traffic data (volume, occupancy, speed, vehicle classification)	Roadway Traffic Detection System	Traffic Management Entity-Based SPD-HARM App	Hardline (fiber, leased telco) or Wireless LAN
DS-14	Regional real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature, location)	Third-Party Weather Feeds	Traffic Management Entity-Based SPD-HARM App	Hardline (fiber, leased telco) or Wireless LAN

ID	Data Element	Data Source	Data Sink	Communication Mode
DS-15	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based SPD-HARM App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DS-16	Aggregated real-time CV performance data	Traffic Management Entity-Based SPD-HARM App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DS-17	Real-time weather data	Traffic Management Entity-Based SPD-HARM App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DS-18	Real-time traffic data	Traffic Management Entity-Based SPD-HARM App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DS-19	Generated target speed recommendations (target speed, location, time)	Traffic Management Entity-Based SPD-HARM App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DS-20	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based SPD-HARM App	Traffic Management Entity-Based SPD-HARM Performance Measurement System	Hardline (fiber, leased telco) LAN
DS-21	Aggregated real-time CV performance data	Traffic Management Entity-Based SPD-HARM App	Traffic Management Entity-Based SPD-HARM Performance Measurement System	Hardline (fiber, leased telco) LAN
DS-22	Real-time weather data	Traffic Management Entity-Based SPD-HARM App	Traffic Management Entity-Based SPD-HARM Performance Measurement System	Hardline (fiber, leased telco) LAN
DS-23	Real-time traffic data	Traffic Management Entity-Based SPD-HARM App	Traffic Management Entity-Based SPD-HARM Performance Measurement System	Hardline (fiber, leased telco) LAN

ID	Data Element	Data Source	Data Sink	Communication Mode
DS-24	Generated target speed recommendations (target speed, location, time)	Traffic Management Entity-Based SPD-HARM App	Traffic Management Entity-Based SPD-HARM Performance Measurement System	Hardline (fiber, leased telco) LAN

4.2 Q-WARN

ID	Data Element	Data Source	Data Sink	Communication Mode
DQ-1	Queue warning message	Traffic Management Entity-Based Q-WARN App	Roadway Dynamic Message Sign	Hardline or Wireless LAN
DQ-2	Queue detection alert (location, affected lanes, length of queue)	Traffic Management Entity-Based Q-WARN App	V2I Roadside Equipment	Hardline or Wireless LAN
DQ-3	Queue detection alert	V2I Roadside Equipment	On-Board Q-WARN App	I2V communication (DSRC, cellular, Wi-Fi)
DQ-4	Individualized queue detection alert (time and distance to end of queue, recommended response [brake, change lanes, divert])	On-Board Q-WARN App	Connected Vehicle Driver Interface System	In-vehicle communication
DQ-5	Queue prediction alert (predicted time of formation, location, affected lanes, length of queue)	Traffic Management Entity-Based Q-WARN App	V2I Roadside Equipment	Hardline or Wireless LAN
DQ-6	Queue prediction alert	V2I Roadside Equipment	On-Board Q-WARN App	I2V communication (DSRC, cellular, Wi-Fi)

ID	Data Element	Data Source	Data Sink	Communication Mode
DQ-7	Individualized queue prediction alert (time and distance to end of queue, recommended response [brake, change lanes, divert])	On-Board Q-WARN App	Connected Vehicle Driver Interface System	In-vehicle communication
DQ-8	Real-time CV weather data (external air temperature, barometric pressure, wiper status, headlight status	On-Board Connected Vehicle Sensor System	On-Board Q-WARN App	In-vehicle communication
DQ-9	Real-time CV performance data (location, heading, velocity, accelerometer [lateral, longitudinal], anti-lock braking system status, traction control, stability control, rate of change of steering wheel, yaw rate, differential wheel speed, brake status, brake boost, impact sensor)	On-Board Connected Vehicle Sensor System	On-Board Q-WARN App	In-vehicle communication
DQ-10	Self-generated queue detection alert	On-Board Q-WARN App (Subject Vehicle)	On-Board Q-WARN App (Remote Vehicle)	V2V communication (DSRC, cellular, Wi-Fi)
DQ-11	Propagated remote vehicle-generated queue detection alert	On-Board Q-WARN App (Remote Vehicle 1)	On-Board Q-WARN App (Remote Vehicle 2)	V2V communication (DSRC, cellular, Wi-Fi)
DQ-12	Real-time CV performance data	On-Board Q-WARN App (Subject Vehicle)	On-Board Q-WARN App (Remote Vehicle)	V2V communication (DSRC, cellular, Wi-Fi)
DQ-13	Real-time CV weather data	On-Board Q-WARN App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DQ-14	Real-time CV performance data	On-Board Q-WARN App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DQ-15	Aggregated real-time CV-collected weather data	V2I Roadside Equipment	Traffic Management Entity-Based Q-WARN App	Hardline (fiber, leased telco) or Wireless LAN
DQ-16	Aggregated real-time CV performance data	V2I Roadside Equipment	Traffic Management Entity-Based Q-WARN App	Hardline (fiber, leased telco) or Wireless LAN

ID	Data Element	Data Source	Data Sink	Communication Mode
DQ-17	Real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature)	Roadway Weather Detection System	Traffic Management Entity-Based Q-WARN App	Hardline (fiber, leased telco) or Wireless LAN
DQ-18	Real-time traffic data (volume, occupancy, speed, vehicle classification)	Roadway Traffic Detection System	Traffic Management Entity-Based Q-WARN App	Hardline (fiber, leased telco) or Wireless LAN
DQ-19	Regional real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature, location)	Third-Party Weather Feeds	Traffic Management Entity-Based Q-WARN App	Hardline (fiber, leased telco) or Wireless LAN
DQ-20	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based Q-WARN App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DQ-21	Aggregated real-time CV performance data	Traffic Management Entity-Based Q-WARN App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DQ-22	Real-time weather data	Traffic Management Entity-Based Q-WARN App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DQ-23	Real-time traffic data	Traffic Management Entity-Based Q-WARN App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DQ-24	Queue detection alert (location, affected lanes, length of queue)	Traffic Management Entity-Based Q-WARN App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DQ-25	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based Q-WARN App	Traffic Management Entity-Based Q-WARN Performance Measurement System	Hardline (fiber, leased telco) LAN

ID	Data Element	Data Source	Data Sink	Communication Mode
DQ-26	Aggregated real-time CV performance data	Traffic Management Entity-Based Q-WARN App	Traffic Management Entity-Based Q-WARN Performance Measurement System	Hardline (fiber, leased telco) LAN
DQ-27	Real-time weather data	Traffic Management Entity-Based Q-WARN App	Traffic Management Entity-Based Q-WARN Performance Measurement System	Hardline (fiber, leased telco) LAN
DQ-28	Real-time traffic data	Traffic Management Entity-Based Q-WARN App	Traffic Management Entity-Based Q-WARN Performance Measurement System	Hardline (fiber, leased telco) LAN
DQ-29	Queue detection alert (location, affected lanes, length of queue)	Traffic Management Entity-Based Q-WARN App	Traffic Management Entity-Based Q-WARN Performance Measurement System	Hardline (fiber, leased telco) LAN

4.3 CACC

ID	Data Element	Data Source	Data Sink	Communication Mode
DC-1	Platoon entry request	Connected Vehicle Driver Interface System	On-Board CACC App	In-vehicle communication
DC-2	Platoon entry request	On-Board CACC App (Subject Vehicle)	On-Board CACC App (Remote Vehicle)	V2V DSRC

ID	Data Element	Data Source	Data Sink	Communication Mode
DC-3	Platoon exit notification	Connected Vehicle Driver Interface System	On-Board CACC App	In-vehicle communication
DC-4	Platoon exit notification	On-Board CACC App (Subject Vehicle)	On-Board CACC App (Remote Vehicle)	V2V DSRC
DC-5	Real-time CV performance data (location, heading, velocity, accelerometer [lateral, longitudinal], anti-lock braking system status, traction control, stability control, rate of change of steering wheel, yaw rate, differential wheel speed, brake status, brake boost, impact sensor, fuel consumption, range, range rate)	On-Board Connected Vehicle Sensor System	On-Board CACC App	In-vehicle communication
DC-6	Real-time CV performance data	On-Board CACC App (Subject Vehicle)	On-Board CACC App (Remote Vehicle)	V2V DSRC
DC-7	Longitudinal control instructions (velocity, throttle, braking)	On-Board CACC App	Vehicle Control Interface	In-vehicle communication
DC-8	Link-based target speed and gap recommendations	Traffic Management Entity-Based CACC/SPD-HARM App	V2I Roadside Equipment	Hardline or Wireless LAN
DC-9	Platoon-level target speed and gap recommendations	V2I Roadside Equipment	On-Board CACC App	I2V communication (DSRC, cellular, Wi-Fi)
DC-10	Platoon-level target speed and gap recommendations	On-Board CACC App (Subject Vehicle)	On-Board CACC App (Remote Vehicle)	V2V DSRC
DC-11	Platoon-level target speed and gap recommendations	On-Board CACC App	Vehicle Control Interface	In-vehicle communication
DC-12	Real-time CV weather data (external air temperature, barometric pressure, wiper status, headlight status, roadway surface condition)	On-Board Connected Vehicle Sensor System	On-Board CACC App	In-vehicle communication

ID	Data Element	Data Source	Data Sink	Communication Mode
DC-13	Real-time CV performance data (location, heading, velocity, accelerometer [lateral, longitudinal], anti-lock braking system status, traction control, stability control, rate of change of steering wheel, yaw rate, differential wheel speed, brake status, brake boost, impact sensor)	On-Board Connected Vehicle Sensor System	On-Board CACC App	In-vehicle communication
DC-14	Real-time CV weather data	On-Board CACC App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DC-15	Real-time CV performance data	On-Board CACC App	V2I Roadside Equipment	V2I communication (DSRC, cellular, Wi-Fi)
DC-16	Aggregated real-time CV-collected weather data	V2I Roadside Equipment	Traffic Management Entity-Based CACC App	Hardline (fiber, leased telco) or Wireless LAN
DC-17	Aggregated real-time CV performance data	V2I Roadside Equipment	Traffic Management Entity-Based CACC App	Hardline (fiber, leased telco) or Wireless LAN
DC-18	Real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature)	Roadway Weather Detection System	Traffic Management Entity-Based CACC App	Hardline (fiber, leased telco) or Wireless LAN
DC-19	Real-time traffic data (volume, occupancy, speed, vehicle classification)	Roadway Traffic Detection System	Traffic Management Entity-Based CACC App	Hardline (fiber, leased telco) or Wireless LAN
DC-20	Regional real-time weather data (precipitation type, precipitation levels, surface conditions, wind direction and speed, air temperature, surface temperature, location)	Third-Party Weather Feeds	Traffic Management Entity-Based CACC App	Hardline (fiber, leased telco) or Wireless LAN
DC-21	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based CACC App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN

ID	Data Element	Data Source	Data Sink	Communication Mode
DC-22	Aggregated real-time CV performance data	Traffic Management Entity-Based CACC App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DC-23	Real-time weather data	Traffic Management Entity-Based CACC App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DC-24	Real-time traffic data	Traffic Management Entity-Based CACC App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DC-25	Generated target speed and gap recommendations (target speed and gap, location, time)	Traffic Management Entity-Based CACC App	Freeway Data Environment	Hardline (fiber, leased telco) or Wireless LAN
DC-26	Aggregated real-time CV-collected weather data	Traffic Management Entity-Based CACC App	Traffic Management Entity-Based CACC Performance Measurement System	Hardline (fiber, leased telco) LAN
DC-27	Aggregated real-time CV performance data	Traffic Management Entity-Based CACC App	Traffic Management Entity-Based CACC Performance Measurement System	Hardline (fiber, leased telco) LAN
DC-28	Real-time weather data	Traffic Management Entity-Based CACC App	Traffic Management Entity-Based CACC Performance Measurement System	Hardline (fiber, leased telco) LAN
DC-29	Real-time traffic data	Traffic Management Entity-Based CACC App	Traffic Management Entity-Based CACC Performance Measurement System	Hardline (fiber, leased telco) LAN
DC-30	Generated target speed and gap recommendations (target speed and gap, location, time)	Traffic Management Entity-Based CACC App	Traffic Management Entity-Based CACC Performance Measurement System	Hardline (fiber, leased telco) LAN
DC-31	Platoon-specific target speed and gap recommendations (target speed and gap, location, time)	On-Board Connected Vehicle Sensor System	On-Board CACC App	In-vehicle communication

ID	Data Element	Data Source	Data Sink	Communication Mode
DC-32	Platoon-specific target speed and gap recommendations (target speed and gap, location, time)	V2I Roadside Equipment	On-Board CACC App	I2V communication (DSRC, cellular, Wi-Fi)
DC-33	Platoon-specific target speed and gap recommendations (target speed and gap, location, time)	On-Board CACC App (Subject Vehicle)	On-Board CACC App (Remote vehicles in platoon)	V2V DSRC

APPENDIX A. Current List of Stakeholders

Khaled Abdelghany (Southern Methodist University)

Sheila Andrews (American Motorcyclist Association)

Juan Aparicio (Siemens)

Morgan Balogh (Washington State DOT (WSDOT))

John Benda (Illinois Tollway)

Roger Berg (DENSO)

Glenn Blackwelder (Utah DOT)

Bob Burrows (G4 Apps Inc.)

Darryl Dawson (Illinois Tollway)

Rick Dye (Maryland DOT)

Paul Eichbrecht (VIIC)

Henry Guerriero (Illinois Tollway)

Mohammed Hadi (Florida International University)

Ali Haghani (University of Maryland)

Larry Head (University of Arizona)

Bernard Istasse (ESIS)

Tom Jacobs (University of Maryland)

Howard Jennings, Jr. (Arlington Transportation Partners)

Bob Koeberlein (Idaho Transportation Department)

Peter Koonce (City of Portland)

Walter Kosiak (Delphi Electronics and Safety Systems)

Thomas Kurihara (TKstds Management)

Eil Kwon (University of Minnesota, Duluth)

Ken Laberteaux (Toyota Research Institute-North America)

Melissa Lance (Virginia Department of Transportation)

Greg Larson (Caltrans)

Bill Legg (Washington State DOT (WSDOT))

Alvin Marquess (Maryland DOT)

Richard McDonough (New York State Department of Transportation)

Jim Misener (Booz Allen Hamilton)

Dennis Mitchell (Oregon Department of Transportation (ODOT))

Dan Murray (ATRI)

Bryan Myers (Skyline)

Steve Novosad (Atkins Global)

Hilary Owen (Michigan Department of Transportation)

Michael Pack (University of Maryland)

Jennifer Portanova (NCDOT)

Kala Quintana (Northern Virginia Transportation Authority)

Frank Quon (LACMTA (Los Angeles Metro))

Bob Rausch (TransCore)

Steven Shladover (University of California PATH Program)

Brian Smith (University of Virginia)

Albert Sole (Colegio San Gabriel)

Candice Sutton (Virginia Department of Transportation)

Peter Thompson (SANDAG)

Stephan Travia (IDOT)

Ardalan Vahidi (Clemson University)

Harry Voccola (NAVTEQ)

Nhan Vu (Virginia Department of Transportation)

Tom West (University of California PATH Program)

Vann Wilber (VIIC)

Balaji Yelchuru (Booz Allen Hamilton)

David Zavattero (Chicago Department of Transportation (CDOT))

Xuesong Zhou (University of Utah)

APPENDIX B. List of Acronyms

The following is a list of the acronyms described in this document:

AAC	Acceleration Advice Controller
AACC	Autonomous Adaptive Cruise Control
AASHTO	American Association of State Highway and Transportation Officials
ACC	Adaptive Cruise Control
ADA	Advanced Driver Assistance
ADOT	Arizona Department of Transportation
ATIS	Advanced Traveler Information System
ATM	Active Traffic Management
ATMS	Advanced Traffic Management System
CACC	Cooperative Adaptive Cruise Control application
CCC	Conventional Cruise Control
CCTV	Closed-Circuit Television
ConOps	Concept of Operations
DMA	Dynamic Mobility Application
DMS	Dynamic Message Sign
DSRC	Dedicated Short-Range Communications
ESC	Electronic Stability Control
FDOT	Florida Department of Transportation
FOT	Field Operational Test
HCM	U.S. Highway Capacity Manual
IDM	Intelligent Driver Model
INFLO	Intelligent Network Flow Optimization
ITS	Intelligent Transportation System
LED	Light-Emitting Diode
MIDAS	Motorway Incident Detection and Automatic Signaling (United Kingdom)
MoDOT	Missouri Department of Transportation
NDOT	Nevada Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NJTA	New Jersey Turnpike Authority
NTCC	National Traffic Control Center (Netherlands)

OFDM	Orthogonal Frequency-Division Multiplexing
Q-WARN	Queue Warning application
RWIS	Roadway Weather Information System
SPD-HARM	Speed Harmonization application
SRTRI	Swedish Road and Transport Research Institute
TMC	Traffic Management Center
TxDOT	Texas Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure/Infrastructure-to-Vehicle
V2V	Vehicle-to-Vehicle
VC	Vehicular Communications
VDOT	Virginia Department of Transportation
VMS	Variable Message Sign
VMT	Vehicle Miles Traveled
VSL	Variable Speed Limit
VSS	Variable Speed Sign
VTTI	Virginia Tech Transportation Institute
WSDOT	Washington State Department of Transportation

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