Report on Detailed Requirements for the INFLO Prototype

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Final Report — December 27, 2013
FHWA-JPO-14-171

U.S. Department of Transportation

Produced by Battelle Memorial Institute / Texas A&M Transportation Institute
U.S. Department of Transportation
Research and Innovative Technology Administration
Federal Highway Administration

Cover Photo: Beverly T. Kuhn, Texas A&M Transportation Institute

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-14-171		

4. Title and Subtitle	5. Report Date
Report on Detailed Requirements for the INFLO Prototype	December 27, 2013
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
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9. Performing Organization Name And Address	10. Work Unit No. (TRAIS)
Battelle 505 King Avenue Columbus, Ohio 43201	11. Contract or Grant No. DTFH61-12-D-00040 / O&ITS-13-12

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
United States Department of Transportation ITS Joint Program Office Research And Innovative Technology Administration (RITA) 1200 New Jersey Avenue, SE Washington, DC 20590	**Draft Report** 14. Sponsoring Agency Code

15. Supplementary Notes
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16. Abstract

This report documents the System Requirements for the implementation of the Intelligent Network Flow Optimization (INFLO) Prototype bundle within the Dynamic Mobility Applications (DMA) portion of the Connected Vehicle Program. It builds off of the previous system requirements report and adds requirements specific to the INFLO Prototype Development and Demonstration, including the use of a nomadic device that allows for both cellular and DSRC communications

17. Key Words	18. Distribution Statement
Intelligent Network Flow Optimization, INFLO, SPD-HARM, Q-WARN, Speed Harmonization, Queue Warning, Dynamic Mobility Applications, DMA	Draft document. Limited Distribution. Has not been checked for Section 508 compliance.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	101	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgements

This report builds on the previous work captured in the *Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO): Functional and Performance Requirements, and High-Level Data and Communication Needs)*, ITS JPO Publication Number FHWA-JPO-13-013, and as such, uses a copy of the system requirements and associated definitions from this prior document as the basis for the tailored requirements associated with this next phase of the INFLO project as contained herein.

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Chapter 1 Scope

Identification of System

This report documents the Detailed Requirements for the Prototype development and demonstration of the Intelligent Network Flow Optimization (INFLO) application bundle, with a focus on the Speed Harmonization (SPD-HARM) and Queue Warning (Q-WARN) applications. These two applications together comprise a tightly integrated bundle that is a key research activity within the Dynamic Mobility Applications (DMA) portion of the Connected Vehicle Program. This document focuses on the requirements necessary to design, build, and demonstrate the INFLO Prototype application.

Terminology

The meanings of the auxiliary verbs used in this document are defined as follows:

- Shall — Compliance with a requirement, specification or a test is mandatory
- Should — Compliance with a requirement, specification, or a test is recommended
- May — Expresses a permissible way to achieve compliance

The meanings of the verification methods are as follows:

- Inspection — *Inspection is observation using one or more of the five senses, simple physical manipulation, and mechanical and electrical gauging and measurement to verify that the item conforms to its specified requirements*
- Demonstration — *Demonstration is the actual operation of an item to provide evidence that it accomplishes the required functions under specific scenarios*
- Test — *Test is the application of scientific principles and procedures to determine the properties or functional capabilities of items*
- Analysis — *Analysis is the use of established technical or mathematical models or simulations, algorithms, or other scientific principles and procedures to provide evidence that the item meets its stated requirements*

Introduction

Task 2.2 of the INFLO Prototype Development and Small-Scale Demonstration of Dynamic Speed Harmonization with Queue Warning Project prescribes the development of system requirements for the INFLO prototype. In order to achieve this, both an assessment of the prior systems engineering work, tailored to meet the specific requirements of this prototype, along with any new user needs and associated requirements necessary to fulfill the stated goals of the prototype, will be included herein.

Approach

The content of this document was generated through the incorporation of previously documented information related to the INFLO applications, as well as the results of additional requirements analysis and design work performed specific to this implementation of an INFLO Prototype. As noted in the Task Order Proposal Request (TOPR), only the speed harmonization (SPD-HARM) and queue warning (Q-WARN) applications will be included in this demonstration. And while it is not intended to duplicate the previous efforts, this document has been prepared to be standalone in its content. However, this document does assume the reader has familiarity with INFLO, the DMA program, and the overall Connected Vehicle initiative.

Document Organization

As previously noted, this document comprises a single report which identifies the prototype-specific system requirements as defined for INFLO Prototype development and demonstration activities. This report is comprised of the following major sections:

- A brief concept of operations discussion for the demonstration activities.
- An evaluation of the applicability of previous INFLO requirements as it relates to the proposed demonstration.
- Development of the prototype-specific needs and requirements.

The structure of this document is consistent with the Institute of Electrical and Electronics Engineers (IEEE) Standard 1233-1998 IEEE Guide for Developing System Requirements Specifications and Federal Highway Administration's (FHWA) System Engineering Guidebook (SEGB) that adapted IEEE-1233. It has been tailored to include the relationship to the previous INFLO requirements development work, as indicated by the government task order.

Chapter 2.0 documents the high level concept of operations and represents an adaptation of the General Description section of the previously published *Report on Functional and Performance Requirements and High-Level Data and Communication Needs*[1] as for the specific INFLO Prototype development activities.

Chapter 3.0 documents the assessment of the applicability to the prototype demonstration for each of the previously defined INFLO requirements, as identified in publication # FHWA-JPO-13-013. These requirements will be superseded by those now captured in Chapter 6.0 for the purposes of the INFLO prototype project. Requirements in Chapter 6.0 are adapted specifically for this project.

[1] November 1, 2012, US DOT Publication FHWA-JPO-13-013, Produced by Science Applications International Corporation (SAIC) for the U.S. Department of Transportation.

Chapter 4.0 describes the major systems, sub-systems and interfaces that are envisioned to be developed in support of the INFLO prototype.

Chapter 5.0 captures the additional User Needs that were developed in order to support the INFLO prototype, as well as documents the existing user needs, as traced to the detailed requirements. Note that some of the user needs listed will not be met, due to the defined scope of the INFLO prototype project.

Chapter 6.0 captures the new functional and performance requirements that were specific to the government scope of work related to this project, and the ability to support the prototype demonstration and evaluation. System design, development and testing will be based on the requirements captured in this chapter.

Chapter 2 High-Level Concept of Operations

This section contains the description of the proposed applications within the INFLO bundle as originally documented in the *Concept Development and Needs Identification* and as adapted to reflect the specific prototype that will be demonstrated as part of this task order. This information is included in order to allow this document to be standalone in its understanding.

Dynamic Speed Harmonization (SPD-HARM)

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. Specific to this prototype demonstration, the concept of a nomadic device, which allows for V2I communications in the forms of both Dynamic Short Range Communications (DSRC), and traditional cellular technology, such as 4G LTE, will be used to facilitate the V2I and I2V communications. This same device, when coupled with sensing equipment, both when installed in-vehicle, and when in mobile mode, will allow for basic weather-related data collection as well.

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.

Queue Warning (Q-WARN)

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.

Chapter 3 Assessment of Existing Requirements

This section identifies the subset of the originally defined INFLO Functional and Performance requirements that are expected to be fulfilled as part of INFLO Prototype demonstration. These requirements are organized in the same manner and include the same cross-references as the original requirements, but include additional columns to capture the applicability to this specific prototype demonstration. In order, the columns and a brief description are as follows:

- Rqmt. No – Requirement Number as defined for each applications area.
- Requirement – Text of the requirement.
- User Need ID – References ID of User Need captured in the original system requirement documentation.
- Included in Prototype – Indicates whether or not these previously developed INFLO requirements will or will not be included. NOTE: A few TBD entries also remain in this draft as further clarification with partners remain.
- Notes / Comments – Documents specific conditions on meeting a requirement or justification for those requirements which cannot be fulfilled under this effort.

In addition to these carry over elements, additional information is included for each of the two applications, as noted below.

SPD-HARM Functional and Performance Requirements

The SPD-HARM applications serves to provide a traveler with either an advisory, or possibly enforceable speed limit, that is intended to optimize travel flow and avoid the 'shockwave' that commonly develops during periods peak periods and near common chokepoints. For purpose of the INFLO prototype demonstration of the SPD-HARM application, the focus will be two-fold. The first is the augmentation of existing algorithms to consider the additional connected vehicle (CV) data streams in determining the harmonization speeds. As such, the enhancement is constrained to this additional input, and is not an attempt to revisit or refine the entire algorithm for purposes of this prototype. Our analysis of the previous requirements reflects this constraint, particularly as it refers to performance objectives of the algorithm. The second major focus is on the development and demonstration of a 'nomadic' device that is capable of being fully mobile, as well as integrating with a vehicle's onboard systems. Given that this device will support both DSRC and cellular connections but will be based on readily available technology, the ability to deliver lane-specific positioning information in real-time is not feasible. Again, the analysis of the previous requirements reflects this constraint.

Table 3-1. SPD-HARM Functional and Performance Requirements

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-1.1	The Connected Vehicle-based SPD-HARM application shall pass target speed recommendations to the driver interface system.	S1,S8	Yes	
RS-1.2	The Connected Vehicle driver interface system shall communicate segment-specific target speed recommendations to the driver.	S1,S8	Yes	
RS-1.2.1	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.	S1,S8	Yes	
RS-2.1	The Connected Vehicle shall have the ability to detect the lane in which it is traveling.	S2,S8	Partial	Lane Specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
RS-2.2	The Connected Vehicle-based SPD-HARM application shall pass target lane recommendations to the driver interface system.	S2,S8	Partial	Lane Specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
RS-2.3	The Connected Vehicle driver interface system shall communicate target lane recommendations to the driver.	S2,S8	Partial	Lane Specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-2.3.1	The Connected Vehicle driver interface system shall communicate target lane recommendations to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	S2,S8	Partial	Lane Specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
RS-3.1	The Connected Vehicle-based SPD-HARM application shall pass speed change justification information to the driver interface system.	S3,S8	Yes	
RS-3.2	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver.	S3,S8	Yes	
RS-3.2.1	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver utilizing auditory or visual (on-screen) messages.	S3,S8	Yes	
RS-4.1	The Connected Vehicle-based SPD-HARM application shall utilize secure data transmission methods when disseminating any personally identifiable information.	S4	Yes	
RS-4.2	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	S4	Yes	
RS-4.3	The Traffic Management Entity shall use secure transmission methods for disseminating target speed and lane recommendations and justification for speed changes.	S4	Yes	
RS-4.4	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	S4	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-5.1	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access (IVNA) System to gather real-time vehicle-collected data from the vehicle network.	S5	Yes	
RS-5.1.1a	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.	S5	Partial	When available, this data will be collected from the IVNA. However, this specific data (as listed) may also be collected from the Nomadic device.
RS-5.1.1b	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, and anti-lock braking status) from the vehicle network.	S5	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RS-5.1.2	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.	S5	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RS-5.1.3	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.	S5	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RS-5.2	Communications between the Connected Vehicle-based SPD-HARM application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	S5	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-6.1	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.	S6	No	Some of the data elements are part of the already existing messages exchanged between vehicles like the BSM. As SPD-HARM requires TME in the loop however, it is not the expectation to include a V2V component for this application beyond what is already included in the BSM messages.
RS-6.2a	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current speed, current location, and current acceleration/deceleration) to infrastructure systems utilizing V2I communication.	S6	Yes	
RS-6.2b	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.	S6	Yes	
~~RS-7.1~~	~~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.~~	~~S7~~	~~TBD~~	This requirement is being dropped. The SPD-HARM application is only a client of the TME based SPD-HARM algorithms and does not do any calculations and does not need to receive this data.
RS-7.2	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.	S7	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-9.1	The Traffic Management Entity (TME)-based SPD-HARM application shall have a data collection capability for receiving real-time data from multiple sources.	S9	Yes	
RS-9.1.1	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.	S9	Yes	
RS-9.1.2a	The TME-based SPD-HARM application shall have the capability to receive real-time traffic (including location and speed) from connected vehicles.	S9	Yes	
RS-9.1.2b	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.	S9	Partial	The TME-based SPD-HARM application will receive vehicle performance data as previously identified. Road conditions such as icy or wet, or weather conditions such as clear or rainy will not be directly provided by the connected vehicle.
RS-9.2	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).	S9	Yes	In this context, historical data is defined as that data which has been previously collected as a result of captured 'connected vehicle' data.
RS-10.1	The TME-based SPD-HARM application shall be capable of fusing and processing data from various sources to make target speed recommendations.	S10	Yes	
RS-10.1.1a	The TME-based SPD-HARM application shall utilize real-time traffic data when calculating the recommended target speed.	S10	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.1.1b	The TME-based SPD-HARM application shall utilize historical and predicted traffic data when calculating the recommended target speed.	S10	Partial	The SPD-HARM algorithm will include historical data when calculating the recommended target speed; however the implementation of predicted traffic conditions is beyond the time and scope of this effort.
RS-10.1.2	The TME-based SPD-HARM application shall utilize real-time and predicted weather data when calculating the recommended target speed.	S10	Partial	Real-time weather data will be used as part of the algorithm, However currently, while it may be possible to develop a system which integrates weather forecasts to predict future traffic operating conditions (i.e., forecasted traffic volumes and speeds, etc.), it is beyond what can be accomplished within the time and budget allocated to the prototype development.
RS-10.1.3	The TME-based SPD-HARM application shall utilize real-time and predicted road surface data when calculating the recommended target speed.	S10	Partial	Real-time road surface data will be used in making decisions. Predicted road surface data use will depend on review of existing strategies. We are not aware of any algorithm in use that includes road surface information based on forecasted weather conditions.
RS-10.2	The TME-based SPD-HARM application shall have a shockwave detection capability for known fixed bottleneck locations.	S10	Yes	
RS-10.2.1	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.	S10	Partial	The prototype effort is limited in its duration and scale, and as such, the performance of the algorithm and the effort necessary to meet this specific performance requirement is unknown. It is quite possible that the algorithm, for our test cases, will meet this requirement, however that is not our primary focus. However, we will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.2.2	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.	S10	Partial	The prototype effort is limited in its duration and scale, and as such, the performance of the algorithm and the effort necessary to meet this specific performance requirement is unknown. It is quite possible that the algorithm, for our test cases, will meet this requirement, however that is not our primary focus. However, we will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.
RS-10.2.3	The TME-based SPD-HARM application shall detect formed shockwaves within TBD seconds of formation at known fixed bottleneck locations.	S10	Yes	Deployment experience is needed to develop a baseline for performance of the algorithms. Processes will be included in the algorithm that will allow data to be collected for generating these performance metrics.
RS-10.2.4	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave.	S10	Partial	The prototype effort is limited in its duration and scale, and as such, the performance of the algorithm and the effort necessary to meet this specific performance requirement is unknown. It is quite possible that the algorithm, for our test cases, will meet this requirement, however that is not our primary focus. However, we will include process and data collection procedures that would allow for the generation of this type of performance metric.
RS-10.2.4.1	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave within TBD seconds of shockwave detection.	S10	Yes	See response for RS-10.2.3 above.
RS-10.2.5	The TME-based SPD-HARM application shall determine the length of the formed shockwave.	S10	Yes	
RS-10.2.5.1	The TME-based SPD-HARM application shall determine the length of the formed shockwave to within 10 ft.	S10	No	Not possible given accuracy of GPS or infrastructure technology.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.2.5.2	The TME-based SPD-HARM application shall determine the length of the formed shockwave within 5 seconds of shockwave detection.	S10	No	The performance of existing vehicle- and infrastructure-based communication technologies is not expected to currently be able to support this requirement. We will include a method of capturing and retaining the defined data requirements if they can be generated by the algorithm.
RS-10.2.5.3	The TME-based SPD-HARM application shall update the current shockwave length estimation once per second.	S10	Partial	Currently, most TME aggregate data at 20-30 second intervals. To achieve this objective will require TME to obtain and aggregate data at a higher resolution. Similarly, the use of non-DSRC based communications to transmit vehicle data at retest that support once-per-second updates is bandwidth prohibitive, not to mention the potential cost impacts.
RS-10.2.6a	The TME-based SPD-HARM application shall utilize real-time traffic data in shockwave detection algorithms.	S10	Yes	
RS-10.2.6b	The TME-based SPD-HARM application shall utilize road condition and weather data in shockwave detection algorithms.	S10	Yes	Most existing SP-HARM use weather information to set recommended speeds, instead of using weather information to detect shockwave. We will review existing algorithms to determine if and how real-time road condition and weather data are used to detect shockwave conditions.
RS-10.3	The TME-based SPD-HARM application shall have a shockwave/breakdown prediction capability for known fixed bottleneck points.	S10	No	Predictions of traffic states are not currently used in most deployed SPD-HARM applications. This requirement focuses on the long-term capabilities of the speed harmonization application, in an environment where the majority are equipped with connected vehicle technology. At present, there is insufficient data to represent this environment, and as such, demonstrating this requirement is outside of the scope of this INFLO prototype implementation.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.3.1	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.2	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.3	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.4	The TME-based SPD-HARM application shall determine the expected time of formation of the predicted shockwaves/breakdowns.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.4.1	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.4.2	The TME-based SPD-HARM application shall update the shockwave/breakdown time of formation prediction once per second.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.5	The TME-based SPD-HARM application shall determine the expected lane(s) impacted by the predicted shockwave/breakdown.	S10	No	See response for requirement RS-10.3 above.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.3.5.1	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.5.2	The TME-based SPD-HARM application shall update the shockwave/breakdown impacted lane(s) prediction once per second.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.6	The TME-based SPD-HARM application shall determine the expected length of the predicted shockwave/breakdown.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.6.1	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.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.6.2	The TME-based SPD-HARM application shall determine the expected length of the formed shockwave/breakdown within 5 seconds of shockwave/breakdown determination.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.6.3	The TME-based SPD-HARM application shall update the shockwave/breakdown length prediction once per second.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.7	The TME-based SPD-HARM application shall determine the expected duration of the predicted shockwave/breakdown.	S10	No	See response for requirement RS-10.3 above.
RS-10.3.8	The TME-based SPD-HARM application shall utilize real-time and historical data in shockwave/breakdown prediction algorithms.	S10	No	See response for requirement RS-10.3 above.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-10.3.9	The TME-based SPD-HARM application shall utilize online and offline modeling for shockwave/breakdown prediction.	S10	No	Similar situation as defined in RS-10.3 response above. Current applications of SPD-HARM algorithms generally do not use model traffic data.
RS-11.1	The TME-based SPD-HARM application shall have a target speed generation capability.	S11	Yes	
RS-11.1.1	The TME-based SPD-HARM application shall generate target speed strategies for different segments of the roadway.	S11	Yes	
RS-11.1.2a	The TME-based SPD-HARM application shall generate target speed strategies that consider downstream traffic conditions, weather, and local roadway surface conditions.	S11	Yes	
RS-11.1.2b	The TME-based SPD-HARM application shall generate target speed strategies that consider predicted future traffic conditions.	S11	No	Outside of the scope of the INFLO prototype implementation.
RS-11.1.3	The TME-based SPD-HARM application shall utilize online or offline modeling to generate target speed strategies.	S11	No	Outside the scope of the prototype implementation.
RS-11.1.4	The TME-based SPD-HARM application shall take into account the anticipated levels of driver compliance when generating specific target speed strategies.	S11	No	We agree that driver compliance is a key factor of a speed harmonization process; however, including a direct feedback of driver compliance into the algorithm could not be accomplished in the timeframe and budget allocated for the prototype development.
RS-11.2	The Traffic Management Entity shall provide user education on the need to comply with recommended speed targets.	S11	No	Policy-related requirements of this nature are outside of the scope of the prototype demonstration.
RS-12.1	The TME-based SPD-HARM application shall have a target speed recommendation dissemination capability.	S12	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-12.1.1	The TME-based SPD-HARM application shall disseminate target speed recommendations to SPD-HARM enabled connected vehicles on the facility via I2V communications.	S12	Yes	Standard messages to be utilized need to be identified.
RS-12.1.2	The TME-based SPD-HARM application shall disseminate target speed recommendations to DMS locations.	S12	Yes	
RS-13.1	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	S13	Partial	The TME-Based SPD-HARM prototype shall generate the data required to conduct performance analysis of the system and log the data into log files to be used by the assessment contractor.
RS-13.1.1	The TME-based SPD-HARM application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and capacity drop.	S13	Partial	The TME-Based SPD-HARM prototype shall generate the data required to conduct performance analysis of the system and log the data into log files to be used by the assessment contractor.
RS-13.1.2	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	S13	Partial	We will provide structure and system to capture data to allow independent evaluator to perform this level of analysis. Inclusion as function of TME is not feasible within scope of this effort. These specific data requirements need to be defined by others.
RS-13.2	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	S13	Partial	We will provide structure and system to capture data to allow independent evaluator to perform this level of analysis. Inclusion as a function of TME is not feasible within scope of this effort. These specific data requirements need to be defined by others.
RS-13.3	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	S13	Partial	We will provide structure and system to capture data to allow independent evaluator to perform this level of analysis. Inclusion as function of TME is not feasible within scope of this effort. These specific data requirements need to be defined by others.
RS-13.4	The TME-based SPD-HARM application shall be modifiable such that algorithms and software performance can be improved.	S13	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-13.5	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.	S13	Partial	The prototype INFLO algorithm shall be designed to include the generation of calibration factors based on monitoring system performance. The prototype will not include an automated process for making adjustments to the algorithm parameters. The process of making adjustment to the algorithm will have to occur using an off-line assessment of the performance measures.
RS-13.6	The TME-based Performance Monitoring Subsystem shall provide a means to identify, track, and analyze unidentified or mis-identified shockwave/breakdown formation events.	S13	Partial	The prototype INFLO algorithm shall generate detailed log files that include information used by the system in making its decisions to facilitate tracking of the system performance and identification of breakdowns in algorithm operation. The prototype will not include an automated process for making adjustments to the algorithm parameters. The process of making adjustment to the algorithm will have to occur using an off-line assessment of the performance measures.
RS-13.7	The TME-based Performance Monitoring Subsystem shall provide a means to compare predicted versus actual shockwave/breakdown occurrences and characteristics.	S13	No	Predicted shock wave occurrences will not be generated by the system.
RS-14.1	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.	S14	Yes	Will require definition of the interface with these applications and frequency of sharing data and decisions made.
RS-14.2	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.	S14	Partial	The application shall make the SPD-HARM derived information based on real-time data available to other applications. Information based on predicted conditions is beyond the scope of this prototype deployment.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RS-14.3	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.	S14	Yes	Will require definition of the interface with these applications and frequency of sharing data and decisions made.

Source: USDOT publication as annotated by Battelle

Q-WARN Functional and Performance Requirements

The Q-WARN application serves to provide a traveler with information about an existing or impending queue that may affect the travelers current trip, and similar to SPD-HARM, is intended to optimize travel flow and avoid the 'shockwave' that commonly develops during periods peak periods and near common chokepoints. Additionally, it allows for information as to the specific queues. Similar to SPD-HARM, the INFLO Prototype demonstration for Q-WARN focuses on the augmentation of existing algorithms to consider the additional connected vehicle (CV) data streams, and the use of the nomadic device to collect and disseminate information. The analysis of the previous Q-WARN requirements below reflects this constraint.

Table 3-2. Q-WARN Functional and Performance Requirements

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-1.1a	The Connected Vehicle-based Q-WARN application shall pass individualized queue warnings and queue characteristic information (based on vehicle's distance to back of queue) to the driver interface system.	1,8	Yes	
RQ-1.1b	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.	1,8	Yes	
RQ-1.2.1	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.	1,8	Yes	
RQ-1.2a	The Connected Vehicle driver interface system shall communicate queue warnings and queue characteristic information (based on vehicle's distance to back of queue) to the driver.	1,8	Yes	The Connected Vehicle Driver interface system shall communicate the following to the driver: the travel distance (in miles) from the vehicles current position) to the expected Back of Queue, the lane in which the stopped condition exists, and recommended course of action. Example message "Expect Stopped Traffic in 2 miles. Reduce speed." This requirement applies for vehicles upstream of queue. (How far upstream TBD during design process.)

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-1.2b	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.	1,8	Partial	The Connected Vehicle Driver interface system shall communicate the following to the driver: expected distance drive will be in queued state (Example message "Expect Stop and Go Traffic for next 2 miles") and expected time to be clear of queue state i.e., expected delay -- Example message" Expect to clear congestion in X minutes).
RQ-2.1	The Connected Vehicle-based Q-WARN application shall pass individualized queue response strategies (based on vehicle's distance to back of queue) to the driver interface system (speed reduction, lane change, diversion recommendations).	2,8	Yes	Only rudimentary action message (e.g., Reduce Speed) can be implemented in prototype. Recommended action CANNOT be in conflict with other external information (e.g., in WZ lane closure, the lane that is open will OFTEN have a longer queue than the lane that is closed. We DO NOT want to recommend that driver move to lane that is closed only to be forced back into open lane). This would require integration with other system (e.g., lane closure management beyond scope of project). Likewise don't want to advise vacating a lane when driver expects to exit.
RQ-2.2	The Connected Vehicle driver interface system shall communicate queue response strategies (speed reduction, lane change, diversion recommendations) to the driver.	2,8	Partial	See response for requirement RQ-2.1 above.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-2.2.1	The Connected Vehicle driver interface system shall communicate queue response strategies to the driver utilizing auditory or visual (on-screen) messages.	2,8	Yes	
RQ-3.1	The Connected Vehicle-based Q-WARN application shall utilize secure data transmission methods when disseminating any personally identifiable information.	3	Yes	
RQ-3.2	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	3	Yes	
RQ-3.3	The Traffic Management Entity shall use secure transmission methods for disseminating queue warnings, queue characteristic information, and response strategies.	3	Yes	
RQ-3.4	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	3	Yes	
RQ-4.1	The Connected Vehicle-based Q-WARN application shall have the ability to detect when the vehicle is in a queued state.	4	Yes	
RQ-4.2	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.	4	Yes	
RQ-4.2.1a	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.	4	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-4.2.1b	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, and anti-lock braking status) from the vehicle network.	4	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RQ-4.2.2	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.	4	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RQ-4.2.3	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.	4	Partial	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
RQ-4.3	Communications between the Connected Vehicle-based Q-WARN application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	4	Yes	
RQ-5.1	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.	5	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-5.2	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to infrastructure systems via V2I communication.	5	Yes	
RQ-6.1	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via I2V communication channels.	6	Yes	
RQ-6.2	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via V2V communication channels.	6	Yes	
RQ-7.1	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.	7	Yes	
RQ-7.2	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies based on distance to back of queue.	7	Yes	
RQ-7.2	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies based on local traffic, weather, and roadway conditions.	7	Yes	
RQ-7.3	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies that include speed reduction, lane change, or diversion recommendations.	7	No	Functionality to support this requirement is dependent on the long-term penetration of connected vehicles and is therefore outside of the scope of this prototype demonstration.
RQ-7.3.1	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based SPD-HARM application to generate appropriate speed reduction targets.	7	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-7.3.2	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based SPD-HARM application to generate appropriate lane change recommendations.	7	No	The GPS accuracy of the prototype does not support lane level accuracy. Additional information is needed to provide recommendation for lane change. Integrating other information is beyond scope of prototype.
RQ-7.3.3	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.	7	No	Integration with other DMA programs is not feasible within the scope of this effort.
RQ-9.1	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.	9	Yes	
RQ-9.1.1	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.	9	Yes	
RQ-9.1.2	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.	9	Partial	The TME-based Q-WARN application will receive vehicle performance data as previously identified. Road conditions such as icy or wet, or weather conditions such as clear or rainy will not be directly provided by the connected vehicle.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-9.2	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).	9	Partial	A data environment will exist such that the TME-based Q-WARN application may access the data, but the specific need to perform this action will be dependent on the needs of the demonstrated algorithm.
RQ-10.1	The Traffic Management Entity shall communicate traffic, road condition, and weather data to connected vehicles/devices via I2V communications systems.	10	Partial	It is not necessary to transmit all of the data specified, from the Infrastructure to the Vehicle, in order to fulfill the needs of the Q-WARN application. Only that which is necessary will be transmitted.
RQ-11.1	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue detection.	11	Yes	
RQ-11.1.1a	The TME-based Q-WARN application shall utilize real-time data in queue detection algorithms.	11	Yes	
RQ-11.1.1b	The TME-based Q-WARN application shall utilize predicted and historical traffic data in queue detection algorithms.	11	TBD	If an algorithm is identified that supports predicted and/or historical traffic data, this requirement may be partially or fully fulfilled.
RQ-11.1.2a	The TME-based Q-WARN application shall utilize real-time weather data in queue detection algorithms.	11	TBD	If an algorithm is identified that utilizes real-time weather data, this requirement may be partially or fully fulfilled.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-11.1.2b	The TME-based Q-WARN application shall utilize predicted weather data in queue detection algorithms.	11	No	Use of predicted weather data is not feasible within scope of this effort.
RQ-11.1.3a	The TME-based Q-WARN application shall utilize real-time road surface data in queue detection algorithms.	11	TBD	The capabilities inherent in the TME-based Q-WARN application will be dependent on those capabilities that exist in the selected algorithm. The goal of this project is to extend the algorithm to include connected vehicle data, not necessarily to change the underlying algorithm.
RQ-11.1.3b	The TME-based Q-WARN application shall utilize predicted road surface data in queue detection algorithms.	11	No	Use of predicted road surface data is not feasible within scope of this prototype effort.
RQ-11.2	The TME-based Q-WARN application shall have a queue detection capability for known fixed queue generation locations.	11	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-11.2.1	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.	11	No	The prototype effort is limited in its duration and scale, and as such, the performance of the algorithm and the effort necessary to meet this specific performance requirement is unknown. It is quite possible that the algorithm, for our test cases, will meet this requirement, however that is not our primary focus. However, we will include process and data collection procedures that would allow for the generation of this type of performance metric.
RQ-11.2.2	The TME-based Q-WARN application shall have a missed detection rate no more than 1% of all formed queues at known fixed queue generation locations.	11	No	The prototype effort is limited in its duration and scale, and as such, the performance of the algorithm and the effort necessary to meet this specific performance requirement is unknown. It is quite possible that the algorithm, for our test cases, will meet this requirement, however that is not our primary focus. However, we will include process and data collection procedures that would allow for the generation of this type of performance metric.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-11.2.3	The TME-based Q-WARN application shall detect formed queues within 5 seconds of formation at known fixed queue generation locations.	11	No	At this time we do not know what the level of performance can be achieved at this time and we are concerned about the 5 second requirement. Deployment experience is needed to develop a baseline of performance. Processes will be included in the algorithm that will allow data to be collected for generating these performance metrics.
RQ-11.3	The TME-based Q-WARN application shall determine the lane(s) impacted by the formed queue.	11	Partial	Lane-level accuracy will be provided to the extent it is possible to make a reasonably accurate determination given the error of the onboard location services, but considering the capability of infrastructure-based systems.
RQ-11.3.1	The TME-based Q-WARN application shall determine the lane(s) impacted by the formed queue within 5 seconds of queue detection.	11	No	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, and the accuracy of proposed onboard GPS capability, will not support this performance requirement.
RQ-11.4	The TME-based Q-WARN application shall determine the length of the formed queue.	11	Yes	This will assume the beginning of the queue to be the first detection station at the known bottleneck location. The length of queue will consist of the section that is known to be congested.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-11.4.1	The TME-based Q-WARN application shall determine the length of the formed queue to within 10 ft.	11	No	The accuracy of proposed onboard GPS capability will not support this performance requirement.
RQ-11.4.2	The TME-based Q-WARN application shall determine the length of the formed queue within 5 seconds of queue detection.	11	No	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, and the accuracy of proposed onboard GPS capability, will not support this performance requirement.
RQ-11.4.3	The TME-based Q-WARN application shall update the current queue length estimation once per second.	11	No	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, will not support this performance requirement.
RQ-11.5	The TME-based Q-WARN application shall determine the number of vehicles in the formed queue.	11	Yes	Can provide estimate by determining the length of the roadway in queued state, and then assuming vehicle length and separation to estimate number of vehicles in queue.
RQ-11.5.1	The TME-based Q-WARN application shall determine the number of vehicles in the formed queue within 5 seconds of queue detection.	11	No	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, and the accuracy of proposed onboard GPS capability, will not support this performance requirement.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-11.5.1.2	The TME-based Q-WARN application shall update the current car count estimation once per second.	11	No	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, and the accuracy of proposed onboard GPS capability, will not support this performance requirement.
RQ-11.6	The TME-based Q-WARN application shall determine the traveling speed and direction of the formed queue.	11	Yes	
RQ-11.6.1	The TME-based Q-WARN application shall determine the traveling speed of the formed queue within 5 seconds of queue detection.	11	Partial	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle, and the accuracy of proposed onboard GPS capability, will not support this performance requirement.
RQ-11.6.2	The TME-based Q-WARN application shall update the estimation of the traveling speed of the queue once per second.	11	Partial	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle will not support this performance requirement.
RQ-11.6.3	The TME-based Q-WARN application shall determine the traveling speed of the formed queue to within 5 mph.	11	Partial	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle will not support this performance requirement.
RQ-12.1	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue prediction.	12	Yes	
RQ-12.1.1	The TME-based Q-WARN application shall utilize real-time, predicted, and historical traffic data in queue prediction algorithms.	12	Partial	Algorithm will consider real-time and historical data.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-12.1.2	The TME-based Q-WARN application shall utilize real-time and predicted weather data in queue prediction algorithms.	12	Yes	
RQ-12.1.3	The TME-based Q-WARN application shall utilize real-time and predicted road surface data in queue prediction algorithms.	12	Partial	Real-Time Only.
RQ-12.1.4	The TME-based Q-WARN application shall utilize online or offline modeling in queue prediction algorithms.	12	No	It would not be possible to integrate a computer simulation model for the prototype development. This is not intended to imply that integrating a computer simulation tool would not be a worthwhile effort in the future – only that it could not be done within the timeframe and budget of the prototype development.
RQ-12.2	The TME-based Q-WARN application shall have a queue prediction capability for known fixed queue generation locations.	12	TBD	
RQ-12.2.1	The TME-based Q-WARN application shall have a false positive identification rate of no more than TBD% of all queue detection events at known fixed queue generation locations.	12	TBD	At this time we do not know what the level of performance can be achieved. Deployment experience is needed to develop a baseline of performance. Processes will be included in the algorithm that will allow data to be collected for generating these performance metrics.
RQ-12.2.2	The TME-based Q-WARN application shall have a missed prediction rate no more than TBD % of all formed queues at known fixed queue generation locations.	12	TBD	See Response for RQ-12.2.1

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-12.3	The TME-based Q-WARN application shall determine the time of formation of the predicted queue.	12	TBD	See Response for RQ-12.2.1
RQ-12.3.1	The TME-based Q-WARN application shall determine the time of formation of the predicted queue to within TBD seconds of actual queue formation.	12	TBD	See Response for RQ-12.2.1
RQ-12.4	The TME-based Q-WARN application shall determine the lane(s) impacted by the predicted queue.	12	Yes	See Response for RQ-12.2.1
RQ-12.4.1	The TME-based Q-WARN application shall determine the lane(s) impacted by the predicted queue within TBD seconds of queue determination.	12	TBD	See Response for RQ-12.2.1
RQ-12.5	The TME-based Q-WARN application shall determine the length of the predicted queue.	12	Yes	See Response for RQ-12.2.1
RQ-12.5.1	The TME-based Q-WARN application shall determine the length of the predicted queue to within TBD ft. of actual formed queue length.	12	TBD	See Response for RQ-12.2.1
RQ-12.5.2	The TME-based Q-WARN application shall determine the length of the predicted queue within TBD seconds of queue determination.	12	TBD	See Response for RQ-12.2.1
RQ-12.5.3	The TME-based Q-WARN application shall update the current queue length prediction TBD per second.	12	TBD	See Response for RQ-12.2.1
RQ-12.6	The TME-based Q-WARN application shall determine the expected duration of the predicted queue.	12	TBD	See Response for RQ-12.2.1
RQ-12.6.1	The TME-based Q-WARN application shall update the expected duration of the predicted queue TBD per second.	12	TBD	See Response for RQ-12.2.1
RQ-12.7	The TME-based Q-WARN application shall determine the number of vehicles in the predicted queue.	12	TBD	See Response for RQ-12.2.1
RQ-12.7.1	The TME-based Q-WARN application shall determine the number of vehicles in the predicted queue within TBD seconds of queue determination.	12	TBD	See Response for RQ-12.2.1

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-12.7.2	The TME-based Q-WARN application shall update the car count estimation for the predicted queue TBD per second.	12	TBD	See Response for RQ-12.2.1
RQ-12.8	The TME-based Q-WARN application shall determine the traveling speed and direction of the predicted queue.	12	TBD	See Response for RQ-12.2.1
RQ-12.8.1	The TME-based Q-WARN application shall determine the traveling speed of the predicted queue within TBD seconds of queue determination.	12	TBD	See Response for RQ-12.2.1
RQ-12.8.2	The TME-based Q-WARN application shall update the estimated traveling speed of the predicted queue TBD per second.	12	TBD	See Response for RQ-12.2.1
RQ-12.8.3	The TME-based Q-WARN application shall determine the traveling speed of the predicted queue to within TBD mph of the speed of the actual formed queue.	12	TBD	See Response for RQ-12.2.1
RQ-13.1	The TME-based Q-WARN application shall have a queue warning response strategy generation capability.	13	TBD	
RQ-13.1.1	The TME-based Q-WARN application shall generate queue warning response strategies that include speed reduction and diversion recommendations.	13	Partial	Lane Change is outside of the scope of this effort.
RQ-13.1.1.1	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate speed reduction targets.	13	Yes	
RQ-13.1.1.2	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate lane change recommendations.	13	No	Not sure that it is appropriate for infrastructure to make lane change recommendations. This assumes that infrastructure know destination of vehicle. See RQ 2.2.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-13.1.1.3	The TME-based Q-WARN application shall interface with the TME-based EnableATIS and/or FRATIS applications to generate appropriate route diversion recommendations.	13	No	Not sure that it is appropriate for infrastructure to make route diversion recommendations. This assumes that infrastructure knows destination of vehicle. See RQ 2.2.
RQ-13.1.2a	The TME-based Q-WARN application shall generate target speed strategies that consider distance to back of queue.	13	Yes	
RQ-13.1.2b	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.	13	TBD	This requirement consists of several specific requirements. Need a better definition as to what it is that the requirement is trying to achieve. Can provide estimated travel time (or delay) in queue based on current travel speed in queue. Not sure we can tell driver to travel faster than what speed in queue is.
RQ-13.1.3	The TME-based Q-WARN application shall utilize online or offline modeling to generate queue warning response recommendations.	13	No	Integrating a decision support system that uses modeling, whether off-line or on-line, is beyond what can be accomplished in prototype development
RQ-13.3	The Traffic Management Entity shall provide user education on the need to comply with queue warning response recommendations.	13	No	Beyond scope of prototype development.
RQ-14.1	The TME-based Q-WARN application shall have a queue warning and queue information dissemination capability.	14	Yes	

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-14.1.1	The TME-based Q-WARN application shall disseminate queue warnings and queue information to DMS locations.	14	Yes	
RQ-14.1.2	The TME-based Q-WARN application shall disseminate queue warnings and queue information to connected vehicles.	14	Yes	
RQ-14.1.3	The TME-based Q-WARN application shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	14	Yes	Prototype develop will generate a generic queue warning message that other applications can use.
RQ-15.1	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	15	Partial	Prototype will log all data inputs, process results, and message that can be analyzed to assess unidentified or mis-identified queue information events.
RQ-15.1.1	The TME-based Q-WARN application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and capacity drop.	15	No	Implementation of a performance monitoring system is outside of the scope of the prototype demonstration.
RQ-15.1.2	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	15	No	Implementation of a performance monitoring system is outside of the scope of the prototype demonstration.
RQ-15.2	The TME-based Q-WARN application shall provide a means to identify, track, and analyze unidentified or mis-identified queue formation events.	15	Partial	Prototype will log all data inputs, process results, and message that can be analyzed to assess unidentified or mis-identified queue information events.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-15.3	The TME-based Q-WARN application shall provide a means to compare predicted versus actual queue occurrences and characteristics.	15	No	Implementation of a performance monitoring system is outside of the scope of the prototype demonstration.
RQ-15.4	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	15	No	Implementation of a performance monitoring system is outside of the scope of the prototype demonstration.
RQ-15.5	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	15	No	Implementation of a performance monitoring system is outside of the scope of the prototype demonstration.
RQ-15.6	The TME-based Q-WARN application shall be modifiable such that algorithms and software performance can be improved.	15	Yes	
RQ-17.1	The Arterial Signal System shall have a dissemination capability to provide approaching connected vehicles signal phasing information.	17	No	The effort to integrate the Arterial Signal System in INFLO is outside of the present scope of the system.
RQ-18.1	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.	18	No	Data will be logged in data environment, but that is the extent of how this requirement will be satisfied.
RQ-18.2	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	18	Yes	Data will be logged in data environment, but that is the extent of how this requirement will be satisfied.

Rqmt No.	Requirements	User Need ID	Included in Prototype	Notes/Comments
RQ-19.1	The Data Capture and Management Environment shall collect, aggregate, and disseminate queue warning related data to freeway and arterial traffic management entities.	19	Yes	

Source: USDOT publication as annotated by Battelle

Chapter 4 INFLO Prototype System of Interest

As the user needs are further detailed and refined into system requirements, it is necessary to identify all of the key systems, subsystems, and the interfaces between these entities, and to organize the requirements based on these entities. This section provides for that organization and is consistent with the presentation of the requirements in Chapter 6. Figure 4-1 shows the system-level diagram, organized by system, with arrows indicating the various information flows between the entities. A detailed description of each of these entities follows:

- **Connected Vehicle (Nomadic Device)** – dual-radio device that can move from car to transit to pedestrian and includes ability to collect weather data. This device contains the following subsystems:

- **Driver Interface System (UI)** – the in-vehicle system that displays system output and receives user input.
- **Q-WARN Application** – the core in-vehicle application that processes real-time data and either makes individual queue warning determinations or responds to the queue warning messaging from the traffic management entity (TME).
- **Communication System** – the in-vehicle system that communicates wirelessly with infrastructure and other nomadic devices to send and receive data and instructions (DSRC and/or cellular communication).
- **Weather System** – the Nomadic Device will need the ability to sense and disseminate environmental conditions (temperature, barometric pressure, etc.) The Weather System is responsible for providing those sensors. If the Nomadic Device is installed in a vehicle with access to the on-board diagnostics, and if the vehicle provides environmental data (pressure, external temperature, etc.) then the system will utilize that information. The Nomadic Device will also have on-board environmental sensors that will provide localized environmental sensing.
- **Integrated Vehicle Network Access System** – the in-vehicle systems that reads real-time vehicle data (if available; speed, heading, temperature, etc.) to make it available to the INFLO applications.

- **Traffic Management Entity (TME)** – the generalized system (which could refer to a traffic management center [TMC]) that is responsible for (a.) making segment-specific and network-wide target speed recommendations for SPD-HARM-enabled Nomadic Devices (b.) creating Q-WARN recommendations and policies on the transportation network using safety and mobility measures (c.) creating WRTM recommendations and policies on the transportation network using safety and mobility measures (d.) collecting information to permit agencies to monitor and evaluate the effectiveness of the Q-WARN, WRTM and SPD-HARM applications information. The TME will communicate these recommendations to the Nomadic Devices via I2V communications. The TME is comprised of the following subsystems:

- **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.
- **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.
- **TME-based WRTM Application** – the core infrastructure-based application that processes real-time and historical transportation network data to determine weather responsive traffic management recommendations.
- **TME-based Information Dissemination Subsystem** – the subsystem that sends speed harmonization and queue warning recommendations to road users on specific segments of the road via I2V communications and/or traditional dynamic message signs (DMSs). Will manage outgoing messaging, high-level protocols, prioritization, routing, security, etc.
- **Data Storage (Warehouse)** – used to store data gathered from Nomadic Devices and fixed-location sensors as well as the data generated by the Q-WARN, WRTM and SPD-HARM applications to enable the Performance Monitoring Subsystem to measure the effectiveness of speed harmonization and queue warning heuristics, recommendations and policies on the transportation network using safety and mobility measures. This component also supports the Impacts Assessment (IA) element of the prototype project.
- **TME-based Information Collection Subsystem** – software and hardware in the TME that manages information input into the TME. Data can come from various external entities (Mobile Weather Systems, Traffic Sensor Systems, etc.) as well as the network of Nomadic Devices in the field.

- **Roadside Equipment** – the infrastructure-based communication systems that receive and send information between Nomadic Devices and the TME (may include DSRC and/or cellular communication).
- **TME Performance Monitoring Subsystem** – the subsystem of the TME that monitors the effectiveness of speed harmonization and queue warning heuristics, recommendations, and policies on the transportation network using safety and mobility measures. The TME-Performance Monitoring System will collect and store data that would potentially allow one to go back and determine if a need for increased enforcement might exist, but we don't envision it doing the assessment directly. What the system would include is the recommended target speed as well as the measured travel speed for each segment. By comparing these two measures, one could get a feel for the "level of compliance" that might exist. This would work for the queue warning and weather recommended target speeds that rely on conditions other than speed in making a target speed recommendation. This approach however probably will not work for the shockwave detection algorithm (i.e., SPD-HARM) because it uses measured speed to determine recommended target speeds.
- **Other Applications** – represents other applications that could contribute to and benefit from the data available for the SPD-HARM/Q-WARN/WRTM application.

- ***Arterial Signal System***
- ***Traveler Information Systems***
- ***EnableATIS application***
- ***FRATIS application***

- ***Other DMA Applications***

- **Infrastructure-Based Detection Equipment** – existing, infrastructure-based sensors and other measurement equipment currently in use for queue, speed and weather/road condition detection purposes.

- ***Mobile Weather Systems***
- ***Road Weather Information System***
- ***Traffic Sensor Systems***
- ***Weather Information Service Provider***
- ***Historical Traffic Database***

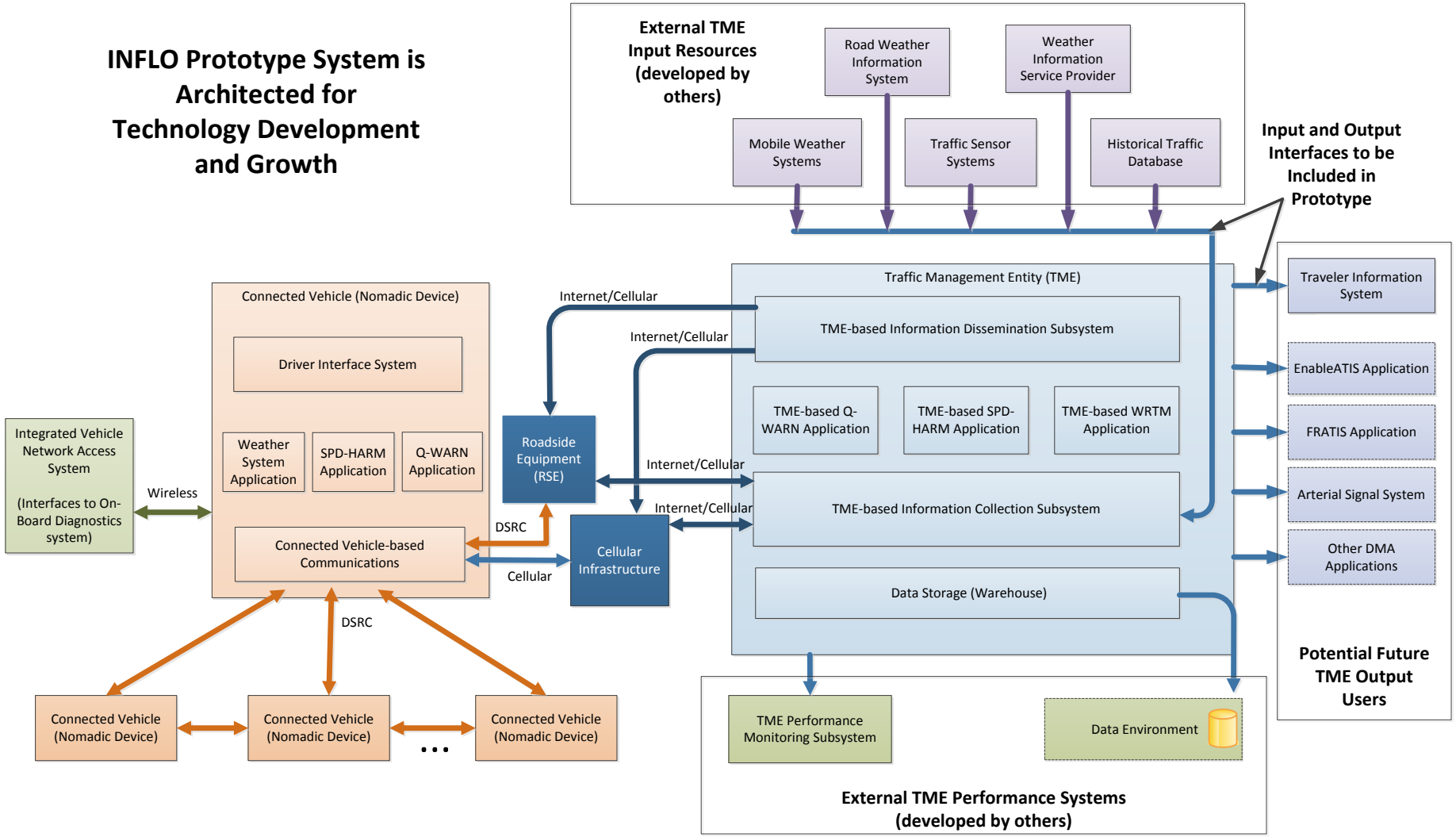

Figure 4-1. INFLO Prototype System Diagram

Chapter 5 User Needs

A rigorous systems engineering process starts with the identification of user needs. From these needs, system requirements are then developed, and those in turn serve as the building block for system design and test. Similar to earlier discussions related to the system requirements, prior work activities for INFLO resulted in the development of user needs for both the Q-WARN and SPD-HARM applications. These user needs are included below, both to allow for this document to be stand-alone in nature, and in order to provide the traceability, as specified in the Task Order Proposal Request (TOPR). Additionally, as a result of the added elements of conducting a prototype demonstration and evaluation, additional user needs were articulated. As such, the complete set of User Needs that have been identified to support the Q-WARN and SPD-HARM applications, including the prototype demonstration and evaluation, are included in Table 5-1 below. The new user needs are identified with an 'N' prefix, Q-WARN with a Q, and SPD-HARM with an S.

Table 5-1. User Needs

User Need ID	User	High-Level User Need	Discussion
N01	Evaluator	Needs to support the Impacts Assessment	The prototype must support the needs of both the INFLO Impacts Assessment (IA) Contractor and Battelle development test engineers by logging relevant sensor and communications data.
N02	Evaluator	Needs to support the DMA Evaluator	The prototype must support the needs of both the overall US DOT DMA Evaluator Contractor and Battelle development test engineers by logging relevant sensor and communications data.
N03	Vehicle Operator	Needs to support a nomadic device	The device(s) developed to facilitate the SPD-HARM and Q-WARN interactions with the user must support being be carried by a single person throughout a complete door to door trip, including pedestrian, transit and private vehicle modes, and that the device function will vary throughout the trip, e.g., nomadic.
N04	Traffic Management Entity	Needs to demonstrate integration with Traffic Mgmt. Center (TMC)	The prototype system should implement a "virtual" TMC to avoid the cost, risk and complexity of interfacing with a real TMC.
N05	Evaluator	Needs to support the Advanced Travel Demand Model (ATDM) assessment.	The prototype must support the needs of both the US DOT ATDM Evaluation Contractor and Battelle development test engineers by logging relevant sensor and communications data.

User Need ID	User	High-Level User Need	Discussion
N06	Prototype Implementation	Needs to utilize open-source components where possible	The SPD-HARM and Q-WARN program artifacts (design, code, data, documentation, etc.) should be readily available to the greater transportation research community.
N07	Prototype Implementation	Needs to provide robust logging capabilities	The major subsystems (virtual TMC and the in-vehicle components) should have robust logging capabilities to support system level testing, optimization, and pre/post INFLO experiment analysis.
Q01	Vehicle Operator	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.
Q02	Vehicle Operator	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 back 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.
Q03, S04	Vehicle Operator	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. Note: combined with S4 since they are the same and we are designing needs at the INFLO system level.
Q04	Connected Vehicle/Device (queued vehicle)	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.
Q05	Connected Vehicle/Device (queued vehicle)	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 Need ID	User	High-Level User Need	Discussion
Q06	Connected Vehicle/Device (upstream of queue)	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.
Q07	Connected Vehicle/Device (upstream of queue)	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 back of queue, estimated duration of the queue, and other descriptions of the queue condition, should be generated.
Q08	Connected Vehicle/Device (upstream of queue)	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.
Q09	Traffic Management Entity	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.
Q10	Traffic Management Entity	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 Need ID	User	High-Level User Need	Discussion
Q11	Traffic Management Entity	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).
Q12	Traffic Management Entity	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.
Q13	Traffic Management Entity	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 back of queue, estimated duration of the queue, and other descriptions of the queue condition, should be generated.
Q14	Traffic Management Entities	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).
Q15	Traffic Management Entity	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 Need ID	User	High-Level User Need	Discussion
Q16	Traffic Management Entity	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.
Q17	Arterial Signal Systems	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.
Q18	Data Capture and Management Environment	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.
Q19	Data Capture and Management Environment	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.
S01	Vehicle Operator	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.
S02	Vehicle Operator	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 Need ID	User	High-Level User Need	Discussion
S03	Vehicle Operator	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.
S05	Connected Vehicle/Device	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.
S06	Connected Vehicle/Device	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.
S07	Connected Vehicle/Device	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.
S08	Connected Vehicle/Device	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.

User Need ID	User	High-Level User Need	Discussion
S09	Traffic Management Entity	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.
S10	Traffic Management Entity	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.
S11	Traffic Management Entity	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.
S12	Traffic Management Entity	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.
S13	Traffic Management Entity	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.
S14	Data Capture and Management Environment	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.

Source: Battelle

Chapter 6 Detailed Requirements

As previously discussed, this requirement document used the previously developed requirements as a starting point for the development of the complete set of requirements necessary for implementing and demonstrating the INFLO prototype. This section identifies the new functional or performance requirements that are necessary as a result of the prototype-specific demonstration, as well as those needs specific to the INFLO Prototype experimental plan, the data gathering and sanitizing effort, the impacts assessment team needs, and the overall DMA program evaluation needs. These requirements are organized according to the subsystems which they support. For purposes of traceability, these requirements are referenced to both the user need that it fulfills (when applicable), and also to the source requirement, when it exists.

Table 6-1. Detailed System Requirements

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
0	Common Requirements					
0.1		Common	All time sensitive data used in the applications shall be timestamped using a common time reference.	A		
1	Connected Vehicle (Nomadic Device)					
1.1	RS-2.1	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) , when operating in a vehicle, shall have the ability to detect the road segment on which it is traveling.	D	S2,S8	
1.2	RS-2.1	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device), when operating in a vehicle, should have the ability to detect the lane in which it is traveling.	D	S2,S8	Lane specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
1.3		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) when operating in a vehicle, shall have the capability of determining the speed of the vehicle (within 5 mph).	T	S2,S8	
1.4		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) when operating in a vehicle, shall have the capability of determining its direction of travel (i.e., heading).	T	S2,S8	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
1.5	RS-9.1.2a	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device), when operating in a vehicle, shall have the capability to transmit location, heading and speed data on regular configurable intervals ranging from once every 30 seconds to at most, 10 times per second.	T	S9	Revised requirement to ensure point of view is consistent with the stated subsystem. Revised real-time to put an achievable and measureable constraint.
1.6	RS-9.1.2b	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device), when operating in a vehicle, shall have the capability to transmit data that may allow for the determination of road conditions (e.g. ice, wet) and weather (e.g. clear, rainy and snowy) on regular configurable intervals ranging from once every 30 seconds to at most, 10 times per second.	T	S9, Q9	Revised requirement to ensure point of view is consistent with the stated subsystem. Revised real-time to put an achievable and measureable constraint. Road conditions such as icy or wet, or weather conditions such as clear or rainy will not be directly provided by the connected vehicle.
1.7	RS-12.1.1	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive target speed recommendations from the TME-based SPD-HARM application via I2V communications.	D	S12	Revised requirement to ensure point of view is consistent with the stated subsystem. Standard messages to be utilized need to be identified in detailed design.
1.8	RQ-10.1	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive traffic, road surface condition, and weather data from the TME-based Vehicle Message Generator via I2V communications subsystems.	D	Q10	It is not necessary to transmit all of the data specified, from the Infrastructure to the Vehicle, in order to fulfill the needs of the Q-WARN application. Only that which is necessary will be transmitted.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
1.8.1		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive target speed recommendations from the TME-based Vehicle Message Generator via I2V communication subsystems.	D	Q10	This would be either regulatory or advisory speed recommendations.
1.8.2.		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive speed change justification information from the TME-based Vehicle Message Generator via the I2V communication subsystem.	D	Q10	E.g., “Congestion”, “queue” “Limited Visibility” , “Icy Conditions”, etc.
1.8.3		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive location information for the speed change from the TME-based Vehicle Message Generator via the I2V communication subsystems.	D	Q10	
1.8.4		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive target lane recommendations from the TME-based Vehicle Message Generator via the I2V communication subsystems.	D	Q10	
1.8.5	RQ-10.1	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive roadway reference information from the TME-based Vehicle Message Generator via I2V communication subsystems.	D	Q10	We need something that allows the vehicle to locate itself on a mile-maker referencing systems.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
1.9	RQ-14.1.2	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive queue warnings and queue information from the TME-based Vehicle Message Generator via I2V communications.	D	Q14	Revised requirement to ensure point of view is consistent with the stated subsystem.
1.9.1		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive information about location of the front of queue from the TME Vehicle Message Generator via I2V communication systems.	D	Q14	
1.9.2		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive information about location of the back of queue from the TME Vehicle Message Generator via I2V communication systems.	D	Q14	
1.9.3		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive information about the rate of growth of the queue from the TME Vehicle Message Generator via I2V communication systems.	D	Q14	
1.9.4		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive information about the direction of growth of the queue from the TME Vehicle Message Generator via I2V communication systems.	D	Q14	
1.9.5		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall receive information about the speed in queue from the TME Vehicle Message Generator via I2V communication systems.	D	Q14	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
1.10		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall be able to operate both as a portable device, stand alone, and as a device installed in a vehicle.	D	N03	
1.11		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall be able operate on battery power when not installed in a vehicle.	D	N03	
1.12		Connected Vehicle (Nomadic Device)	The vehicle installed Connected Vehicle (Nomadic Device) equipment shall not obstruct the vehicle driver's field of view.	D	N03	
1.13		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall operate and charge the battery on the voltage supplied by the Test Vehicle.	D	N03	
1.14		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall log all alerts issued to the driver including the parameters that triggered the alerts.	D	N01, N02, N03, N05, N07	
1.15		Connected Vehicle (Nomadic Device)	All log data associated with the Connected Vehicle (Nomadic Device) shall include GPS position, GPS timestamp with millisecond resolution, Device ID and Trip ID.	D	N01, N02, N03, N05, N07	Requirement exists for prototype testing and data gathering. Use of Device ID for real-world implementation must deal with PII issues.
1.16		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall log all outbound messages generated by the vehicle-based applications.	D	N01, N02, N03, N05	
1.17		Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic Device) shall have a mechanism for which the data can be retrieved from the system without any data loss.	D	N01, N02, N03, N05	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
1.19	RQ-4.2.1a	Connected Vehicle (Nomadic Device)	The Connected Vehicle (Nomadic device) shall have access to vehicle state data when installed in the vehicle.	D	Q4,S5, N03	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
2	Connected Vehicle / Nomadic Device User Interface System (UI)					
2.1	RS-1.2.1	Connected Vehicle Driver Interface System (UI)	The UI shall communicate segment-specific target speed recommendations received from the Connected Vehicle-based SPD-HARM application to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	D	S1,S8, N03, N07	Revised requirement to ensure point of view is consistent with the stated subsystem. The target speed recommendations will come from the TME based SPD-HARM application which are sent to the Connected Vehicle based SPD-HARM application which sends them to the UI for display.
2.2	RS-2.3.1	Connected Vehicle Driver Interface System (UI)	The UI shall communicate target lane recommendations received from the Connected Vehicle-based SPD-HARM application to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	D	S2,S8	Lane Specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
2.3	RS-3.1, RS-3.2, RS-3.2.1	Connected Vehicle Driver Interface System (UI)	The UI shall communicate speed change justification information received from the Connected Vehicle-based SPD-HARM application to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	D	S3,S8	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
2.4	RQ-1.1a, RQ-1.1b, RQ-1.2a, RQ-1.2.1	Connected Vehicle Driver Interface System (UI)	The UI shall communicate individualized queue warnings and queue characteristic information (length of queue, lane(s) impacted, other descriptions of the queue condition) as received from the Connected Vehicle-based Q-WARN application, to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	D	Q1,Q8	The Connected Vehicle Driver interface system shall communicated the following to the driver: the travel distance (in miles) from the vehicles current position to the expected "Back of Queue", the lane in which the stopped condition exists, and recommended course of action. Example message "Expect Stopped Traffic in 2 miles. Reduce speed." This requirement applies for vehicle upstream of queue. How far upstream will be determined in detailed design.
2.5	RQ-2.1, REQ-2.2, RQ-2.2.1	Connected Vehicle Driver Interface System (UI)	The UI shall communicate individualized queue response strategies (speed reduction, lane change, diversion recommendations) as received from the Connected Vehicle-based Q-WARN application, to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	D	Q2,Q8	Only rudimentary action message (e.g., Reduce Speed) can be implemented in prototype. Recommended action CANNOT be in conflict with other external information (e.g., in WZ lane closure, the lane that is open will OFTEN have a longer queue than the lane that is closed. We DO NOT want to recommend that driver move to lane that is closed only to be forced back into open lane). This would require integration with other system (e.g., lane closure management beyond scope of project). Likewise don't want to advise vacating a lane when driver expects to exit.
2.6		Connected Vehicle Driver Interface System (UI)	The UI latency from receipt of event to aural and visual display shall be less than 500 milliseconds.	T		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
2.7		Connected Vehicle Driver Interface System (UI)	The UI shall provide a display to the vehicle driver that indicates that the applications are operational even when there are no alerts or warnings.	I		
3	Connected Vehicle-based Q-WARN Application					
3.1	RQ-6.1	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall have the ability to receive TME-based queue warning messages from Connected Vehicle Communication Sub-system.	D	Q6	
3.2	RQ-6.2	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages from other connected vehicles via the Connected Vehicle Communication Sub-system.	D	Q6	
3.3	RQ-4.2	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to obtain real-time vehicle state data (location, velocity, heading, lateral and longitudinal acceleration) from the vehicle network.	D	Q4	
3.4		Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application, while operating in a vehicle, shall have the capability of determining its position on the roadway to the 10^{th} of a mile.	T		Needs to determine its position in terms of roadway mile markers.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
3.5	RQ-4.1	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.	D	Q4	
3.6	RQ-7.2	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall generate appropriate queue response strategies (speed reduction, lane change, diversion recommendations) based on distance to back of queue.	D	Q7	
3.7	RQ-7.1	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 back of the queue.	D	Q7	
3.8	RQ-1.1a	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall pass vehicle's calculated distance to back of queue to the driver interface system.	T	Q1,Q8	
3.9	RQ-1.1b	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall pass queue warnings and queue characteristic information received from the TME (length of queue, lane(s) impacted, other descriptions of the queue condition) to the driver interface system.	T	Q1,Q8	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
3.10	RQ-2.1	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall pass individualized queue response strategies (based on vehicle's distance to back of queue) to the driver interface system (speed reduction, lanes queued).	T	Q2,Q8	
3.11	RQ-3.1	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.	A	Q3	For the prototype system we assume using the optional message authentication and encryption protocols which are standardized in IEEE 1609.2. No further over-the-wire or in-rest encryption is planned.
3.12	RQ-4.2.2	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather weather data (external air temperature, wiper status, headlight status) from the vehicle network for the test make/model.	D	Q4	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
3.13	RQ-4.2.3	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather road surface data (traction control status, stability control status, differential wheel speed) from the vehicle network for the test make/model.	D	Q4	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
3.14	RQ-4.3	Connected Vehicle-based Q-WARN Application	Communications between the Connected Vehicle-based Q-WARN application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	D	Q4	There are some elements that are available through standard ODB-II codes but the majority of them are still proprietary. We do intend to define an ICD that specifies the extent of data elements needed and prescribed an approach to do so, however, it is not within our scope to create a new standard for the data sets. That effort would lie within the SDOs.
3.15	RQ-5.1	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.	D	Q5	
3.16	RQ-5.2	Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to infrastructure systems via V2I communication.	D	Q5	
3.17		Connected Vehicle-based Q-WARN Application	The Connected Vehicle-based Q-WARN application shall be developed in accordance with practices allowing for open-source use of the application.	D	N06	
4	Connected Vehicle-based SPD-HARM Application					
4.1	RS-1.1	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall pass target speed recommendations to the driver interface system.	T	S1,S8	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
4.2	RS-2.2	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall pass target lane recommendations to the driver interface system.	T	S2,S8	Lane specific detection requires an accuracy of equipment greater than what US DOT has qualified on the Research-QPL and of that which was proposed. However, lane-level guidance, such as 'stopped traffic on exit ramp', may be provided in cases where the lane-specific data can be identified.
4.3	RS-3.1	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall pass speed change justification information to the driver interface system.	T	S3,S8	
4.4	RS-4.1	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	S4, N06	
4.5	RS-5.1	Connected Vehicle-based SPD-HARM Application	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.	D	S5	
4.6	RS-5.1.1a	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall have access to following data: time, location, velocity, heading, barometric pressure, lateral and longitudinal acceleration.	D	S5	When available, this data will be collected from the IVNA. However, this specific data (as listed) may also be collected from the Nomadic Device.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
4.7	RS-5.1.1b	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall obtain the following vehicle movement data (yaw rate, rate of change of steering wheel, brake status, brake boost status, impact sensor status, and anti-lock braking status) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
4.8	RS-5.1.2	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall have access to the following weather data (external air temperature, wiper status, headlight status) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
4.9	RS-5.1.3	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall have access to the following road surface condition data (traction control status, stability control status, differential wheel speed) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
4.10	RS-5.2	Connected Vehicle-based SPD-HARM Application	Communications between the Connected Vehicle-based SPD-HARM application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	D	S5	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
4.11	RS-6.2a, RS-6.2b	Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current speed, current location, current acceleration/deceleration, other vehicle movement data, weather related data, and road surface condition data) to infrastructure systems utilizing V2I communication.	T	S6	
4.12	RS-7.2	Connected Vehicle-based SPD-HARM Application	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.	T	S7	
4.13	RQ-7.3.1	Connected Vehicle-based 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.	A		Driver instructions will be arbitrated both in the TME and in the vehicle where appropriate. Details of the arbitration scheme will be documented during detailed design and adjustable during the prototype demonstration to give designers more flexibility.
4.14		Connected Vehicle-based SPD-HARM Application	The Connected Vehicle-based SPD-HARM application shall be developed in accordance with practices allowing for open-source use of the application.	A	N06	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
5	Connected Vehicle Communication System					
5.1	RQ-5.1	Connected Vehicle Communication System	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.	D	Q5	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.
5.2	RQ-6.2	Connected Vehicle Communication System	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via V2V communication channels.	D	Q6	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.
5.3		Connected Vehicle Communication System	The Connected Vehicle-based Q-WARN application shall have the ability to receive messages from the TME-based Q-WARN application via I2V communication channels.	D		The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.
5.4		Connected Vehicle Communication System	The Connected Vehicle-based SPD-HARM application shall have the ability to receive messages from the TME-based SPD-HARM application via I2V communication channels.	D		The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.
5.5		Connected Vehicle Communication System	The Connected Vehicle Communications System shall generate and transmit Basic Safety Messages in compliance with SAE standard J2735 version 2009-11.	D		
5.6		Connected Vehicle Communication System	The Connected Vehicle Communications System shall be able to interoperate with other equipped vehicles and Deployment RSE according to IEEE 802.11p-2010 and IEEE1609.2 -2013, 1609.3-2010, 1609.4-2010 standards and the SAE J2735:2009 message standards.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
5.7		Connected Vehicle Communication System	The Connected Vehicle Communications System shall be able to transmit a SAE J2735 Basic Safety Message (BSM) at 10 times per second.	T		
5.8		Connected Vehicle Communication System	The Connected Vehicle Communications System shall be able to communicate with the TME using cellular infrastructure when DSRC transmissions are not available (or when latency requirements do not require use of DSRC).	T		
5.9		Connected Vehicle Communication System	The Connected Vehicle Communications System shall be able to switch between use of cellular infrastructure to DSRC within 1 second.	T		
6	Connected Vehicle Weather System					
6.1		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the outside ambient temperature and make that data available for transmittal to the TME.	D		
6.2		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the outside ambient temperature and make that data available to the Connected Vehicle-based Q-WARN application.	D		
6.3		Weather System	The Weather System should provide an ambient temperature range of -50 to 50°C +/- 2°.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
6.4		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the ambient air pressure around the device or associated sensor and make that data available for transmittal to the TME.	D		
6.5		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the ambient air pressure around the device and make that data available to the Connected Vehicle-based Q-WARN application.	D		
6.6		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the humidity around the device and make that data available for transmittal to the TME.	D		
6.7		Weather System	The weather system in the Connected Vehicle (Nomadic Device) will measure, when appropriately positioned, the humidity around the device and make that data available to the Connected Vehicle-based Q-WARN application.	D		
6.8		Weather System	The weather system will provide a humidity range of 0 to 100% relative humidity +/-10%.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
7	Integrated Vehicle Network Access System					
7.1	RS-5.1.1b RQ-4.2.1b	Integrated Vehicle Network Access System	The Connected Vehicle 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, and anti-lock braking status) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
7.2	RS-5.1.2 RQ-4.2.2	Integrated Vehicle Network Access System	The Connected Vehicle shall communicate with the Integrated Vehicle Network Access System to gather weather data (external air temperature, wiper speed, headlight status) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
7.3	RS-5.1.3 RQ-4.2.3	Integrated Vehicle Network Access System	The Connected Vehicle shall communicate with the Integrated Vehicle Network Access System to gather road surface data (traction control status, stability control status, differential wheel speed) from the vehicle network for the test make/model.	D	S5	The message(s) that will be implemented for this interface will include this information (as noted), but in demonstrating the prototype, as the availability is make/model dependent, it is not guaranteed that all of the identified data items will be available.
7.4	RS-5.2 RQ-4.3	Integrated Vehicle Network Access System	Communications between the Connected Vehicle and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	D	S5	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8	Traffic Management Entity (TME)					
8.1	RS-4.2, RQ-3.2	Traffic Management Entity (TME)	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	D	S4	
8.2	RS-4.3, RQ-3.3	Traffic Management Entity (TME)	The Traffic Management Entity shall use secure transmission methods for disseminating target speed and lane recommendations and justification for speed changes.	A	S4	
8.3	RS-4.4, RQ-3.4	Traffic Management Entity (TME)	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	A	S4	
8.4	RS-4.4, RQ-3.4	Traffic Management Entity (TME)	The Traffic Management Entity shall ensure data is authenticated.	A	S4	
8.5	RQ-9.1	Traffic Management Entity (TME)	The Traffic Management Entity (TME) shall have a data collection capability for receiving real-time traffic, road surface conditions, and weather data from multiple sources. (TME-based Information Collection Subsystem)	A		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.6	RS-6.2a	Traffic Management Entity (TME)	The TME shall receive vehicle-collected movement data (current speed, current location, and current acceleration/deceleration) from the Connected Vehicle-based applications utilizing V2I communications.	T	S6	
8.7	RS-6.2b	Traffic Management Entity (TME)	The TME shall receive vehicle-collected weather data from the Connected Vehicle-based applications utilizing V2I communication.	T	S6	
8.8	RQ-9.1.1	Traffic Management Entity (TME)	The Traffic Management Entity (TME) shall have a data collection capability for receiving real-time traffic, road surface condition, and weather data from infrastructure-based systems.	D		
8.8.1		Traffic Management Entity (TME)	The TME shall have the capability to obtain traffic condition information for each lane from infrastructure-based traffic sensors.	D		
8.8.2		Traffic Management Entity (TME)	The TME shall have the capability to obtain average speed for each lane from the infrastructure-based traffic sensors.	D		
8.8.3		Traffic Management Entity (TME)	The TME shall have the capability to obtain average lane occupancy for each lane from the infrastructure-based traffic sensors.	D		
8.8.4		Traffic Management Entity (TME)	The TME shall have the capability to obtain vehicle flow rate for each lane from the infrastructure-based traffic sensors.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.8.5		Traffic Management Entity (TME)	The TME shall have the capability to obtain data from the traffic sensor on a user-defined interval (e.g. every 20 seconds).	D		
8.8.6		Traffic Management Entity (TME)	The TME shall have the capability to aggregate lane detector data to station-level detector data.	D		
8.8.7		Traffic Management Entity (TME)	The TME shall be able to determine which traffic sensor station apply to each segment of the freeway.	D		
8.8.8		Traffic Management Entity (TME)	The TME shall be able to determine the operational state of each detector station.	D		
8.8.9		Traffic Management Entity (TME)	The TME shall be able to verify the quality of the data before it is applied in the algorithms.	A		
8.8.10		Traffic Management Entity (TME)	The TME shall be able to dynamically configure freeway detection zones to use based on the results of the data quality verification.	D		
8.9		Traffic Management Entity (TME)	The TME shall have the capability to obtain atmospheric and road weather information from infra-structured based environmental sensing stations (ESS) deployed in the corridor.	D		
8.9.1		Traffic Management Entity (TME)	The TME shall communicate with ESSs using the most current version on the NTCIP 1204 Environmental Sensor Station Interface Standards.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.9.2		Traffic Management Entity (TME)	The rate at which the TME obtains weather information from ESSs shall be configurable and consistent with the ESS contributor.	D		This will most likely be done through a configuration file.
8.9.3		Traffic Management Entity (TME)	The TME shall be able to associate one or more environmental sensor station with the freeway segment.	D		This will most likely be done through a configuration file.
8.9.4		Traffic Management Entity (TME)	The TME shall determine the operational state of all available environmental sensor stations.	D		
8.9.5		Traffic Management Entity (TME)	The TME shall obtain information about wind conditions from each ESS that supports this measurement.	D		Note: The specific data objects likely to be used include the following: 5.6.9 Wind Sensor Table 5.6.10 Wind Sensor Table, which includes: windSensorIndex windSensorHeight windSensorLocation windSensorAvgSpeed windSensorAvgDirection windSensorSpotSpeed windSensorSpotDirection windSensorGustSpeed windSensorGustDirection windSensorSituation

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.9.6		Traffic Management Entity (TME)	The TME shall obtain information about precipitation conditions from each ESS that supports this measurement.	D		Note: The specific data objects likely to be used include the following: 5.8.6 Precipitation Indicator 5.8.9 Precipitation Situation
8.9.7		Traffic Management Entity (TME)	The TME shall obtain information about the prevailing visibility conditions from each ESS that supports this measurement.	D		Note: The specific data objects likely to be used include the following: 5.10.1 Visibility 5.10.2 Visibility situation
8.10		Traffic Management Entity (TME)	The TME shall have the capability to obtain road weather condition information from mobile weather monitoring devices (as defined by NTCIP 1204) active in the corridor.	D		Note: This source of data is different than the data available through SAE J2735. These data elements are from specially-equipped maintenance vehicles. Note: The specific data objects likely to be used include the following: 5.3.7 Mobile Block, which includes essLatitude essLongitude essReferenceHeight essVehicleSpeed essVehicleBearing essVehicleOdemeter essMobileFriction essMobileObservationGroundState essMobileObservationPavement essPaveTreatmentAmount essPaveTreatmentWidth

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.11		Traffic Management Entity (TME)	The TME shall have the capability to obtain weather forecast information from external weather provider(s).	D		
8.11.1		Traffic Management Entity (TME)	The TME shall obtain forecasted type weather event from external weather provider.	D		
8.11.2		Traffic Management Entity (TME)	The TME shall obtain forecasted start time of weather event from external weather provider.	D		
8.11.3		Traffic Management Entity (TME)	The TME shall obtain forecasted duration of weather event from external weather provider.	D		
8.11.4		Traffic Management Entity (TME)	The TME shall obtain forecasted severity/intensity of weather event from external weather provider.	D		
8.12	RS-6.2b	Traffic Management Entity (TME)	The TME shall receive vehicle-collected data (current lane, actions [acceleration, deceleration, compliance with target speed], road condition, and weather information) from the Connected Vehicle-based SPD-HARM application utilizing V2I communication.	T	S6	
8.13		Traffic Management Entity (TME)	The TME shall have an application to mitigate the impacts of shockwaves in the freeway traffic stream. (TME-based SPD-HARM)	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.14		Traffic Management Entity (TME)	The TME shall have an application to mitigate the impacts of recurring queues in the freeway traffic stream. (TME-based Q-WARN)	D		
8.15		Traffic Management Entity (TME)	The TME shall have an application to mitigate the impacts of travel conditions caused by adverse weather on the freeway. (TME-based WRTM)	D		
8.16		Traffic Management Entity (TME)	The TME shall have the ability to combine the recommended traffic management strategies from the various applications to determine the appropriate responses to be communicated to travelers in the corridor.	D		
8.17		Traffic Management Entity (TME)	The TME shall have the ability to formulate recommended traffic management strategies for display on infrastructure-based traveler information systems.	D		
8.18	RS-12.1.1 RQ-10.1	Traffic Management Entity (TME)	The TME shall communicate recommended traffic management strategies to the connected Vehicle utilizing I2V communication.	T	S7	
8.19	RS-14.1	Traffic Management Entity (TME)	The TME shall make recommended traffic management strategies available for sharing with other dynamic mobility applications.	D	S14	Will require definition of the interface with these applications and frequency of sharing data and decisions made.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
8.20	RS-14.2, RS-14.3 RQ-18.2	Traffic Management Entity (TME)	The TME shall make the shockwave/breakdown, queuing, and roadway condition information available for sharing with other dynamic mobility applications.	D	S14	The application shall make the SPD-HARM derived information based on real-time data available to other applications. Information based on predicted conditions is beyond the scope of this prototype deployment.
8.21	RQ-10.1	Traffic Management Entity (TME)	The TME shall communicate traffic, road condition, and weather data to connected vehicles/devices via I2V communications systems.	D	Q10	It is not necessary to transmit all of the data specified, from the Infrastructure to the Vehicle, in order to fulfill the needs of the Q-WARN application. Only that which is necessary will be transmitted.
8.22	RQ-19.1	Traffic Management Entity (TME)	The TME shall have a Data Environment to collect, aggregate, and disseminate queue warning related data to freeway traffic management entities.	T	Q19	
8.23		Traffic Management Entity (TME)	The TME shall have the ability to communicate recommended traffic management strategy data to a Performance Measures Subsystem.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
9	TME-based Performance Monitoring System (no requirements for Prototype)					
10	TME-based Q-WARN Application					
10.1	RQ-9.1	TME-based Q-WARN Application	The Traffic Management Entity (TME)-based Q-WARN application shall interface with the data environment to obtain the data collected from multiple sources.	D	Q9	
10.2	RQ-9.1.1	TME-based Q-WARN Application	The Traffic Management Entity (TME)-based Q-WARN application shall have the ability to access real-time traffic, road surface condition, and weather data from infrastructure-based systems.	D	Q9	
10.3	RQ-9.1.2	TME-based Q-WARN Application	The TME-based Q-WARN application shall have the capability to access real-time traffic conditions from connected vehicles.	D	Q9	The TME-based Q-WARN application will receive vehicle performance data as previously identified. Road conditions such as icy or wet, or weather conditions such as clear or rainy will not be directly provided by the connected vehicle.
10.4		TME Performance Monitoring Subsystem	The TME-based Q-WARN application shall have the capability to access real-time pavement conditions from connected vehicles.	D		
10.5	RQ-11.2	TME-based Q-WARN Application	The TME-based Q-WARN application shall have a queue detection capability for known fixed queue generation locations.	D	Q11	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
10.6	RQ-11.1 RQ-11.1.1a	TME-based Q-WARN Application	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to detect queues in real-time and generate queue warning information.	D	Q11	
10.7	RQ-11.3	TME-based Q-WARN Application	The TME-based Q-WARN application shall determine the sections of freeway which are operating in the queued state.	D	Q11	Lane-level accuracy will be provided to the extent it is possible to make a reasonably accurate determination given the error of the onboard location services, but considering the capability of infrastructure-based systems.
10.8	RQ-11.4	TME-based Q-WARN Application	The TME-based Q-WARN application shall determine the length of the formed queue.	D	Q11	This will assume the beginning of the queue will be assumed to be the first detection station at the known bottleneck location. The length of queue will consist of the section that is known to be congested.
10.9	RQ-11.5	TME-based Q-WARN Application	The TME-based Q-WARN application shall estimate the number of vehicles in the formed queue.	D	Q11	Can provide estimate both determine length of roadway in queue state, and then assuming vehicle length to estimate number of vehicles in queue.
10.10	RQ-11.6	TME-based Q-WARN Application	The TME-based Q-WARN application shall determine the traveling speed and direction of the formed queue.	D	Q11	Need to determine the speed of the backward forming shock wave and the speed of the forward recovery wave. Also need to estimate travel speed in queue. Need clarification.
10.11		TME-based Q-WARN Application	The TME-based Q-WARN application shall provide an estimate of average speed of vehicles traveling in the congested state.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
10.12	RQ-11.6.2	TME-based Q-WARN Application	The TME-based Q-WARN application shall update the estimation of the traveling speed of the queue once per second.	D	Q11	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle will not support this performance requirement.
10.13	RQ-12.1	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.	D	Q12	Need to define specifically what data is to be fused and processed.
10.14	RQ-12.2.1	TME-based Q-WARN Application	The TME-based Q-WARN application should have a false positive identification rate of no more than 5% of all queue detection events at known fixed queue generation locations.	D	Q12	
10.15	RQ-12.2.2	TME-based Q-WARN Application	The TME-based Q-WARN application should have a missed prediction rate of less than or equal to 5% of all formed queues at known fixed queue generation locations.	D	Q12	
10.16	RQ-12.8.3	TME-based Q-WARN Application	The TME-based Q-WARN application should determine the traveling speed of the predicted queue to within 10 mph of the speed of the actual formed queue.	D	Q12	
10.17	RQ-13.1	TME-based Q-WARN Application	The TME-based Q-WARN application shall have a queue warning response strategy generation capability.	D	Q13	
10.18	RQ-13.1.1	TME-based Q-WARN Application	The TME-based Q-WARN strategies shall include recommended target speeds, characteristics about queues and queue warning messages for the infrastructure.	D	Q13	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
10.19	RQ-13.1.1.1	TME-based Q-WARN Application	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate speed reduction targets.	T	Q13	
10.20	RQ-13.1.2a	TME-based Q-WARN Application	The TME-based Q-WARN application shall generate upstream recommended target speed strategies that consider distance to back of queue.	D	Q13	
10.21	RQ-13.1.2b	TME-based Q-WARN Application	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.	D	Q13	This requirement consists of several specific requirements. Need a better definition as to what it is requirement trying to achieve. Can provide estimate travel time (or delay) in queue based on current travel speed in queue. Not sure we can tell driver to travel faster that want speed in queue is.
10.22	RQ-14.1	TME-based Q-WARN Application	The TME-based Q-WARN application shall have a queue warning and queue information dissemination capability.	D	Q14	
10.23	RQ-15.2	TME-based Q-WARN Application	The TME-based Q-WARN application shall provide a means to identify, track, and analyze unidentified or mis-identified queue formation events.	D	Q15	The prototype type will log all data inputs, process results, and messaging to assist in assessment of unidentified or miss-identified queue information events.
10.24	RQ-18.2	TME-based Q-WARN Application	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	T	Q18	Data will be logged in the data environment. It is assumed that this is sufficient to satisfy this requirement.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
10.25		TME-based Q-WARN Application	The TME-based Q-WARN Application shall be developed in accordance with practices allowing for open-source use of the application.	D	N06	
11	TME-based SPD-HARM Application					
11.1	RS-9.1.2a	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall have the capability to receive real-time traffic (including location and speed) from connected vehicles.	D	S9	
11.2	RS-9.1.2b	TME-based SPD-HARM Application	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.	D	S9	The TME-based SPD-HARM application will receive vehicle performance data as previously identified. Road conditions such as icy or wet, or weather conditions such as clear or rainy will not be directly provided by the connected vehicle.
11.3	RS-10.1	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.	D	S10	
11.4	RS-10.1.1a	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall utilize real-time traffic data when calculating the recommended target speed.	D	S10	
11.5	RS-10.1.1b	TME-based SPD-HARM Application	The TME-based SPD-HARM application should utilize historical traffic data when calculating the recommended target speed.	D	S10	See comment for requirement 11.3 above.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
11.6	RS-10.1.2	TME-based SPD-HARM Application	The TME-based SPD-HARM application should utilize real-time and forecasted weather data when calculating the recommended target speed.	D	S10	Real-time weather data will be used in making decisions. Predicted weather data use will depend on review of existing strategies. We are not aware of any algorithm that uses weather forecast information.
11.7	RS-10.1.3	TME-based SPD-HARM Application	The TME-based SPD-HARM application should utilize real-time and predicted road surface data when calculating the recommended target speed.	D	S10	Real-time road surface data will be used in making decisions. Predicted road surface data use will depend on review of existing strategies. We are not aware of any algorithm in use that includes road surface information based on forecasted weather conditions.
11.8	RS-10.2	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall have a shockwave detection capability for known fixed bottleneck locations.	D	S10	
11.9	RS-10.2.1	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.	D	S10	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.
11.10	RS-10.2.2	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.	D	S10	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
11.11	RS-10.2.3	TME-based SPD-HARM Application	Deployment experience is needed to develop a baseline of performance. Processes will be included in the algorithm that will allow data to be collected for generating these performance metrics.		S10	Deployment experience is needed to develop a baseline of performance. Processes will be included in the algorithm that will allow data to be collected for generating these performance metrics.
11.12	RS-10.2.4	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall determine the segment(s) impacted by the formed shockwave.	D	S10	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.
11.13	RS-10.2.5	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall determine the location of the formed shockwave.	D	S10	
11.14		TME-based SPD-HARM Application	The TME-based SPD-HARM application shall determine the speed and direction of the formed shockwave.	D	S10	
11.15	RS-10.2.5.3	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall update the current shockwave length estimation once per second.	D	S10	Currently, most TMEs aggregate data at 20-30 second intervals. To achieve this objective will require the TME to obtain and aggregate data at a higher resolution. Similarly, the use of non-DSRC based communications to transmit vehicle data at rates that support once-per-second updates may be bandwidth and/or cost prohibitive.
11.16	RS-10.2.6a	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall utilize real-time traffic data in shockwave detection algorithms.	D	S10	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
11.17	RS-11.1	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall have a recommended target speed generation capability.	D	S11	
11.18	RS-11.1.1	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall generate recommended target speed strategies for different segments of the roadway.	D	S11	
11.19	RS-9.1	TME-based SPD-HARM Application	The Traffic Management Entity (TME)-based SPD-HARM application shall have a data collection capability for receiving real-time data from multiple sources.	D	S9	
11.20	RS-12.1	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall have a target speed recommendation dissemination capability.	D	S12	
11.21	RS-12.1.1	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall disseminate target speed recommendations to SPD-HARM enabled connected vehicles on the facility via I2V communications.	D	S12	Standard messages to be utilized need to be identified.
11.22	RS-12.1.2	TME-based SPD-HARM Application	The TME-based SPD-HARM application shall disseminate target speed recommendations to DMS locations.	D	S12	
12	TME-Based Weather Responsive Traffic Management (WRTM) Application					
12.1		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall obtain road weather information from infrastructure-based environmental sensing stations (ESS) (aka RWIS).	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
12.2		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall obtain road weather information from mobile weather monitoring devices.	D		
12.3		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall obtain weather forecast information from external weather service providers.	D		
12.4		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall obtain road condition information from connected vehicles.	D		
12.5		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall fuse weather information from multiple sources to determine the location of potential hazardous conditions based on inclement weather conditions.	D		
12.6		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall identify traffic management strategies for low visibility conditions.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
12.7		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall identify traffic management strategies for road surface conditions that impact travel speeds.	D		
12.8		TME-Based Weather Responsive Traffic Management	The TME-based WRTM application shall identify traffic management strategies for high wind conditions.	D		
12.9		TME-Based Weather Responsive Traffic Management	The traffic management strategies generated by the TME-based WRTM application shall include recommended travel speeds based on measured road weather conditions for the area in which the affected road segment exists.	D		
12.10		TME-Based Weather Responsive Traffic Management	The traffic management strategies generated by the TME-based WRTM application shall include weather-related traveler warning messages based on measured road weather conditions in the corridor.	D		
12.11		TME-Based Weather Responsive Traffic Management	The traffic management strategies generated by the TME-based WRTM application shall generate weather-related alerts and/or warnings based on forecasted road weather conditions.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
13	TRM-Based Information Dissemination SubSystem					
13.1	RS-9.1 RQ-9.1	TRM-Based Information Dissemination SubSystem	The Traffic Management Entity (TME)-based Information Dissemination application shall have the capability for receiving real-time data from all the TME-based applications.	D	S9. Q9	
13.2	RS-9.1.1 RQ-9.1.1	TRM-Based Information Dissemination SubSystem	The TME-based Information Dissemination application shall have the capability to disseminate the appropriate travel speed for each section of the freeway based on criteria provided by the traffic management operator.	D	S9, Q9	
13.3	RS-11.1.2a	TRM-Based Information Dissemination SubSystem	The TME-based Information Dissemination application shall generate target speed strategies that consider downstream traffic conditions, weather, and local roadway surface conditions.	D	S11	
13.4	RS-14.3	TRM-Based Information Dissemination SubSystem	The TME-based Information Dissemination target speed information and shockwave/breakdown formation information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	T	S14	Will require definition of the interface with these applications and frequency of sharing data and decisions made.
13.5	RQ-13.1.2a	TRM-Based Information Dissemination SubSystem	The TME-based Information Dissemination application shall generate target speed strategies that consider distance to back of queue.	D	Q13	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
13.6	RQ-13.1.2b	TRM-Based Information Dissemination SubSystem	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, and local roadway surface conditions.	D	Q13	
13.7	RQ-18.2	TRM-Based Information Dissemination SubSystem	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	T	Q18	Data will be logged in data environment, but that is the extent of how this requirement will be satisfied.
14	TME-based Communications System					
14.1	RQ-14.1.1	TME-based Communications System	The TME-based application shall disseminate queue warnings and queue information to DMS locations.	D	Q14	
14.2	RQ-14.1.2	TME-based Communications System	The TME-based application shall disseminate queue warnings and queue information to connected vehicles.	D	Q14	
14.3	RQ-14.1.3	TME-based Communications System	The TME-based application shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	D	Q14	The prototype will generate a generic queue warning message that other applications can use.
14.4		TME-based Communications System	The TME-based Communications System shall have the capability to receive near real-time data from the Nomadic Device over the cellular infrastructure.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
14.5		TME-based Communications System	The TME-based Communications System shall have the capability to receive near real-time data from the Roadside equipment over the internet/cellular infrastructure.	T		
14.6		TME-based Communications System	The TME-based Communications System shall have the capability to send messages to the Nomadic Device over the cellular infrastructure.	T		
14.7		TME-based Communications System	The TME-based Communications System shall have the capability to send messages for transmission over DSRC to the Roadside Equipment using the internet/cellular infrastructure.	T		
14.8		TME-based Communications System	The TME shall have the ability to generate messages conveying the recommended target speeds for display on dynamic speed control signs.	D		
14.9		TME-based Communications System	The TME shall have the ability to generate messages conveying the queue/weather warning information for display on dynamic message signs.	D		

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
15	Roadside Equipment					
15.1	RS-6.2a	Roadside Equipment	Roadside equipment shall utilize V2I communication between the Connected Vehicle application and the infrastructure systems to disseminate vehicle-collected data (e.g. current speed, current location, and current acceleration/deceleration).	T	S6	
15.2	RS-6.2b	Roadside Equipment	Roadside equipment shall utilize V2I communication between the Connected Vehicle-based application and the infrastructure systems to disseminate vehicle-collected data (current lane, actions [acceleration, deceleration, compliance with target speed], road condition, and weather information).	T	S6	
15.3	RS-7.2	Roadside Equipment	Roadside equipment shall utilize I2V communications to send target speed recommendations, target lane recommendations and justification for speed changes to the Connected Vehicle-based application.	T	S7	
15.4	RS-13.1.2	Roadside Equipment	The TME-based applications shall disseminate target speed recommendations to DMS locations.	D	S13	
15.5	RQ-14.1.1	Roadside Equipment	The TME-based applications shall disseminate queue warnings and queue information to DMS locations.	D	Q14	

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
15.6		Roadside Equipment	The Roadside Equipment shall be able to interoperate with equipped vehicles according to IEEE 802.11p-2010 and IEEE1609.2 -2013, 1609.3-2010, 1609.4-2010 standards and the SAE J2735:2009 message standards.	D		
16	Other Applications					
16.1	RS-14.3	CACC Application, DMAs	TME-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.	T	S14	Will require definition of the interface with these applications and frequency of sharing data and decisions made.
16.2	RQ-13.1.1	EnableATIS Application, FRATIS Application	The TME application shall generate queue warning response strategies that include recommended target speeds reduction, and lane(s) queued.	D	Q13	
16.3	RQ-14.1.3	Traveler Information Systems	The TME shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	D	Q14	Prototype develop will generate a generic queue warning message that other applications can use.
16.4	RQ-18.2	DMAs	TME-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	T	Q18	Data will be logged in the data environment. It is assumed that this is sufficient to satisfy this requirement.

Rqmt No.	Old Rqmt. ID	System / SubSystem	Requirement	Verification Method	User Need ID	Notes/Comments
17	Legacy Detection Equipment					
17.1		Legacy Detection Equipment	The TME-based applications shall use as an input, data that is obtained from traditional, fixed-point detection equipment.	T	N04	
17.2		Legacy Detection Equipment	The INFLO Prototype shall use either real or simulated data to represent traffic, weather and road conditions.	D	N04, Q09, S09	

Source: Battelle

Glossary

Alert – A level of driver notification with less urgency that a warning but that indicates an impending incident without a change to the current operational characteristic.

Congested State – Indicates a condition where vehicles are traveling at reduced speeds typically as a result of increased volume or incident reducing the free flow speed of a road segment.

ConOps – The Concept of Operations document results from a stakeholder view of the operations of the system being developed. This document will present each of the multiple views of the system corresponding to the various stakeholders. These stakeholders include operators, users, owners, developers, maintenance, and management. This document can be easily reviewed by the stakeholders to get their agreement on the system description. It also provides the basis for user requirements.

Data Environment – Common storage location for current and historical traffic, road conditions and weather data accessible by the TME and other DMA applications.

Missed Prediction – Instance where the timeliness or accuracy of the data is insufficient to determine an impending queue.

Queue – A line of vehicle, bicycles, or persons waiting to be served due to traffic control, a bottleneck, or other causes.

Queue Delay – 1. The amount of time that a vehicle spends in a queued state. 2. When computed from vehicle trajectories, it is the accumulated time step delay over all time steps in which the vehicle is in a queue.

Queue Length – The distance between the upstream and downstream ends of the queue.

Queued State – A condition when a vehicle is within one car length (20ft) of a stopped vehicle and is itself in a stopped state (i.e., has slowed to less than 5 mph).

Real Time – Indicates data that is available for use immediately upon its creation.

Warning – The most urgent level for driver notification, typically in a crash eminent situation.

Weather Event – A condition such as precipitation, wind, fog or other meteorological occurrence that has a potential impact on traffic operations, such as reduce visibility, slippery road surfaces, or reduce vehicle stability.

List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADA	Advanced Driver Assistance
ATIS	Advanced Traveler Information System
ATM	Active Traffic Management
ATMS	Advanced Traffic Management System
ConOps	Concept of Operations
DMA	Dynamic Mobility Application
DMS	Dynamic Message Sign
DSRC	Dedicated Short-Range Communications
HCM	U.S. Highway Capacity Manual
IDM	Intelligent Driver Model
INFLO	Intelligent Network Flow Optimization
ITS	Intelligent Transportation System
IVNA	Integrated Vehicle Network Access
NHTSA	National Highway Traffic Safety Administration
Q-WARN	Queue Warning application
RWIS	Roadway Weather Information System
SPD-HARM	Speed Harmonization application
TMC	Traffic Management Center
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure/Infrastructure-to-Vehicle
V2V	Vehicle-to-Vehicle
VC	Vehicular Communications
VMS	Variable Message Sign
VMT	Vehicle Miles Traveled
VSL	Variable Speed Limit
VSS	Variable Speed Sign

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