Intelligent Network Flow Optimization (INFLO) Prototype Acceptance Test Summary

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Final Report — May 15, 2015

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16. Abstract

This report summarizes the results of System Acceptance Testing for the implementation of the Intelligent Network Flow Optimization (INFLO) Prototype bundle within the Dynamic Mobility Applications (DMA) portion of the Connected Vehicle Program. This document summarizes the phases of testing, the test objectives and the test results met for each phase. These objectives and results are organized as Test Cases, and trace back to the System Requirements.

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Chapter 1 Introduction

Purpose of this Test Summary

This document summarizes the Prototype System Acceptance Test for the Intelligent Network Flow Optimization (INFLO) application bundle, with a focus on the Queue Warning (Q-WARN) and Speed Harmonization (SPD-HARM) with Weather Responsive Traffic Management (WRTM) 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 summarizes the component, system integration and prototype pilot acceptance testing conducted to verify that the system meets its functional and performance requirements. The results of the acceptance tests summarized here may be used by the U.S. DOT to determine whether a small-scale demonstration of the Prototype will be conducted.

Scope of the Test

The principles of system engineering were applied in conducting INFLO Prototype System Acceptance Testing to verify that the developed prototype meets the system requirements defined in Chapter 6 of the Report on Detailed Requirements for the INFLO Prototype (FHWA-JPO-14-171). Specifically, this test summary addresses testing for the following systems and sub-systems, as described in the Report on Architecture Description for the INFLO Prototype (FHWA-JPO-14-170):

- Connected Vehicle (Nomadic Device)
  - Driver Interface System (UI)
  - Q-WARN Application (vehicle component)
  - Communication System
  - Weather System
  - Integrated Vehicle Network Access (IVNA) System
- Traffic Management Entity (TME)
  - TME-based Q-WARN Application
  - TME-based SPD-HARM Application
  - TME-based Weather Responsive Traffic Management (WRTM) (subset of SPD-HARM)
  - TME-based Information Dissemination Sub-system
  - Data Storage (Warehouse)
  - TME-based Information Collection
- Roadside Equipment

The INFLO Prototype System was tested in three phases:

- Phase I – Component Acceptance Testing
- Phase IIa – Communications and Messaging System Integration Acceptance Testing
- Phase IIb – TME-Based Application System Integration Acceptance Testing
- Phase III – On-road Prototype Pilot System Acceptance Testing

Phase I test cases and Phase II test cases were conducted within a laboratory environment using simulated or real data inputs. Phase III test cases were conducted using test vehicles in either a controlled (closed-course) environment or on streets and highways near Battelle in Columbus, Ohio. This report describes the test cases conducted and the results of each.

Note that this summary includes enhancements to the previously published Test Plan made to better verify and demonstration the system functionality and capabilities.

Participation

All testing described within this document was conducted by the Team of Battelle and the Texas A&M Transportation Institute. Upon completion of the testing, the Battelle Team conducted a demonstration of the Phase II and Phase III tests that was witnessed by representatives of the U.S. DOT and selected contractors. Phase III test demonstrations employed a paid, third-party transportation service provider in order to provide a vehicle capable of carrying the test witnesses. This vehicle operator will be briefed on all activities related to their participation and shall follow all federal and local traffic laws.

Security

No testing related to security was planned for this prototype. While Arada has implemented and verified over-the-air-security for DSRC radios as prescribed for the U.S. DOT Safety Pilot Model Deployment in V3.0 of the Roadside Equipment specification, the necessary firmware modifications for the "backpack" form factor were still in development at the time this testing was conducted. Over-the-air-security for DSRC radios will be verified prior to further prototype development or enhancements. Communications using cellular and other internet 'standards', used secure-socket layers, and as necessary, virtual private network connections.

Chapter 2 Reference Documents

Table 2-1 identifies the INFLO Prototype Project Documents referred to herein.

Table 2-1. INFLO Prototype Project Documents

Number	Document Title
FHWA-JPO-13-012	Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO)
FHWA-JPO-13-013	Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO); Functional and Performance Requirements, and High-Level Data and Communication Needs
FHWA-JPO-14-171	Report on Detailed Requirements for the INFLO Prototype
FHWA-JPO-14-170	Report on Architecture Description for the INFLO Prototype
FHWA-JPO-14-168	Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design
FHWA-JPO-14-169	System Design Document for the INFLO Prototype
FHWA-JPO-15-208	Intelligent Network Flow Optimization (INFLO) Prototype Acceptance Test Plan

Source: Battelle

Chapter 3 INFLO Prototype Acceptance Test Overview

INFLO Prototype System Acceptance Testing was conducted according to the principles of system engineering. Individual system components were tested against their requirements (Phase I). Then the system components were integrated and tested in the laboratory (Phase II). Finally the integrated system testing was conducted on a closed course and on-road (Phase III). The objective of this series of tests was to confirm and to demonstrate to the U.S. DOT that the INFLO Prototype System was fully functional and sufficiently robust to support a Small-Scale Demonstration and potential future field pilot tests. This chapter provides a brief overview of the three test phases. It is followed in Chapter 4 by a description of the prototype system under test, including the individual components and the integrated system configuration. Chapters 5 through 7 describe the testing and the results of the INFLO Prototype System Acceptance Tests. Appendix A summarizes the results of component testing. Appendix B provides example Android Log Files. Appendix C provides the Requirements Traceability Matrix for INFLO Prototype System Acceptance Testing. Appendix D provides Acronyms and Abbreviations.

Phase I – Component Acceptance Testing

Phase I test cases were tested within the Battelle Team laboratory environment. During this phase the Battelle Team verified each system component against the system requirements using simulated data inputs. Both the functionality of the component and the external interfaces of the component were tested in this phase. This enabled parallel development and testing of each system component to ensure that they each conform to their basic functional requirements (including those specific to the algorithms).

Phase II – System Integration Acceptance Testing

Phase II integrated the system components to verify the interface performance and functionality of the components as a system. Phase II testing was divided into Phase IIa, Communications and Messaging System Integration Acceptance Testing and Phase IIb – TME-Based Application System Integration Acceptance Testing. As explained in more detail in the following chapters, Phase IIa tested and demonstrated communication of BSM data from nomadic devices to the INFLO Database in the Cloud and Q-WARN and SPD-HARM messages from the INFLO Database to nomadic devices, all in the laboratory. Phase IIb tested and demonstrated the TME-based Q-WARN and SPD-HARM application process, in simulated real time, of obtaining connected vehicle and infrastructure speed data from the INFLO Database, processing and analyzing it and returning Q-WARN and SPD-HARM messages to the INFLO Database. Note that the weather responsive traffic management (WRTM), while shown in the other documents as a separate application, was tested in conjunction with SPD-HARM as a subset of the SPD-HARM application.

Phase III – INFLO Prototype Pilot System Acceptance Testing

During Phase III, nomadic devices were placed in vehicles and the Battelle Team conducted communication and messaging testing of the system on-road and on a closed course. The Test Procedures from Phase IIa replicated on-road the communication of BSM data from nomadic devices to the INFLO Database in the Cloud and Q-WARN and SPD-HARM messages from the INFLO Database to nomadic devices over a range of vehicle speeds and test conditions. The purpose of this Phase was to demonstrate that the system will fully functional in on-road environments and be able to support small-scale field demonstrations. Upon completion of the testing, the Battelle Team conducted a demonstration of the Phase II and Phase III tests that was witnessed by representatives of the U.S. DOT and selected contractors. The results of this acceptance testing may be used by the U.S. DOT to determine whether a small-scale demonstration of the Prototype will be conducted under Task 3 of the INFLO project.

Chapter 4 Prototype Pilot System Test Components and Test Configuration

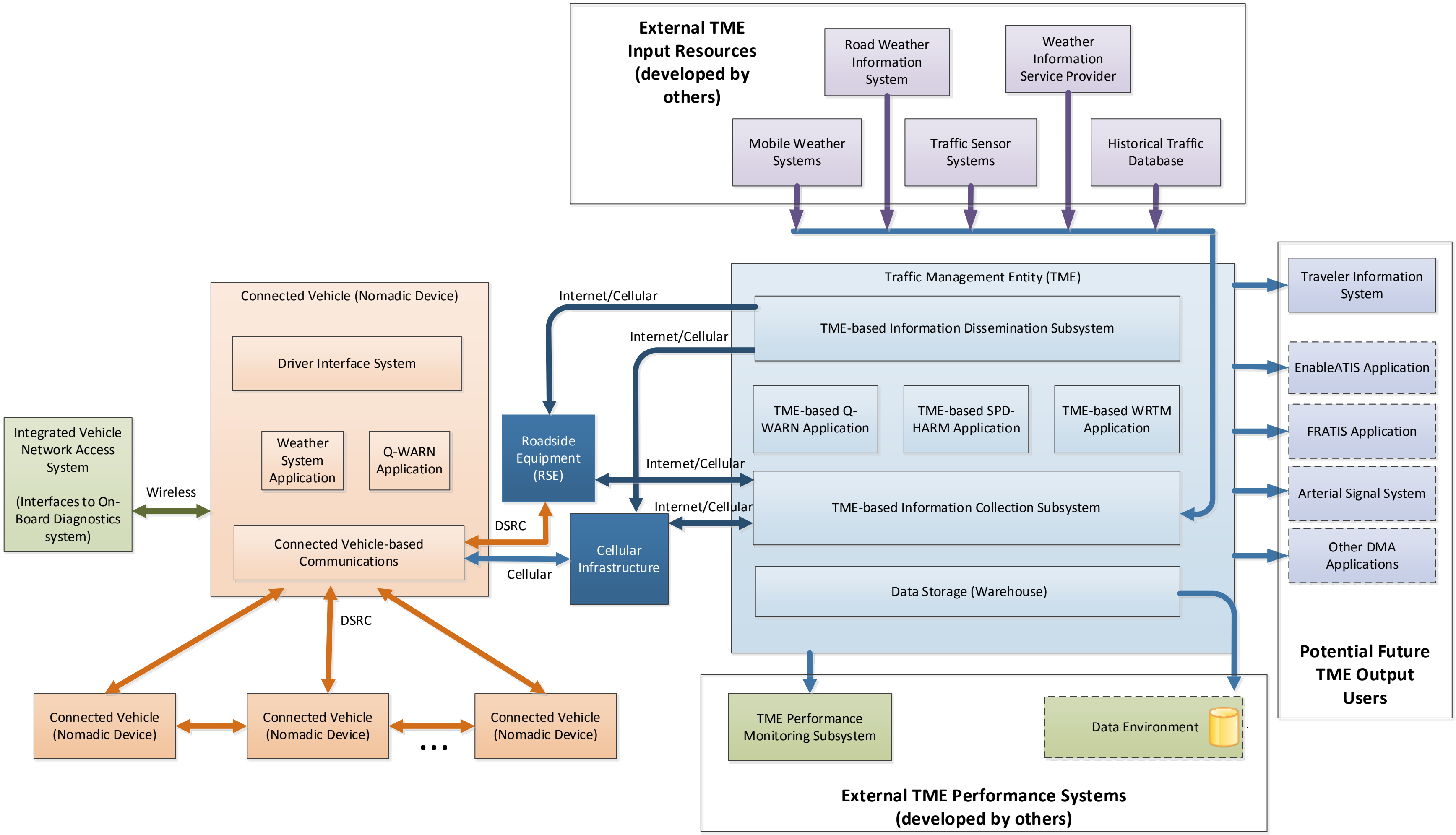
The Battelle Team conducted the tests described in this document throughout the month of April 2014 as the INFLO Prototype System was implemented and integrated. The Phase II and Phase III system level tests were repeated on May 6 and 7, 2014 at Battelle Offices in Columbus, Ohio in a demonstration for the U.S. DOT of the functionality and performance of the INFLO system as confirmed in these acceptance tests. Following are background descriptions of the system components and the system configuration that was tested and demonstrated for the U.S. DOT.

Prototype System Under Test

The INFLO Prototype System consists of multiple components, which exchange data through messages using DSRC or cellular communication. Figure 4-1 shows a comprehensive INFLO system-level diagram, which identifies the components and the communication methods and messages that flow between the components. This figure represents a comprehensive system and current and future capabilities that are described in detail in the *INFLO Architecture Description Document*. Figure 4-2 below is a simplified view of the *Prototype* INFLO System as it has been implemented for the purposes of this project and tested and demonstrated to the U.S. DOT. This system has the functionality and capabilities necessary to support a small-scale demonstration and future potential pilot tests under consideration by the U.S. DOT. Figure 4-3 shows the same figure, with the addition of the messages that are exchanged between components necessary to support the multiple INFLO scenarios and applications.

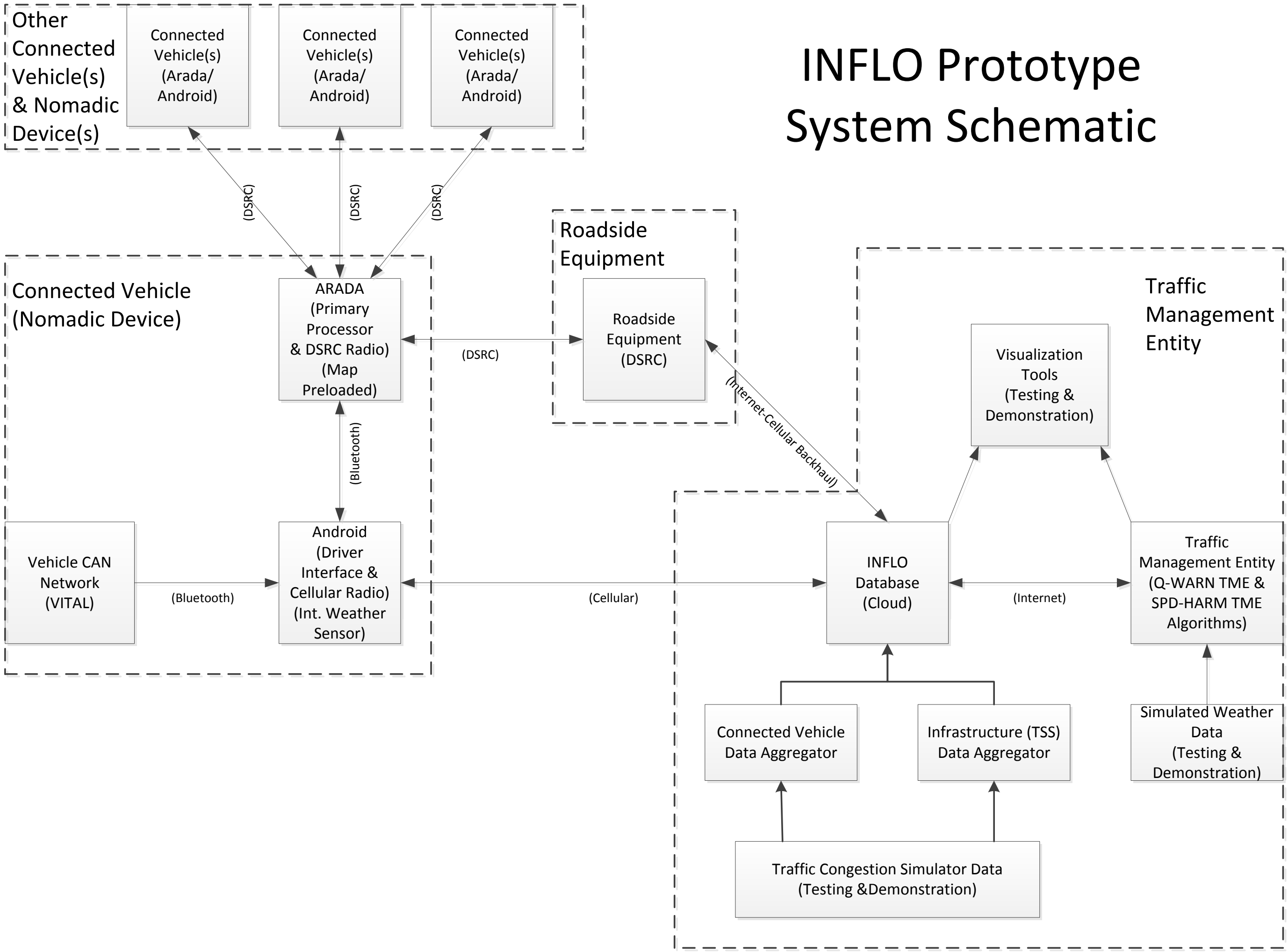
The remainder of this section provides background and overview of the components under test, the implemented INFLO Prototype System and the location and methods by which they were tested and demonstrated. The remainder of this section is organized under the following headings:

- INFLO Prototype System Components
- Messages Types
- INFLO Applications Under Test
- Test Visualization Tools
- On-road and Closed Course Acceptance Test Routes



Source: Battelle

Figure 4-1. INFLO Prototype System Diagram from INFLO Design Report



Source: Battelle

Figure 4-2. Schematic of the Implemented INFLO Prototype System

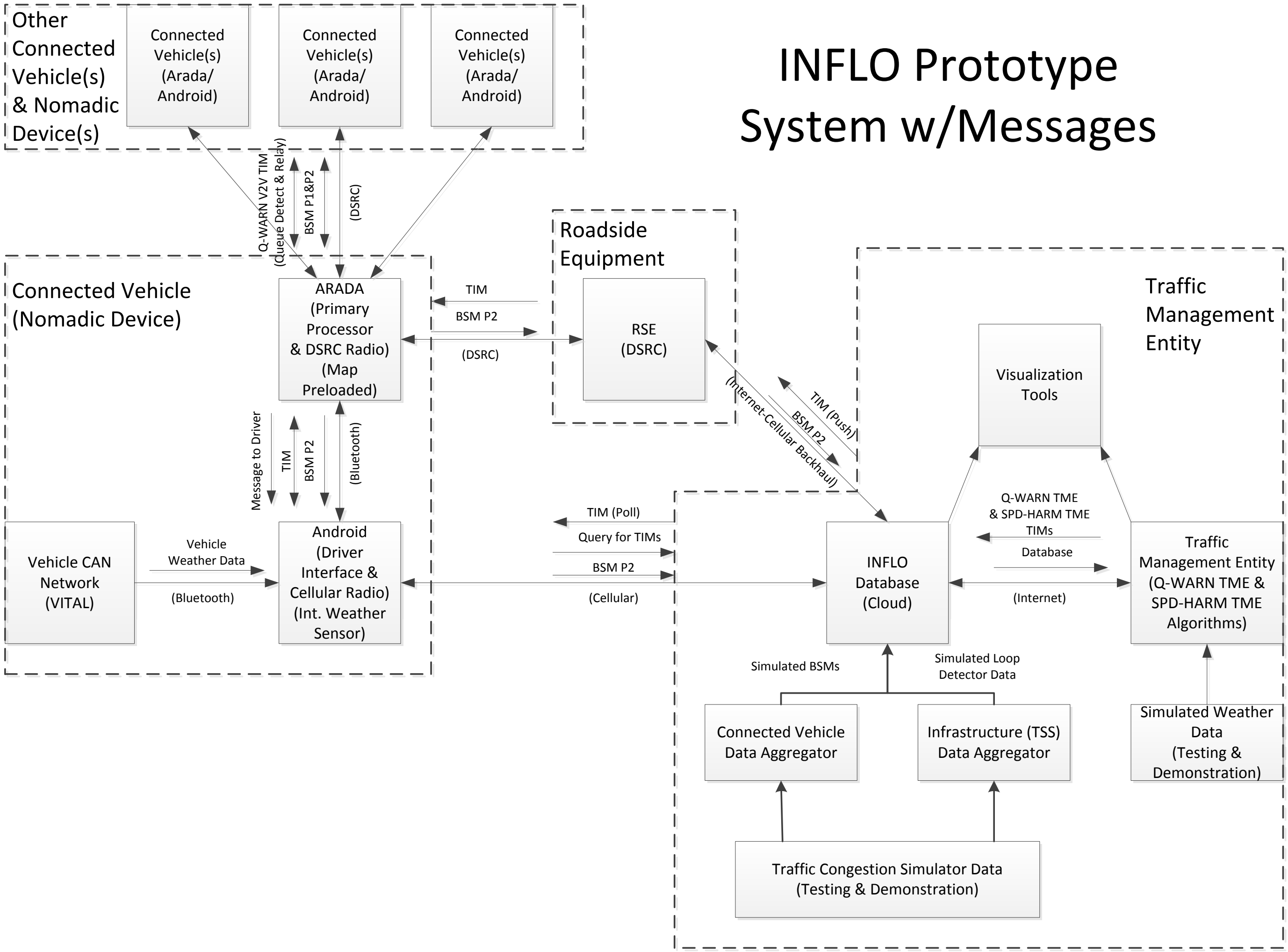


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Figure 4-3. Schematic of the Implemented INFLO Prototype System Showing Messages Transmitted between Components

INFLO Prototype System Components

The INFLO System and its components are described in detail in the INFLO System Design Document. A brief synopsis is provided here for completeness and clarity of this test summary.

The primary functional components of the implemented INFLO Prototype System, shown in Figure 4-2 and Figure 4-3 are the following:

- Connected Vehicle Nomadic Device consisting of
    - Nomadic Device User Interface Module (Android User Interface and Cellular Radio),
    - Nomadic Device DSRC Radio Module (ARADA Processor and DSRC Radio),
    - In Vehicle Network Access System (Vehicle CAN Network)
- Roadside Equipment (RSE)
- Virtual Traffic Management Entity consisting of
    - INFLO Database
    - TME-Based Q-WARN Application
    - TME-Based SPD HARM Application with WRTM
    - Connected Vehicle Data Aggregator
    - Infrastructure (TSS) Data Aggregator
    - Simulated Weather Input Data

The following additional components are used for testing and demonstration

- Traffic Congestion Simulator Data
- Simulated Weather Data
- Test Visualization Tools
    - INFLO Database Map Viewer
    - TME Algorithm Queue Visualization Tool

Following is an overview of each.

Nomadic Device User Interface Module

The Nomadic Device User Interface Module is a mobile device (cell phone) running the Android operating system. The features of this component include

- Provides an interface to the cellular network (i.e., the TME via the Internet)
- Manages the connection back to the Azure Web Service hosting the TME
- Provides ambient weather sensor data (from mobile device sensors)

The mobile device display provides a graphical user interface which communicates the following to the driver:

- INFLO system state
- Nomadic device system state
- SPD-HARM messages (e.g. recommended speed)
- Q-WARN messages (e.g. distance to back of queue, length of queue)

The mobile device interfaces with the DSRC radio module in the nomadic device via Bluetooth connections to send ambient weather data to the DSRC radio module and to receive TME bound messages.

User Interface Message Examples

Figure 4-4 through Figure 4-13 provide screen capture examples of the User Interface Messages on the Android Device for the INFLO Applications. The screens were implemented to be as simple and clear as possible with the goal of displaying[1]:

- SPD-HARM Recommended Speed
- Q-WARN Queue Ahead with distance to the back of queue
- Q-WARN In-Queue with distance and estimated time to the end of queue and estimated time
- Vehicle weather and other data (Diagnostics screen)

Note the following messages and indicators in the User Interface.

- V2V Queued red bullet in Figure 4-5 wherein V2V communications have determined that the vehicle is in a queued state.
- V2V Queue Ahead message in Figure 4-6 wherein V2V communications have determined that a queue is ahead with the distance to the back of queue (BOQ)
- TME Queue Ahead message in Figure 4-7 wherein TME algorithms have determined that a queue is ahead with the distance to the back of queue (BOQ)
- TME In-Queue message in Figure 4-8 wherein TME algorithms have determined that the vehicle is in a queue and the distance and travel time to the front or end of the queue
- TME Speed Harmonization message in Figure 4-9 wherein the TME algorithms have recommended a reduction in speed.
- TME Multiple messages in Figure 4-10 wherein both Speed Harmonization and Queue Ahead messages are issued and displayed simultaneously.
- Diagnostic and Test Verification messages shown in Figure 4-11, Figure 4-12, and Figure 4-13.

[1] Note that Human factors or industrial design is outside the scope of this prototype.

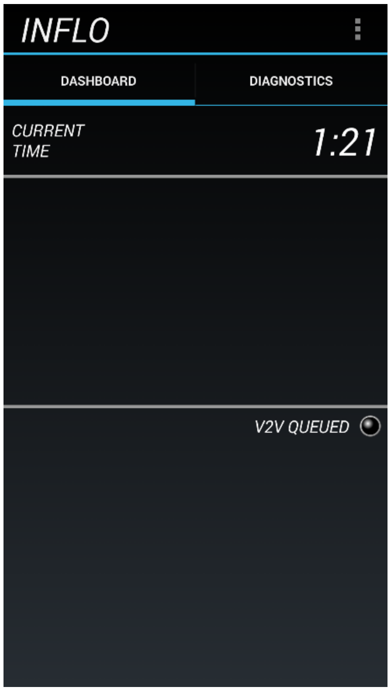

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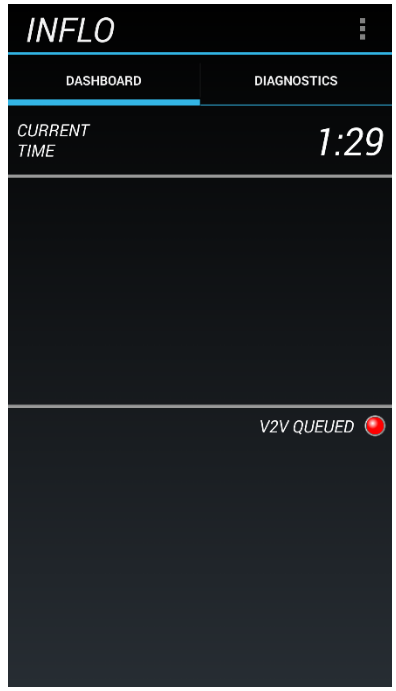
Figure 4-4. User Interface Display

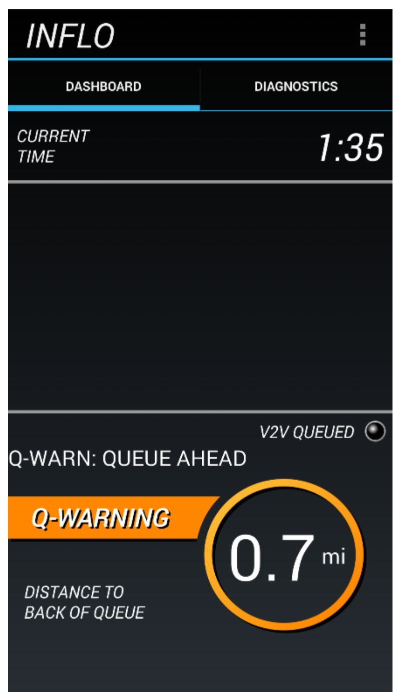


Source: Battelle

Figure 4-5. Queue Detected V2V

Source: Battelle

Figure 4-6. Queue Ahead (V2V)

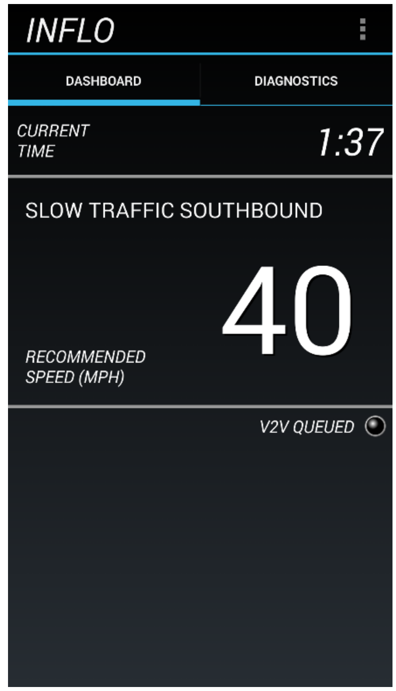


Source: Battelle

Figure 4-7. Queue Ahead (TME)

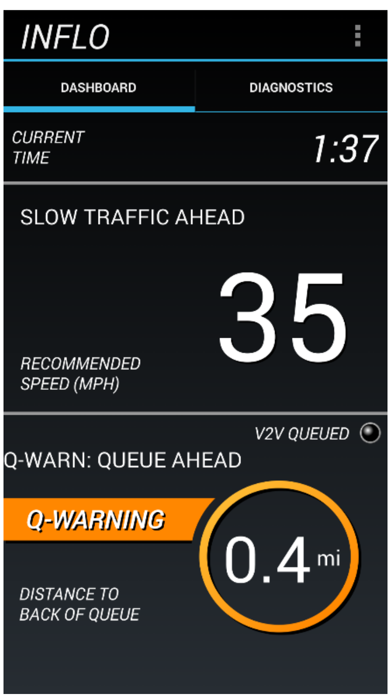
Source: Battelle

Figure 4-8. In Queue (TME)



Source: Battelle

Figure 4-9. SPD-HARM (TME)



Source: Battelle

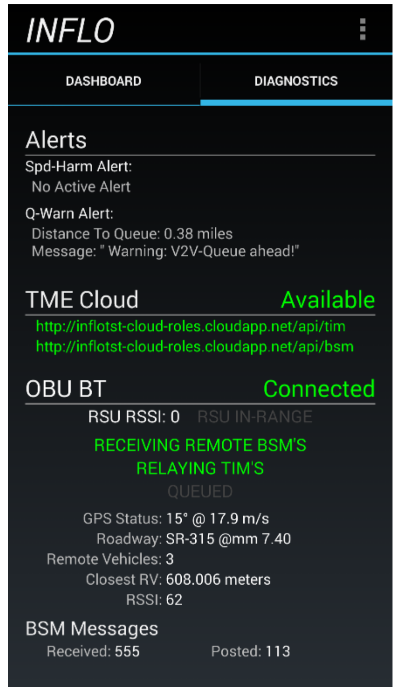
Figure 4-10. TME Multiple Warnings

Source: Battelle

Figure 4-11. Not Connected

Source: Battelle

Figure 4-12. Vehicle Data



Source: Battelle

Figure 4-13. Diagnostic Display

Nomadic Device DSRC Radio Module

The Nomadic Device DSRC Radio Module is a small portable unit that can run on battery power. The unit is the main computational processor for the nomadic device. The unit interfaces to the User Interface Module via Bluetooth. The unit receives messaging from the (internal) DSRC radio and the cellular network (via the Bluetooth paired mobile device). It processes all messages and supplies any needed information for driver alerts and warnings.

The DSRC radio receives both V2V and I2V communications. The DSRC radio transmits Basic Safety Messages (Part I and Part II) to other DSRC radios that are in range and to the Roadside Equipment. The DSRC radio also hosts the Connected Vehicle-based Q-WARN Application, which is 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 TME.

The Basic Safety Message Part 2 data is populated by data from the vehicle, data from the onboard GPS and data collected by weather sensors. The BSM Part 1 is transmitted at 10 Hz with the Part 2 transmitted at 1HZ. The Nomadic Device also transmits Q-WARN indicators calculated in the onboard Q-WARN Application (such as “this Vehicle Queued”) as part of the BSM Part 2.

The Nomadic Device DSRC Radio Module receives messages from other vehicles (V2V) and from the infrastructure (I2V). The nomadic device will receive and process any BSMs from surrounding vehicles and supply the data to the onboard Q-WARN application. The Nomadic device also receives and processes, at a minimum, the Traveler Information Message (TIM) whether it is from a local DSRC radio or the cellular connection. TIM messages received by DSRC are rebroadcast by DSRC for reception by other nomadic devices within radio range and “relay” of vehicle queue information.

Along with TIMs, the Nomadic Device DSRC Radio Module receives MAP messages for use in determining vehicle location on the roadway and applicability of Q-WARN and SPD-HARM messages. For Prototype testing purposes, maps of test routes were preloaded on the Nomadic Device.

Source: Battelle

Figure 4-14. Nomadic Device DSRC Radio Module in the Backpack Form Factor for use with the ANDROID Mobile Device

Source: Battelle

Figure 4-15. Nomadic Device Mounted in Vehicle showing Android Samsung 4 Cellular Phone in Arada BackPack DSRC Radio

In Vehicle Network Access System

The In Vehicle Network Access System (IVNAAS) is used to obtain data from the vehicle CAN bus through the OBD-II interface. The Nomadic Device uses the VITAL module, a proprietary Battelle module that plugs into the OBD-II port, to obtain a vehicle's telemetry data and forward the messages using Bluetooth to a connected device (see Figure 4-16). This module allows the DSRC radio to receive vehicle dynamics to populate the Basic Safety Message Part II. The availability of specific data elements is dependent upon the vehicle.

Source: Battelle

Figure 4-16. VITAL OBD-II Module

Road Side Equipment

The Road Side Equipment used in testing and demonstration is the Arada LocoMate™ RSU, shown in Figure 4-17, which handles all DSRC communications from the TME to vehicles and nomadic devices and DSRC communications from the vehicles to the TME. The Road Side Equipment forwards any warnings from the TME to all devices within its range. The RSE also collects BSM Part II messages and subsequently forwards these messages to the TME for use by the infrastructure-based algorithms.

INFLO Database and Cloud Service

The Cloud Service is a Microsoft Azure Cloud Service that includes the following components:

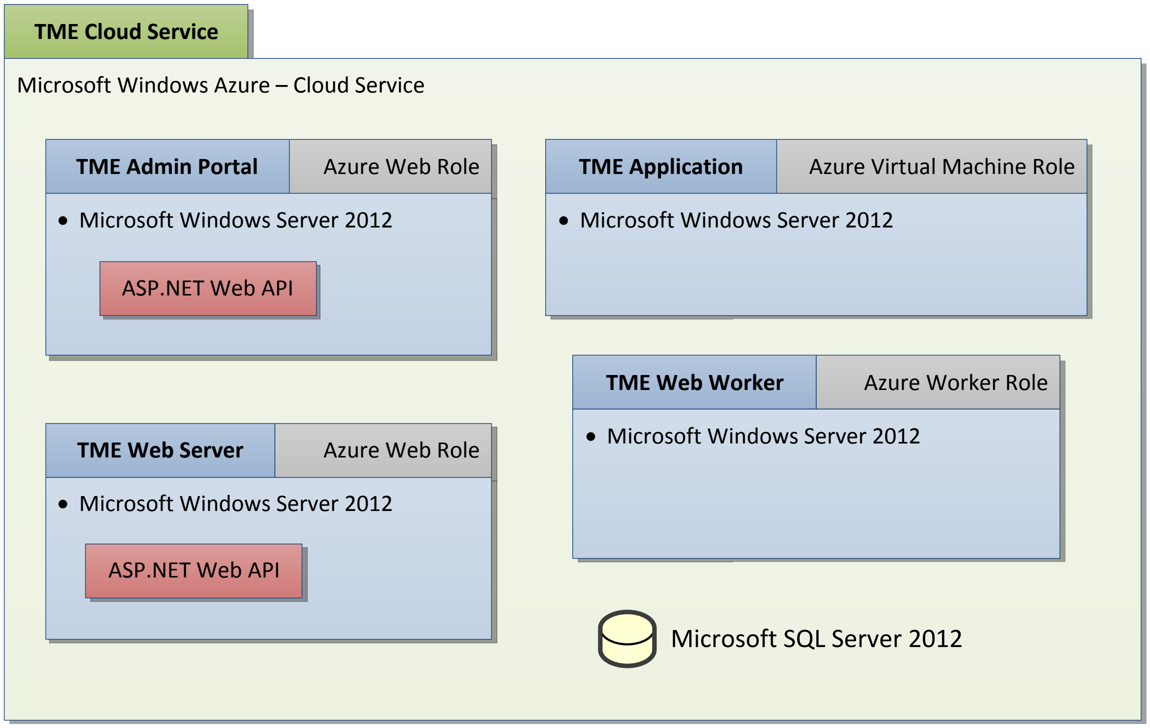
- INFLO Database (SQL)
- Web Role (TME Web Server)
- Web Role (Admin Portal)
- Worker Role (Database Worker)

The computing platforms for each VM in the Azure Cloud Service will be selected as shown in Figure 4-18.

Cloud service(s) provide a user interface to monitor the state of the underlying vehicle-data database, the web services used to facilitate the exchange of data from/to vehicles, to monitor the state of the connected vehicle network, and to allow configuration of parameters associated with this prototype. This interface is intended for the development team.

Source: Battelle

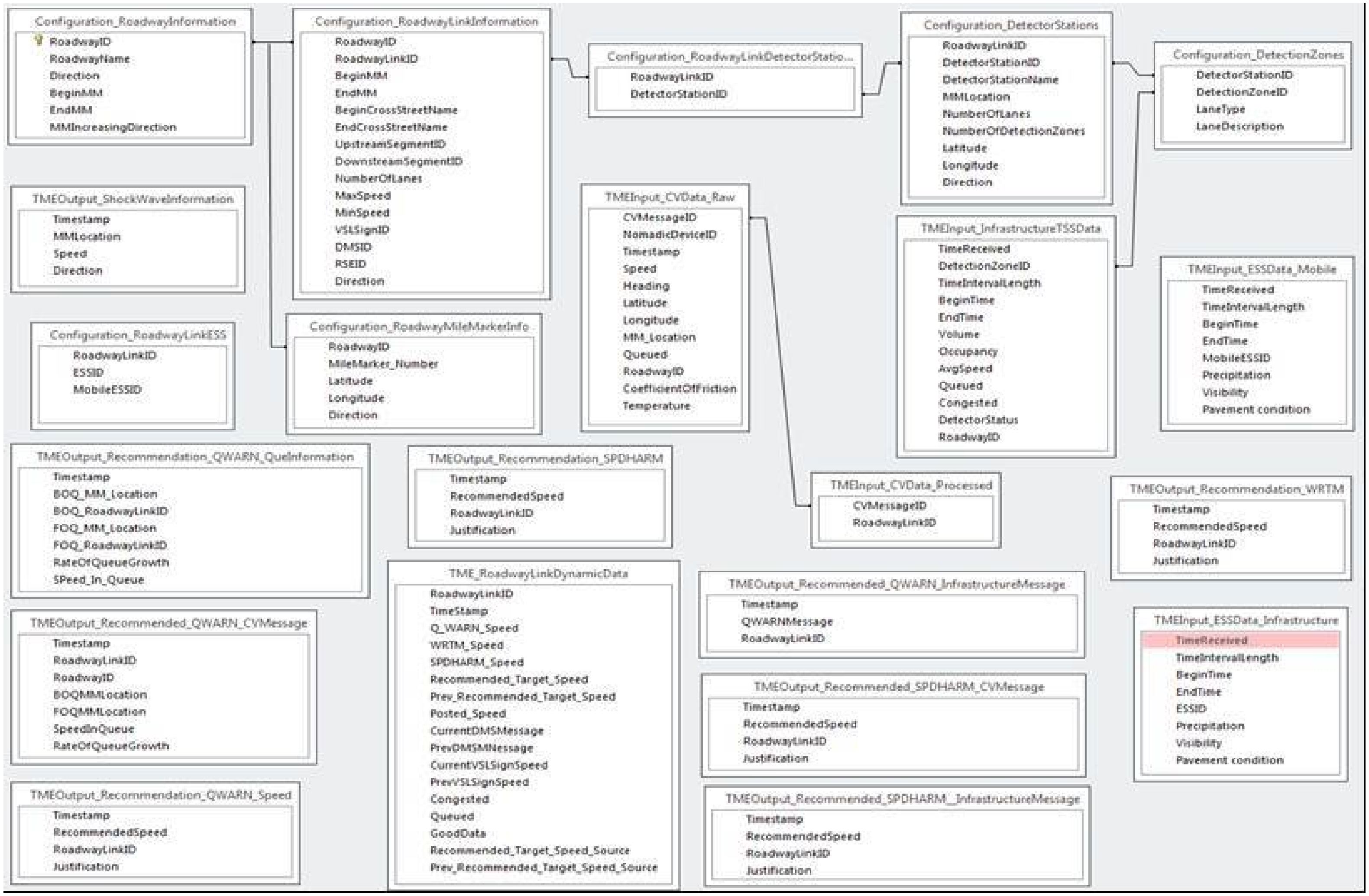
Figure 4-17. Road Side Equipment Arada LocoMate™ RSU



Source: Battelle

Figure 4-18. Cloud Service Computing Platforms

Figure 4-19 documents the data dictionary for the INFLO Database. It holds incoming data from the nomadic devices (BSM data), and incoming messages from the TME such as TIM-based Q-WARN and SPD-HARM messages.



Source: Battelle

Figure 4-19. INFLO Database Tables

Virtual Traffic Management Entity

The virtual TME consists of the hardware and software components required to implement the TME-based INFLO bundle of prototype applications. The TME is built using a modular approach including key components of Data Collector/Aggregators, INFLO Database, TME Link Speed Process, TME Queue Warning Process, TME WTRM Process, TME Link Speed Harmonization Process and TME Message Generator. The data aggregators are responsible for obtaining, processing, formatting, and distributing the data used by the various processes in the INFLO algorithm. A critical component of the virtual TME environment that provides the flexibility needed in designing the algorithms is the INFLO Database system. The INFLO Database is used to store the processed input data collected from the various external sources required by the algorithms and any metadata generated from processing the input data by the data aggregators. The recommendations made by each algorithm and sent to drivers and infrastructure-based signs are also stored in the database. The TME Link Speed Process is responsible for performing the speed harmonization process for the system. The TME Queue Warning Process is responsible for processing the traffic sensor data delivered by the Data Collector/Aggregator and determining which freeway segments are operating in a queue state. The TME WTRM Process is responsible for generating safe speeds for measured weather conditions. The TME Link Speed Harmonization Process receives the results of the various INFLO algorithms and selects the critical message to be sent out to the road users. The TME Message Generator is responsible for determining the appropriate speed messages to be displayed for each section of the freeway.

INFLO Database

The INFLO Database also provides a flexible mechanism for sharing data between the various prototype components and to synchronize the operations of the various components in the TME virtual environment. For example, the speed harmonization algorithm fuses data from multiple sources including external sources like infrastructure-based sensor traffic data and connected vehicle traffic data besides metadata generated by other algorithms like the safe speed recommendations from the Weather-Responsive Traffic Management (WRTM) algorithm. Each of these data sources is acquired or generated at a different frequency. For example, the infrastructure-based sensor data is acquired at 20 second to one minute intervals while the connected vehicle data is acquired at one to five second intervals. On the other hand the WRTM algorithm might generate weather safe speed recommendations every minute or at higher intervals. All of this data will be stored in the INFLO database in real-time and depending on the frequency of running the TME-speed harmonization algorithm, it will query the database for the data it needs and generate the proper speed recommendation for roadway links.

Traffic Sensor System (TSS) Data Aggregator

For the INFLO System Acceptance Test, the Traffic Sensor System (TSS) Data Aggregator collects the data from simulated roadway sensors, aggregates the data according to user defined procedures and thresholds, and populates the INFLO Database. For the prototype, initially only speed data will be used to determine operating states for the link and the lanes within the link.

Connected Vehicle Data Aggregator

For the INFLO System Acceptance Test the Connected Vehicle (CV) Data Aggregator collects the data from all the simulated connected vehicles traveling in the deployment corridor and converts it into link-based information. The CV Data Aggregator is responsible for processing the data from each connected vehicle and determining the average speed, congested state, and queued state of the sublink. The mile marker reference in the CV Data will be used to determine the sublink in which the vehicle is located. Once the sublink location for each connected vehicle has been determined, the CV Data Aggregator will compute the average speed for each sublink for all the connected vehicles located in each sublink. Using the average sublink speed, the CV Data Aggregator will determine the operating state (congested and queued) of each sublink by comparing the percentage of connected vehicles indicating that they are operating in a queued or congested state.

Traffic Simulation Data

To develop, test and verify the INFLO applications, a data set of simulated traffic sensor and connected vehicle data were developed. This data set captures the key features of traffic congestion and provides input to the applications to verify their functionality and performance. The data set were developed using the VISSIM microscopic simulation mode. Each VISSIM run produced the following three output files:

- Connected vehicle data assuming all vehicles are “connected” (100% market penetration) and perfect data.
- 20-second lane-by-lane speeds, volumes, and occupancies obtained from data collection points located at half-mile separation.
- VISSIM-generated queuing statistics for validation purposes.

For the purposes of generating the data used for the testing, a seventeen mile section of two-lane freeway was coded into VISSIM. The section of freeway was coded as a two-lane freeway with no entrance and exit ramps. A lane closure bottleneck was coded for the right lane at Mile marker 12.25. The capacity of the bottleneck was coded to be 1900 vehicles per hour. Traffic sensors were simulated at half mile intervals, beginning at Mile marker 2.0 through Mile marker 13.0. This traffic sensor data were coded to collect the following information in 20-second intervals for each lane:

- Simulation timestamp
- The number of vehicle passing the identified lane detector in each lane during the 20-second interval (lane volume)
- The average speed of all vehicle passing through the detection zone during the 20-second interval (travel speeds)
- The average amount of time the detection zone was occupied by vehicle during the 20-second interval (lane occupancy).

These data were aggregated in an output file which was fed into the Traffic Sensor System (TSS) data aggregator using a post-process application. The TSS data aggregator aggregated the lane-based data to provide the simulation detector station input. The data aggregation process converts the lane-by-lane detector data to produce the following detector station information:

- Station speed – the average speed for all lanes weighted by the recorded volume in each lane.
- Total station volume – the sum of all the volumes recorded in each lane detector associated with a detection station.
- Station Occupancy – the average of all reported lane occupancies from each lane detector associated with a detection station.

Connected vehicle data were generated using a built-in feature of VISSIM. This feature generates (emulates) and saves second-by-second the following data for each vehicle in the simulation:

- Vehicle identification number,
- Location (X-Y coordinate),
- Lane number, and
- Current speed in the network

The VISSIM output file was then post-processed to produce a simulated BSM file for each individual vehicle. This program parsed through VISSIM output, adds a queue-state data field, and separates the data into one-second data streams (files) to emulate connected vehicle data.

The VISSIM simulation sequence consisted of the following:

- A 30-minute (0 to 1800 second interval) warm-up period with a fixed demand of 950 VPH. This warm-up period is sufficient because it takes approximately 850 seconds for the first vehicle to traverse the entire simulated facility.
- A second 30 minute interval (1800 to 3600 second interval) with 4000 vph demand scenarios; and
- A one-hour (3600-5400 second) interval with a fixed demand of 600 VPH to allow the worst-case queue to clear before the end of simulation.

It should be noted that it takes approximately 620 seconds for the vehicles entering the freeway to reach the bottleneck location. Therefore, the impacts of near- or over-capacity demands do not show until simulation time of around 2420 (1800 + 620). There is also a similar lag in the impacts of reduced demand beginning at 3600 seconds.

VISSIM cannot directly produce impacts of adverse weather conditions. If desired, such conditions can be emulated by implementing reduced speeds. For this project, it is sufficient to test if data flows based on certain emulated conditions lead to decisions about speed harmonization coming from the right source. To achieve this goal, a third data stream was developed to emulate weather data based on the following conditions:

- Visibility: ≤ 500 ft and > 500 ft
- Coefficient of Friction: < 0.3; In the interval [0.3, 0.7); and ≥ 0.7

Message Types

Two primary SAE J2735 messages are transmitted and used to communicate data between components in the system, the Basic Safety Message (BSM) Part 2 and the Traveler Information Message (TIM).

The BSM Part 2 is used to communicate the following data, where available, from vehicles: time, location, velocity (speed), heading, barometric pressure, lateral acceleration, longitudinal acceleration, yaw rate, rate of change of steering wheel, brake status, brake, boost status, impact sensor status, anti-lock braking status, external air temperature, wiper status, headlight status, traction control status, stability control status, and differential wheel speed. As shown in Figure 4-3, the BSM Part 2 message is primarily communicated from the Nomadic device to the INFLO Database to capture an individual vehicle's speed and congestion related data. The BSM Part 2 is transmitted by either DSRC through the RSU or by cellular communications when DSRC is not available. This message is sent once per second.

The TIM message is primarily used to communicate TME-based Queue Warning and Speed Harmonization messages from the INFLO Database to Nomadic Devices for processing and, if appropriate, display to the driver. The TIM message may also be transmitted by either DSRC through the RSU or by cellular communications when DSRC is not available.

INFLO Applications Under Test

Four INFLO Application scenarios, described in more detail in the Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design were implemented to test and demonstrate the functionality and performance of the INFLO Prototype System. These were

- TME-Based Queue Warning (Q-WARN)
- TME-Based Speed Harmonization (SPD-HARM) with Weather Responsive Traffic Management (WRTM)
- Cloud-Based Queue Warning
- V2V Queue Warning

Following is a brief description of each of the applications. Details of each application may be found in the separately published Report on Dynamic Speed Harmonization with Queue Warning Algorithm Design[2].

TME-Based Q-Warning Application

The purpose of the TME-based queue warning algorithm is to fuse the vehicle speed data from the infrastructure and the connected vehicles and generate queue warning messages that can be disseminated through both infrastructure signs and connected vehicles. In this application, the decision-making processes reside primarily within the Traffic Management Entity (TME). The connected vehicle is required to process any data other than determining its queue state and generating queue warning displays for the driver from the data provided by the TME.

The TME Q-WARN application is responsible for detecting queues in the traffic stream and for generating appropriate queue warning messages. The TME Q-WARN application interfaces with the INFLO Database to extract both connected vehicle data and infrastructure-based traffic data to determine information about the queue. The application consists of two processes running in parallel: one process for detecting queues using connected vehicle data and the other for detecting queues using information based on infrastructure based traffic data. The TME Q-WARN application uses the queue state data element in both the connected vehicle and infrastructure-based traffic data to determine which links in the network are operating in a queue state. The TME Q-WARN application then produces information about the queue (i.e., the location of the back of the queue, the speed and direction of the queue growth, etc.) by monitoring the links and sublinks defined to be operating in a queued state. The TME Q-WARN application then forwards information about the queue to the TME

[2] Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design – 100030614-251A (FINAL), March 28, 2014.

Message Generator, which uses the information to generate appropriate queue warning alerts for display on infrastructure-based dynamic message signs and for broadcast to connected vehicles.

TME-Based Speed Harmonization Application

The objective of speed harmonization is to minimize the turbulence in the traffic stream approaching a section of the roadway experiencing low speeds. 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. The INFLO SPD-HARM application concept aims to realize these benefits by utilizing connected vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) 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. The INFLO SPD-HARM algorithm was designed to identify, produce, and establish a recommended speed for segments of the corridor. The algorithm identifies the beginning and ending mile point over which the recommended speed is applicable. These speeds may be advisory or regulatory speeds based upon agency policy. For the purpose of the prototype development, speed harmonization was based only in the TME. The Uniform Motor Vehicle Law indicates that state and local agencies are responsible for establishing recommended speeds on public roadway facilities.

Weather-Responsive Traffic Management

The purpose of Weather Responsive Traffic Management algorithm is to determine the recommended travel speed for each link based on the prevailing road weather conditions. In this prototype development, Weather Responsive Traffic Management is implemented as a subset of Speed Harmonization Algorithm in which recommended harmonization speeds may be adjusted based upon road weather conditions. For the purposes of the prototype development, recommended travel speed is based upon visibility and pavement surface conditions. While transportation management agencies will implement reduced travel speed recommendations for high wind conditions, similar concepts could be used to produce recommended travel speeds based on high wind conditions.

Cloud-Based Queue Warning Application

The cloud based queue warning algorithm is a subset of the TME-based Queue Warning Algorithm, which is implemented when no infrastructure elements are being used. Specifically, no infrastructure detectors are present to provide vehicle data and no infrastructure signs (dynamic message signs) are deployed. This means that only connected vehicle data is available from the facility. Similarly any queue warning messages will only be displayed inside a connected vehicle. In such a scenario, a cloud based queue warning system is more applicable to minimize the computing workload of all the queue warning data within a vehicle as well as to have a broader view of the facility.

V2V Queue Warning Application

Vehicles in a V2V Queue Warning Application use DSRC to communicate with other connected vehicles. Each connected vehicle determines its mile marker location and its queued state (Y or N). The connected vehicles will then transmit this information along with BSM to other vehicles. The V2V Queue Warn System relies upon DSRC communication to send and receive BSM messages. The primary purpose of these messages is to enable connected vehicles to determine if they are in a queued state and locate the back of queue (BOQ). Typically queued state depends on the speed of the vehicle as well as the separation distance from the vehicle immediate downstream. If however, a vehicle is unable to determine its distance from vehicles immediately downstream, only the vehicle speed may be used to determine its queued state. The queued state along with BSM is then transmitted to other vehicles.

The connected vehicle receiving information from other connected vehicles identifies and locates all downstream connected vehicles. Based on the mile marker location of the connected vehicles, a non-queued vehicle identifies the BOQ if present from among the downstream vehicles. The location of BOQ is then transmitted by all non-queued vehicles. All upstream vehicles receiving the BOQ message will then display a proper message to the driver and retransmit the location of BOQ. This process of receiving BOQ location and retransmitting it to upstream vehicles is continued for a user defined distance from the BOQ and then ignored as that information may become irrelevant at large distances from the BOQ. If the vehicle is beyond a user-defined distance upstream of the BOQ (e.g., 10-mile for the prototype testing), then the warning information would not be displayed.

Test Visualization Tools

As shown in Figure 4-5 through Figure 4-10, INFLO messages to the driver are displayed directly on the Nomadic device and can be readily demonstrated and verified. However, the INFLO Database is a data repository in the Cloud that is not readily transparent. Figure 4-1 identifies visualization tools that were used to demonstrate and verify the functionality of the INFLO database. These tools include an INFLO Database Map Viewer and the TME Algorithm Queue Visualization Tool, each described below.

INFLO Database Map Viewer

To assist the Battelle Team and the U.S. DOT in observing the functionality of the INFLO Database, Battelle assembled a Map Viewer in which key data from the database are overlaid on a map. Figure 4-20, Figure 4-21 and Figure 4-22 show three zoom levels of simulated congestion data from the Map Viewer. The figures show car icons for vehicle BSMs received and posted in the database. In this case the map viewer is showing the BSMs received from the traffic simulation. The Viewer uses red car icons for cars that meet the TME criteria for being queued and green icons for nonqueued vehicles. Hovering a mouse over any vehicle will display the contents of its BSM Part 1 and 2.

The traffic simulation data used for validation and demonstration is generic and not associated with a specific highway. For the purposes of these demonstrations the simulated traffic data was overlaid on a satellite image of Interstate 71 in Columbus, a frequently congested roadway.

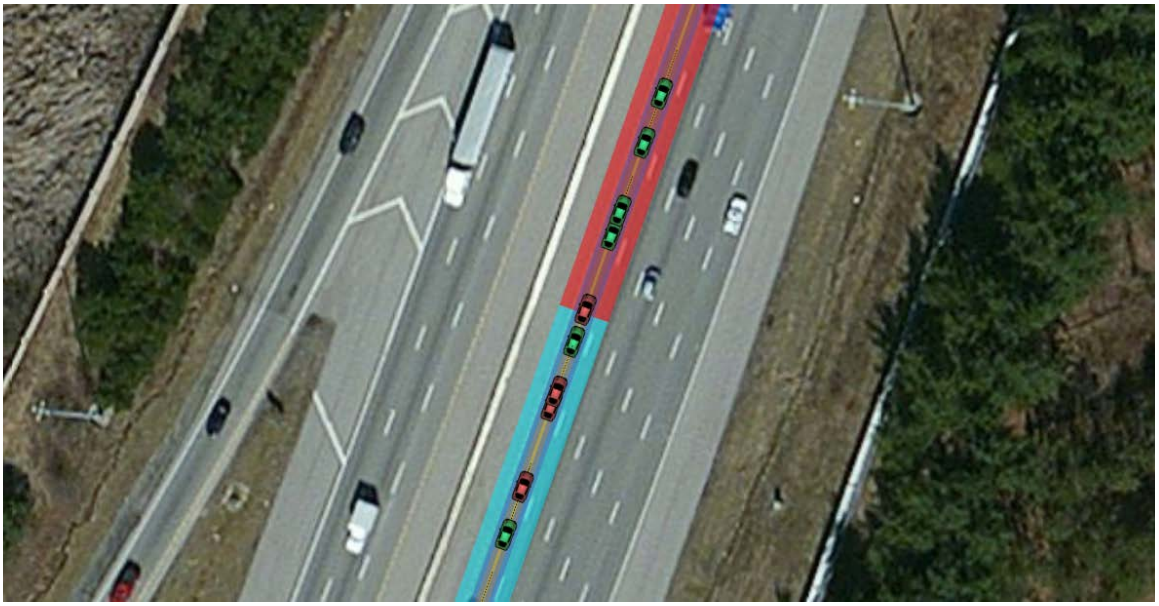
The Map Viewer displays TME-Based Queue region as a magenta highlight and TME-based Speed Harmonization segments as a Cyan (greenish-blue) highlight. This display is fully dynamic and was used during laboratory demonstrations of the TME algorithms to demonstrate the formation and deformation of queues and the formation and deformation of speed harmonization regions upstream. Viewer results were shown in parallel with Nomadic Device Queue Ahead message displays and with TME Algorithm Queue Visualization Tool.

Source: Battelle

Figure 4-20. INFLO Database Map Viewer Displaying Vehicle BSM data with Queue Warning and Speed Harmonization Message Overlay on Satellite Image from Microsoft *Bing*®. Traffic is flowing Northbound or upwards in the figure.

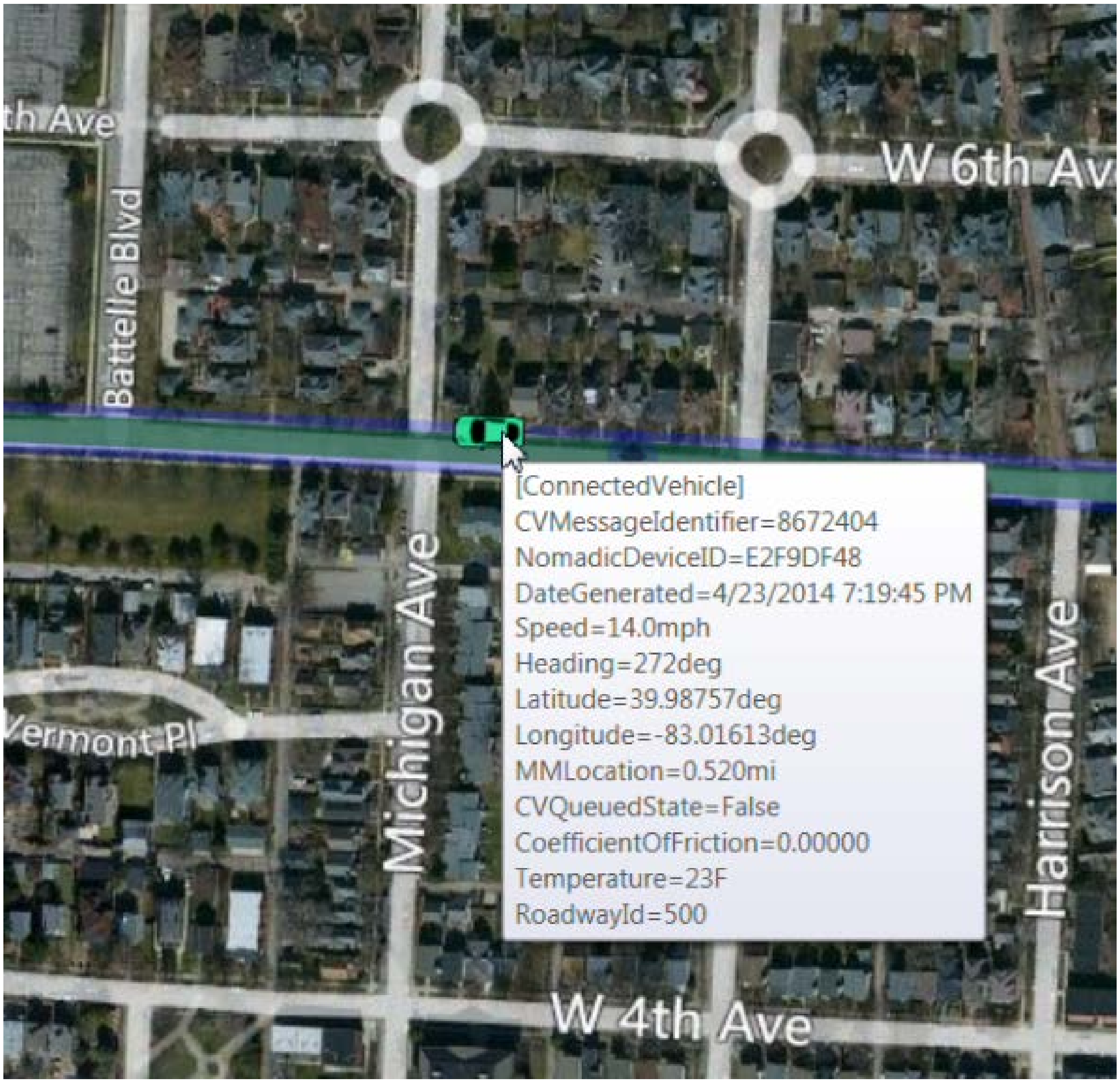
Source: Battelle

Figure 4-21. Medium Zoom View showing Queued Vehicles (Red) and Unqueued Vehicles (Green)



Source: Battelle

Figure 4-22. Close in Zoom Showing Database Vehicles (Red and Green) Overlaid on Satellite Image



Source: Battelle

Figure 4-23. Display of BSM Data for an Individual Vehicle in the Map Viewer[3]

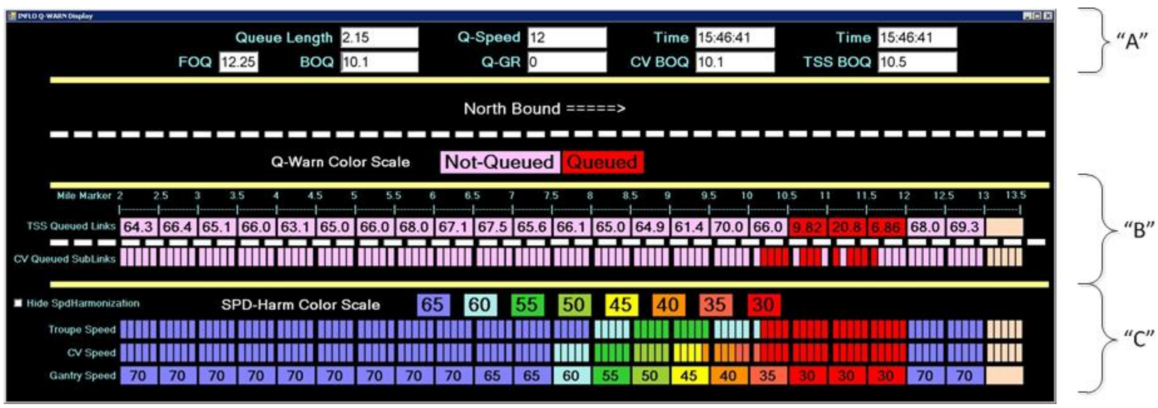
[3] Note Temperature =23C, coding error has been subsequently corrected.

TME Algorithm Queue Visualization Tool

To demonstrate the functionality of the algorithm, TTI developed the display shown in Figure 4-24. The display, which updates in real-time, shows the output of the decision processes coded in the TME algorithms. The display is separated into the following three parts:

- The content of the algorithm output sent to the message generator (labeled as part “A” in the diagram)
- The results of the queue detection/queue warning portion of the algorithm (labeled as part “B” in the diagram)
- The results of the speed harmonization portion of the algorithm (labeled as part “C” in the diagram).

Each section is separately described below.



Source: Battelle

Figure 4-24. TME Algorithm Display Tool showing Queue Parameters, Average Speed of Queued and Not-Queued Road Segments and Speed Harmization Recommendations

Algorithm Outputs

The top portion of the display (part “A”) shows the output results produced by the algorithms. These outputs represent the information that is passed to the message generation process for broadcast either to the connected vehicle or to infrastructure displays (e.g., dynamic message signs). This output includes the following:

- The mile marker location of the Front of the Queue (FOQ)
- The mile marker location of the Back of the Queues (BOQ)
- The length of the queue (Queue Length) in miles
- The average speed of travel in the queue (Q-Speed) in mph
- The average rate of grow of the queue (in miles per second)
- The mile marker location (CV BOQ) and the clock time (Time) of the Back of Queue determined using connected vehicle data only
- The mile marker location (TSS BOQ) and clock time (Time) of the Back of Queue as determined using the traffic sensor system data only.

Queue Warning Results

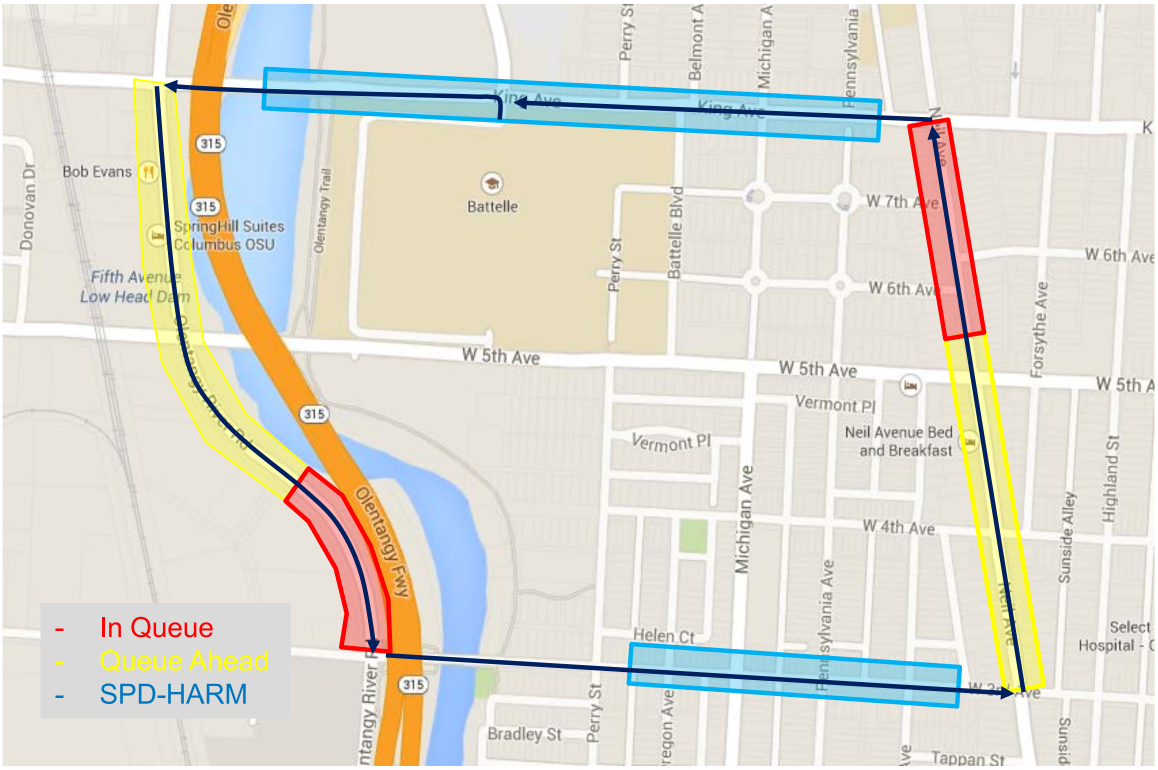
Part “B” of the display shows the results of the queue detection/queue warning process. The top row of boxes (labeled TSS Queued Links) shows the outcome of the queue detection process for each link using the TSS data, while the bottom row of boxes (labeled CV Queue Links) shows the outcome of the queue detection process for each sublink using the CV data. Links (and sublinks) that are determined to be in a queued state are shown in red while those links and sublinks that are determined to be in an un-queued sate are shown in lavender. Also shown on each link is the average speed as measured by the TSS detection systems. Links are determined to be in a queued state if the average link speed is less than 30 mph. Sublinks are determined to be in a queued state if 50 percent of the connected vehicles in those sublinks are reporting that they are in a queued state.

Speed Harmonization Results

Part “C” of the display shows the results of the speed harmonization process. Three speeds are displayed. The first speed is the Troupe Speed. This speed represents the unified speeds for each sublink after fusing link TSS speed and sublink CV data speed (calculated by averaging the speeds of all the connected vehicles in a sublink). Below the Troupe Speed is the CV Speed. The CV Speed is the recommended speed that is broadcast to the connected vehicle, while the Gantry speed represents the recommended speeds to be displayed on infrastructure based variable speed limit signs.

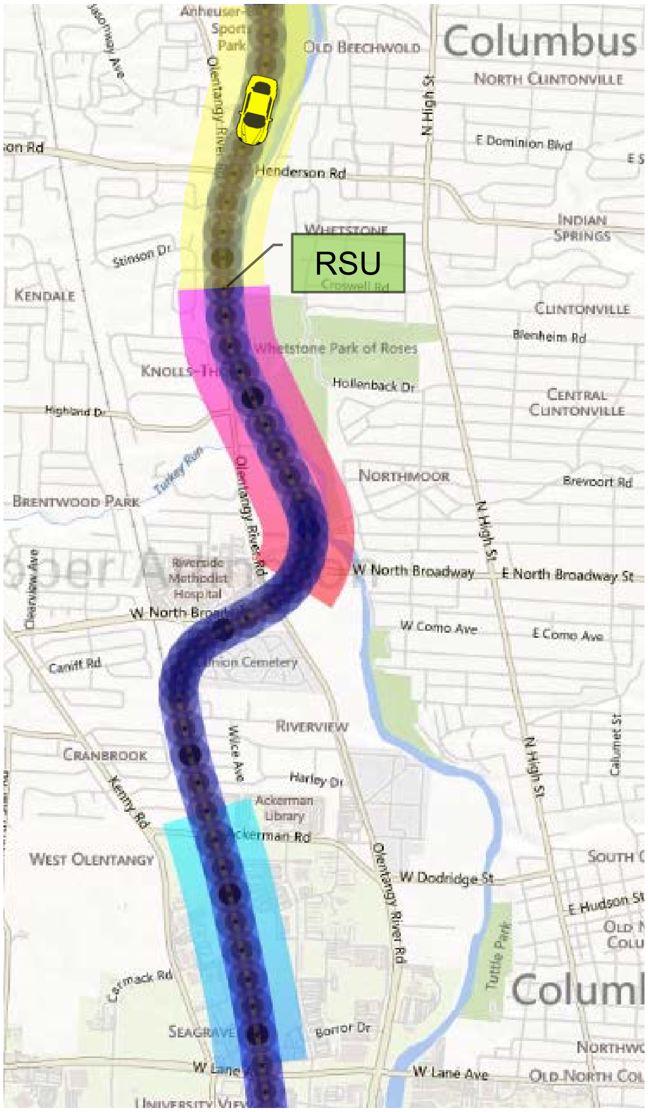
On-road and Closed Course Acceptance Test Routes

Key acceptance test criteria include demonstration that the Nomadic Device displays TME and other messages to drivers correctly on-road segments specified in the INFLO Database. Battelle routinely conducts testing and demonstration at low speeds on the local roads around Battelle and at highway speeds on nearby State Route 315. Figure 4-25 below illustrates the ‘Battelle Connected Vehicle Test Loop” with In-Queue, Queue Ahead and Speed Harmonization segments and where low speed testing and demonstrations were conducted. Figure 4-26 below illustrates the ‘State Highway 315 road segments with In-Queue, Queue Ahead and Speed Harmonization segments and where high speed testing and demonstrations were conducted. Figure 4-27 shows a satellite view of the Ohio DOT Delaware Test Pavement on US23 north of Columbus and Delaware Ohio, which has a four mile length of unused test pavement frontage road. With the permission of the ODOT, Battelle routinely uses the frontage road on both sides of US-23 for V2V and V2I DSRC application testing.



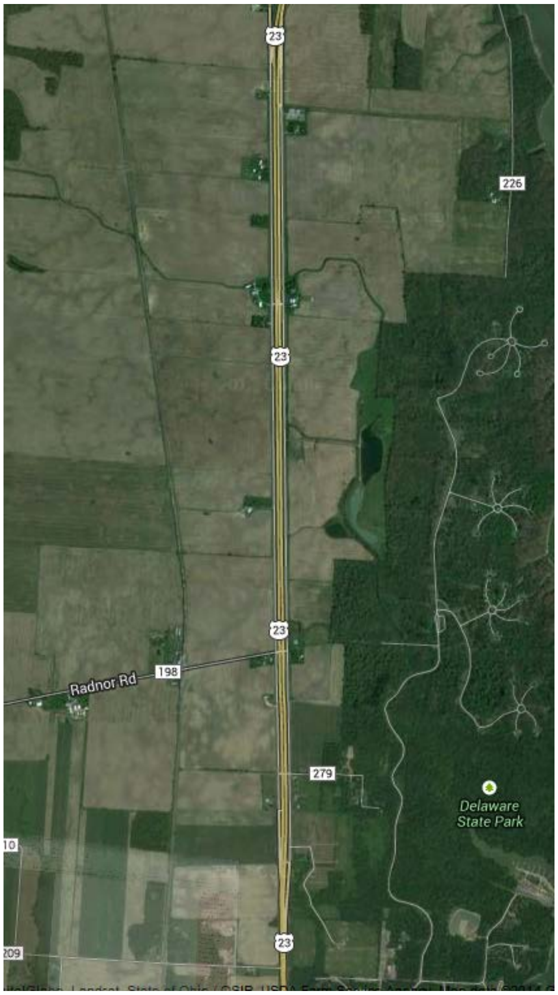
Source: Battelle

Figure 4-25. Map of the "Battelle Connected Vehicle Test Loop" used For Testing and Demonstrating INFLO and other Applications



Source: Battelle

Figure 4-26. Map of State Route 315 just North of Battelle used for Highway Speed Testing and Demonstrations of INFLO and Other Applications



Source: Battelle

Figure 4-27. Satellite Views of Ohio DOT Delaware Test Pavement on US-23 North of Columbus with Frontage Road Used for Testing and Demonstration of INFLO and other DSRC Applications

Chapter 5 Phase I Component Level Acceptance Test Summary

Phase I of the INFLO Prototype Acceptance Testing consisted of testing and verifying the functionality and performance if each of the components making up the INFLO System in the laboratory. This required testing the operational capabilities, data detection, retrieval and transmission capabilities, data logging capabilities and communication capabilities of each of the components. Many the components used in the development of INFLO Prototype were used by Battelle and others in the development and implementation of the systems deployed in Safety Pilot Model Deployment in 2012 and 2013 where their functionality and performance had been well established. Consequently, individual component test was completed quickly and often in conjunction with Phase II – System Integration Acceptance Testing. Furthermore, Phase II System Integration Acceptance Testing provides a more complete verification of the functionality and performance of each component. Consequently, Acceptance Test Demonstration of the component functionality for the U.S. DOT was performed as an integral part of the Phase II and Phase III Acceptance Test Demonstrations.

Table A-1 in Appendix A summarizes the component testing conducted in Phase I. Laboratory tests were conducted on the following components[4]:

- TC 1-01 – Connected Vehicle Nomadic Device Functionality
- TC 1-02 – Connected Vehicle Nomadic Device User Interface System (IU) Functionality
- TC 1-03 – Connected Vehicle Q-WARN Application Functionality
- TC 1-05 – Connected Vehicle Communication (CVC) System Functionality
- TC 1-06 – Connected Vehicle Weather System Functionality
- TC 1-07 – Integrated Vehicle Network Access System (INVAS) Communication
- TC 1-08 – Traffic Management Entity (TME) Functionality
- TC 1-09 – TME Q-WARN application Functionality
- TC 1-10 – TME SPD-HARM Application Functionality
- TC 1-11 – TME WRTM Application Functionality
- TC 1-12 – TME-Based Information Dissemination Sub-system (IDS) Functionality
- TC 1-13 – TME-based Communication System (CS) Functionality
- TC 1-14 – Roadside Equipment (RSE) Functionality

[4] Because the final implementation of SPD-HARM does not have a component resident on the vehicle, TC 1-04 – Connected Vehicle SPD-HARM Application Functionality was not performed.

Testing was conducted on each to verify, as appropriate:

- Operational Capabilities
    - Components ability to perform the function(s) required to support the integrated INFLO Prototype System delivery of messages to the driver where appropriate.
- Data Detection, Retrieval and Transmission Capabilities
    - Component's ability to retrieve required input data from the vehicle, the infrastructure and other components
    - Component's ability to obtain geographic location (road segment), vehicle location (direction of travel and heading), and vehicle speed characteristics when required
    - Component's ability to transmit output data to the vehicle, the driver and other components as required
- Data Logging Capabilities
    - Component's ability to log all alerts issued to driver and associated parameters
    - Component's ability to log all outbound messages generated by vehicle-based applications
    - Component's ability to log travel data (GPS position, timestamp, device and trip IDs)
- Communication Capabilities
    - Device's ability to communicate with other components, when required, to transmit required data, information and messages, data

For each test case, Table A-1 summarizes the

- Test Case Number
- Test Case Name
- Requirements Addressed
- Test Case Objectives
- Test Case Summary
- Test Case Pass/Fail Results
- System Level Validation (INFLO Application System Test)

Table A-1 identifies the INFLO Applications System Tests wherein the component functionality and performance was comprehensively tested and demonstrated.

Chapter 6 Phase IIa Communications and Messaging System Integration Acceptance Test Summary

Phase II testing in this program is focused on laboratory integration of the system components and verifying functionality and performance of the system using simulated vehicle and traffic data. Phase II is divided into two chapters for presentation and discussion purposes. This chapter describes the Phase II laboratory system communications and message acceptance tests which test, verify and demonstrates the functionality of interfaces, communications and transmission of messages between all mobile components and the INFLO Cloud Database. The next chapter describes the Phase II laboratory INFLO TME algorithm system acceptance tests which test, verify and demonstrate the functionality of interfaces, communications and transmission of messages between the INFLO Cloud Database and the TME, including application algorithms. The testing described in these two chapters represents testing and verification of the complete end-to-end INFLO system communications and messaging.

The testing described in this chapter is organized in two test cases:

- Q-WARN and SPD-HARM System Communications and Messaging Test Case
- V2V Q-WARN System Communications and Messaging Test Case

These two test cases test, verify and demonstrate the functionality of interfaces, communications and transmission of messages via between all mobile components and the INFLO Cloud Database.

Q-WARN and SPD-HARM System Communications and Messaging Test Case

Test Case Summary

In this Test Case, the INFLO Cloud Database is prepopulated with TME-based Q-WARN and SPD-HARM messages for a predetermined route for north and southbound travel on State Highway 315. A nomadic device is fed GPS data simulating travel along the highway. TME-Based Q-WARN and SPD-HARM Messages are delivered to the nomadic device via DSRC through the RSU and via cellular communications when the RSU is turned off. Researchers verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when travel is simulated in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when travel in the opposite direction.

Test Case Objective

This Acceptance Test demonstrates the functionality of TME-based Q-WARN and SPD-HARM messaging from the Cloud Database to the Nomadic Devices via DSRC communications through the RSU and through cellular communications when DSRC is not available. This Test Case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that the TME System Elements are operational
- Verifies that when a *simulated* queue is created, the following occurs:
  - TME-based Q-WARN is disseminating the queue strategies to connected vehicle network
  - TME-based SPD-HARM is disseminating target speed recommendations to connected vehicles

Requirements Verified

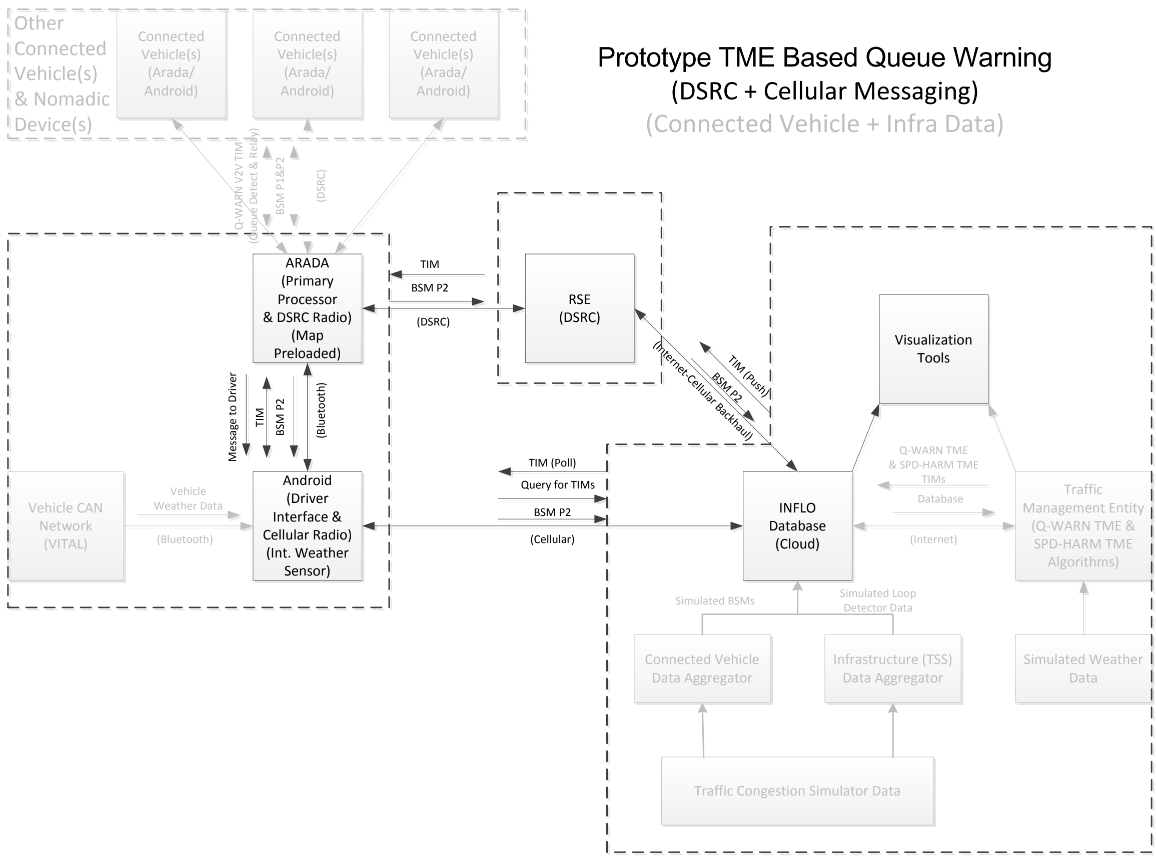
Appendix C details the INFLO System Requirements and the INFLO Application Acceptance Test wherein each requirement is verified.

Requirements verified through TME-Based Q-WARN testing include 1.8.5, 1.9, 1.9.1, 1.9.2, 1.9.3, 1.9.5, 2.4, 2.5, 2.7, 3.1, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.16, 5.3, 8.14, 8.16, 8.17, 8.18, 8.22, 10.1, 10.2, 10.3, 10.5, 10.6, 10.7, 10.8, 10.10, 10.11, 10.12, 10.17, 10.18, 10.19, 10.20, 10.22, 14.2, 16.1, 16.2, 16.4, 17.1, and 17.2.

Requirements verified through TME-Based SPD-HARM with WRTM testing include: 1.1, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.8.1, 1.8.2., 1.8.3, 1.10, 1.11, 1.12, 1.13, 1.19, 2.1, 2.3, 2.7, 4.1, 4.3, 4.5, 4.6, 4.8, 4.11, 4.12, 5.4, 5.8, 6.1, 6.4, 6.6, 7.2, 8.5, 8.6, 8.7, 8.8.1, 8.8.2, 8.8.3, 8.8.4, 8.8.5, 8.8.6, 8.9, 8.9.6, 8.9.7, 8.12, 8.13, 8.15, 8.16, 8.17, 8.18, 8.19, 8.20, 8.21, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.12, 11.13, 11.14, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 12.6, 12.7, 12.10, 13.1, 13.2, 14.4, 14.5, 14.6, 14.7, 15.1, 15.2, 15.3, 16.1, 16.2, 17.1, and 17.2.

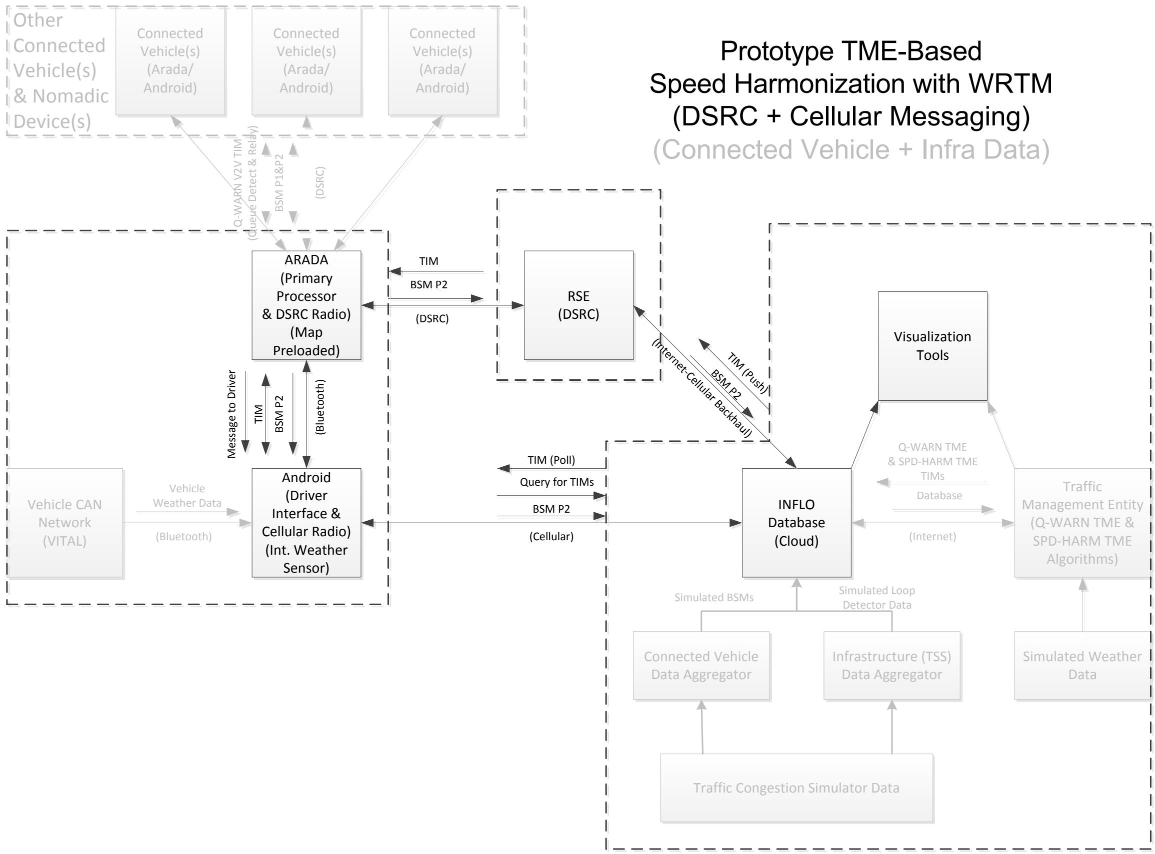
Test Case System Configuration

The INFLO System configuration for Q-WARN System Communications and Messaging Test Case is shown in Figure 6-1. The INFLO System configuration for SPD-HARM System Communications and Messaging Test Case is shown in Figure 6-2.



Source: Battelle

Figure 6-1. Prototype INFLO System Configuration Used in TME-Based Queue Warning Laboratory Testing



Source: Battelle

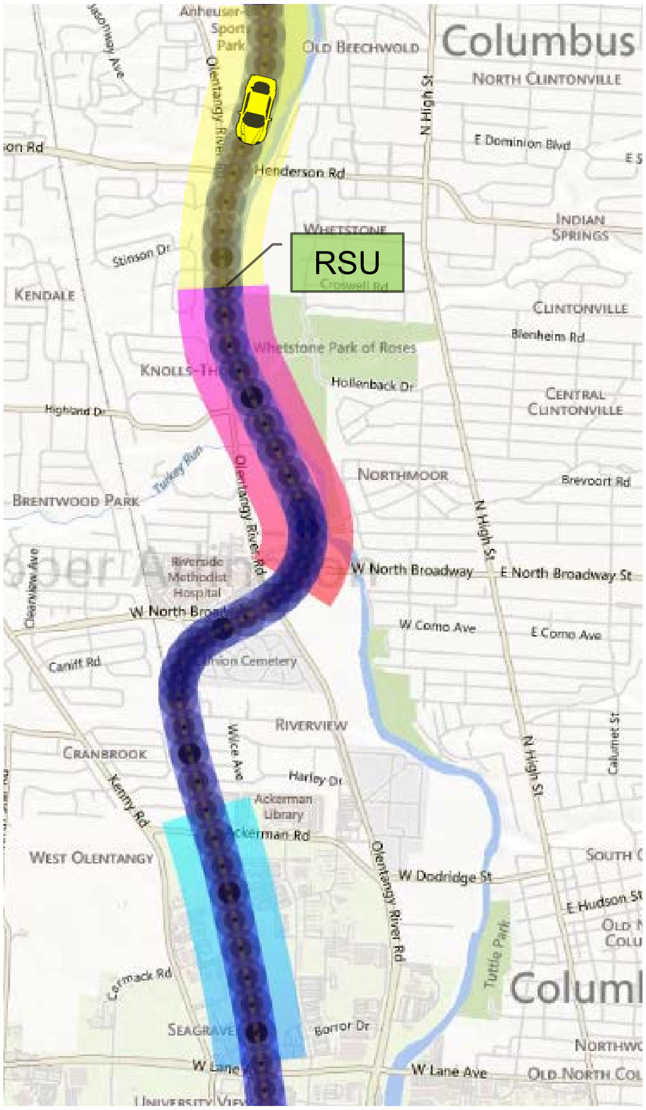
Figure 6-2. Prototype INFLO System Configuration Used in TME-Based Speed Harmonization Laboratory Testing

Test Case Location

Battelle Connected Vehicle Laboratory. U.S. DOT Acceptance Test Demonstration conducted in Visitor Conference Room.

Test Case Setup (Route and Messaging)

The simulated routes traveled during this Prototype Pilot Acceptance Test are illustrated in Figure 6-3, Figure 6-5, and Figure 6-6 below along with color coding to show the location of messages populated in the INFLO Database. Figure 6-3 shows the simulated southbound vehicle location when it displays the Queue Ahead Message indicated by yellow shading. The simulated RSU location is ahead of the vehicle at the boundary between the Queue Ahead and In-Queue messages. Figure 6-4 shows the simulated southbound vehicle location when it displays the In-Queue message indicated by red shading. Figure 6-5 shows the simulated southbound vehicle location when it displays the Speed Harmonization Queue message indicated by light blue shading. The simulated RSU location for this message is at the end of the Speed Harmonization location. Figure 6-6 shows the simulated northbound vehicle location when it displays both the Speed Harmonization and Queue Ahead messages simultaneously, indicated by both yellow and light blue shading.



Source: Battelle

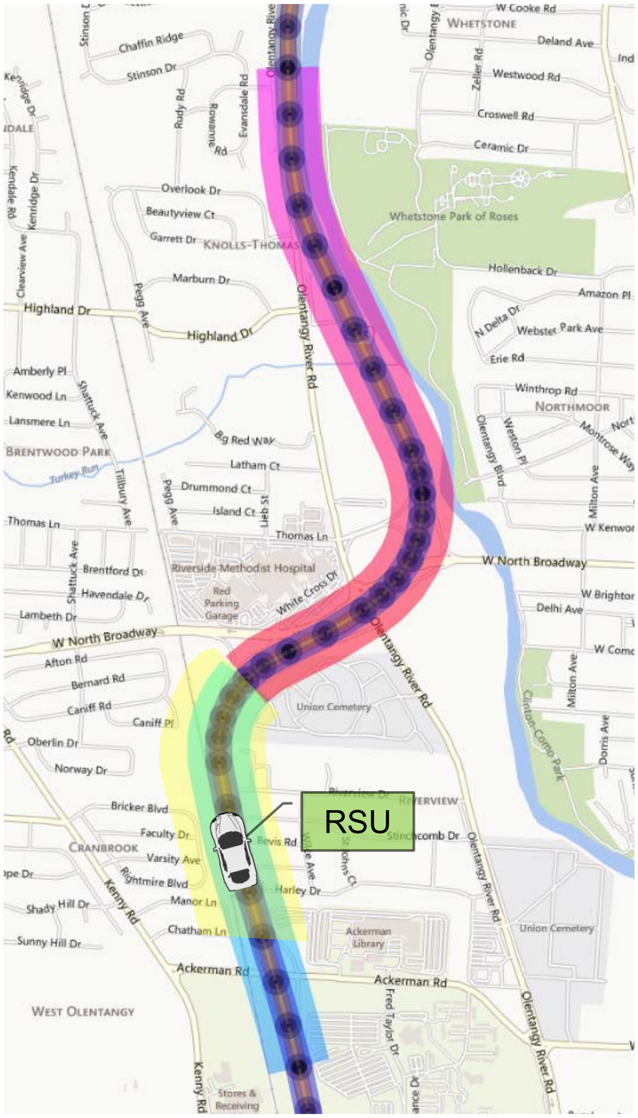
Figure 6-3. Simulated Travel Route Used for Queue Warning and Speed Harmonization Laboratory Testing with Vehicle in the Queue Ahead Message Region

Source: Battelle

Figure 6-4. Simulated Travel Route Used for Queue Warning and Speed Harmonization Laboratory Testing with Vehicle in In-Queue Message Region

Source: Battelle

Figure 6-5. Simulated Travel Route Used for Queue Warning and Speed Harmonization Laboratory Testing with Vehicle in Speed Harm Message Region



Source: Battelle

Figure 6-6. Simulated Travel Route Used for Queue Warning and Speed Harmonization Laboratory Testing with Vehicle in Queue Ahead and Speed Harmonization Message Region

Test Case Pass/Fail Criterion

Researchers must verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when travel is simulated in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling is simulated in the opposite direction.

Test Case Procedure Summary

- The Cloud Database is prepopulated with TME-based Q-WARN and SPD-HARM messages for a predetermined route north and southbound travel on State Highway 315.
- A nomadic device is fed GPS data simulating travel along State Highway 315. TME-Based Q-WARN and SPD-HARM Messages are delivered to the nomadic device via DSRC through the RSU.
- A nomadic device is fed GPS data simulating travel along State Highway 315. TME-Based Q-WARN and SPD-HARM Messages are delivered to the nomadic device via cellular communications when the RSU is off.
- Researchers verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when travel is simulated in the specified direction.
- Researcher also confirmed that the messages are received, but not displayed to the driver when traveling is simulated in the opposite direction.

Test Case Results

Researchers first confirmed that TME-based Q-WARN and SPD-HARM messages were received via DSRC and displayed correctly for both northbound and southbound travel during at least ten simulated circuits of each. The test series was repeating using cellular communications. The messages received were similar to those displayed in Figure 4-7 through Figure 4-10. The messages were shown on the Samsung Driver Display and the location where they were displayed was shown on the Database Visualization Tool.

The operations of the prototype algorithm were demonstrated to FHWA as part of the INFLO Demonstration Workshop held in Columbus, OH May 6-7 as illustrated in Figure 6-7.

Source: Battelle

Figure 6-7. Conference Room Demonstration of Laboratory Communications Testing (Arada Diagnostic Screen Shown on TV, RSU in Background)

Anomalies or Discrepancies Observed

No discrepancies or anomalies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This Q-WARN and SPD-HARM DSRC System Communications and Messaging was successfully demonstrated to U.S. DOT and stakeholder observers in the Conference Room Presentation on May 6, 2014.

V2V Q-WARN System Communications and Messaging Test Case

Test Case Summary

In this Phase II System Integration Acceptance Test Case, simulated GPS data is fed to multiple nomadic devices simulating travel approaching a queue. The second simulated vehicle approaches a stopped vehicle, and determines that it is in a queue and issues a message indicating it is queued. A following simulated vehicle approaches from the same direction and issues a Queue Ahead message to the driver. A fourth simulated vehicle approaching from the opposite direction does not display a message. Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is simulated in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling is simulated in the opposite direction.

Test Case Objective

This Acceptance Test demonstrates the functionality of V2V DSRC based Queue detection and Queue warning in the laboratory environment as well as interfaces communication and messaging. This Test Case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that when a simulated queue is created, the following occurs:
  - CV-based Q-WARN is detecting roadway location and queue state and passing information to other connected vehicles and infrastructure
  - CV-based Q-WARN is providing recommendations to the User Interface which is communicating with driver
  - CV-based Q-WARN is disseminating queue status alerts and information to other connected vehicles

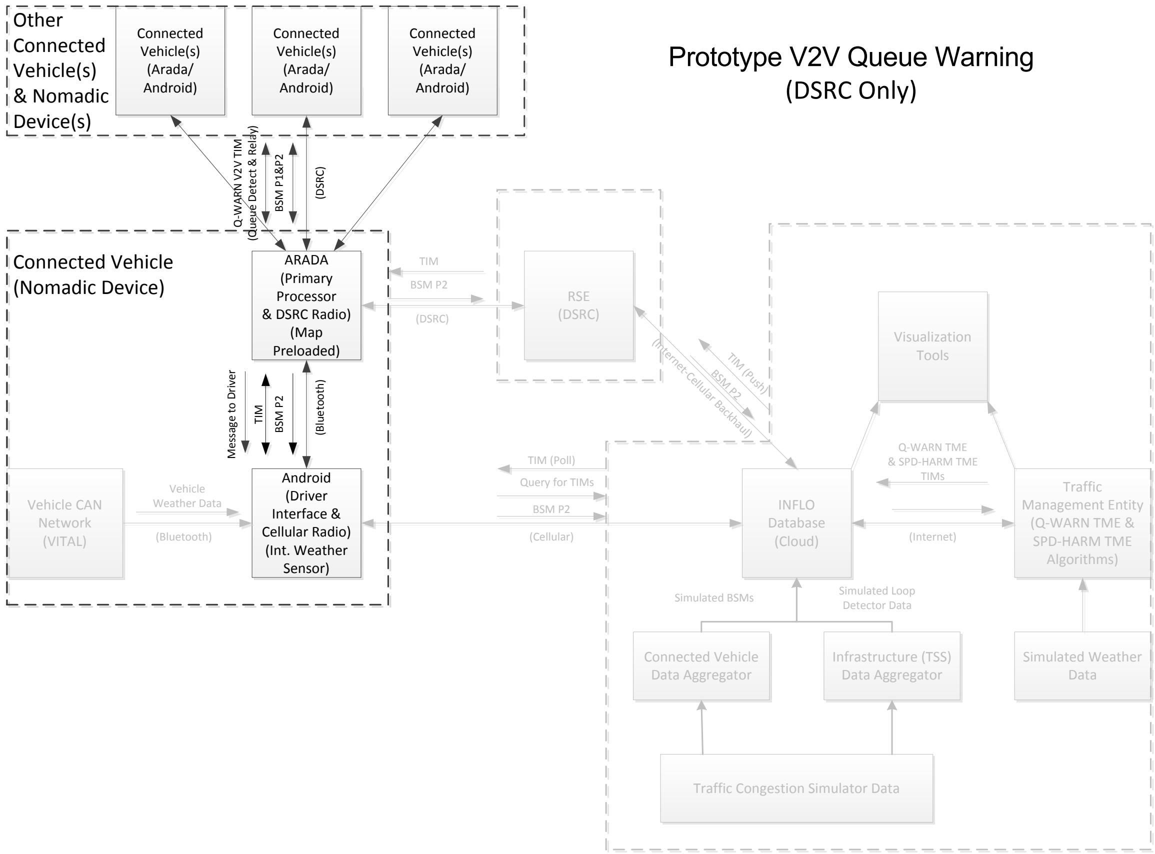
Requirements Verified

Appendix C details the INFLO System Requirements and the INFLO Application Acceptance test wherein each requirement is verified.

Requirements verified through V2V Q-WARN testing include 1.1, 1.4, 1.5, 2.4, 2.5, 2.7, 3.2, 3.4, 3.5, 3.7, 3.8, 3.10, 3.15, 5.1, and 5.2.

Test Case System Configuration

The INFLO System configuration for this Prototype Pilot Acceptance Test Case is shown in Figure 6-8 below.



Source: Battelle

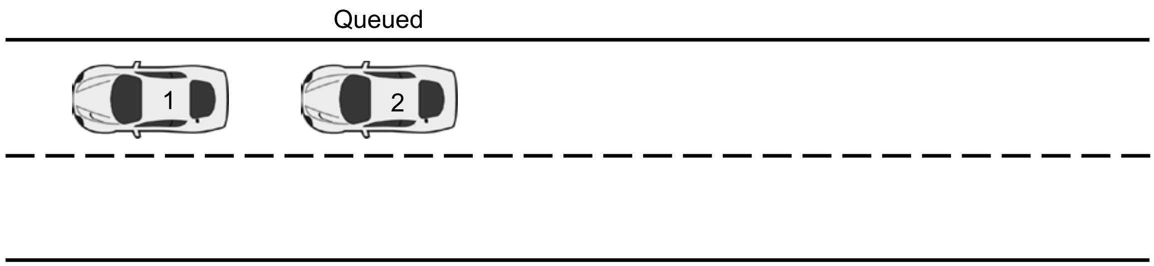
Figure 6-8. Prototype INFLO System Configuration Used in V2V Queue Warning Laboratory Testing

Test Case Location

Battelle Connected Vehicle Laboratory. U.S. DOT Acceptance Test Demonstration conducted in Visitor Conference Room.

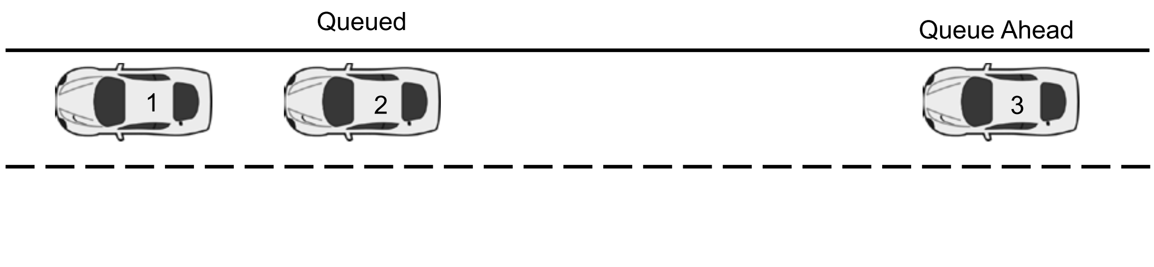
Test Case Setup (Route and Messaging)

The simulated route traveled during this Prototype Pilot Acceptance Test is illustrated in Figure 6-9, Figure 6-10, and Figure 6-11. Figure 6-9 illustrates the configuration when vehicle/nomadic device 7 approaches vehicle/nomadic device 6 and determines that it is queued. Figure 6-10 illustrates the configuration when vehicle/nomadic device 8 approaches, receives the vehicle queued message and delivers the Queue Ahead message to the driver. Figure 6-11 illustrates the configuration when vehicle/nomadic device 9 approaches from the opposite direction, receives the vehicle queued message and *does not* deliver the Queue Ahead message to the driver.



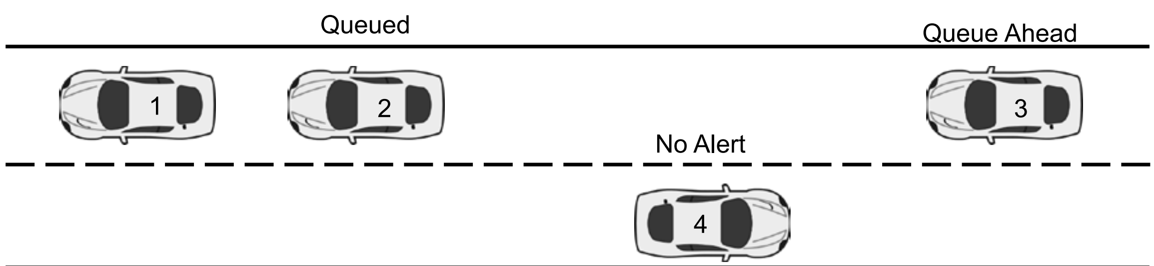
Source: Battelle

Figure 6-9. Simulated Vehicle/Nomadic Device Configuration for DSRC Based Queue Detection



Source: Battelle

Figure 6-10. Simulated Vehicle/Nomadic Device Configuration for DSRC Based Communication of Queue Ahead



Source: Battelle

Figure 6-11. Simulated Vehicle/Nomadic Device Configuration for Verification that Message is not displayed to Vehicles Traveling in the Opposite Direction.

Test Case Pass/Fail Criterion

Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is simulated in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling is simulated in the opposite direction.

Test Case Procedure Summary

- Simulated GPS data is fed to multiple nomadic devices simulating travel approaching a queue.
- The second simulated vehicle approaches a stopped vehicle, and determines that it is in a queue and issues a message indicating it is queued.
- A following simulated vehicle approaches from the same direction and issues a Queue Ahead message to the driver.
- A fourth simulated vehicle approaching from the opposite direction does not display a message.

Test Case Results

Researchers first confirmed that vehicle/nomadic device 7 correctly detects that it is queued and issues a Queue Ahead message. Researchers then confirmed that vehicle/nomadic device 8 received and displayed the message on the Samsung Driver Display correctly for at least ten simulated trials. They also confirmed that the message was not received on vehicle/nomadic device 9. Messages received were similar to those shown in Figure 4-5 and Figure 4-6.

Anomalies or Discrepancies Observed

No discrepancies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This laboratory based Prototype Pilot Acceptance Test Case was successfully demonstrated to U.S. DOT and stakeholder observers in the Conference Room Presentation on May 6, 2014.

Chapter 7 Phase IIb TME-Based Application System Integration Acceptance Test Summary

As the second of two chapters pertaining to Phase II Laboratory Level System Testing this chapter describes the Phase II Laboratory Level INFLO TME Algorithm and System Acceptance Tests which test, verify and demonstrate the functionality of interfaces, communications and transmission of messages between the INFLO Cloud Database and the TME, including application algorithms. The testing described in this and the previous chapter represents testing and verification of the complete INFLO system, end-to-end.

The testing described in this chapter is organized in a single integrated test case

- Q-WARN and SPD-HARM Algorithm System Integration Test Case

In this single test case simulated traffic congestion data is fed into the INFLO Database as the rate that would be expected from Infrastructure-based and connected vehicle-based data collection systems. The algorithms are applied to detect and measure queue formation and evolution and to recommend speed harmonization results. The results are displayed visually.

Q-WARN and SPD-HARM Algorithm System Integration Test Case

Test Case Summary

In this single test case simulated traffic congestion data is fed into the INFLO Database at the rate that would be expected from Infrastructure-based and connected vehicle-based data collection systems. The algorithms are applied to detect and measure queue formation and evolution and to recommend speed harmonization results. The results are displayed visually. Four scenarios are illustrated.

- Queue warning with speed harmonization using TSS data and 100 percent connected vehicles.
- Queue warning with speed harmonization using TSS data only.
- Queue warning with speed harmonization using CV data only at 100 percent connected vehicles. (Cloud Based Queue Warning)
- Queue warning with speed harmonization using TSS data and 50 percent connected vehicles.
- Speed harmonization in response to the formation of a shockwave

Test Case Objective

This test case illustrates the ability of the TME-based Queue Warning and Speed Harmonization algorithms to obtain infrastructure-based and connected vehicle-based data from the INFLO database, analyze and process the data, and then transmit Queue Warning and Speed Harmonization messages in the database for display to the drivers. This Test Case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that the TME System Elements are operational
- Verifies that when a simulated queue is created, the following occurs:
  - TME-based Q-WARN is receiving real-time conditions and queue information from various sources and fusing and processing the data to generate queue response strategies
  - TME-based Q-WARN is disseminating the queue strategies to connected vehicle network
  - TME-based SPD-HARM is receiving real-time traffic, road, and weather conditions from various sources and fusing and processing data to calculate speed target recommendations
  - TME-based SPD-HARM is disseminating target speed recommendations to connected vehicles and DMS locations

Requirements Verified

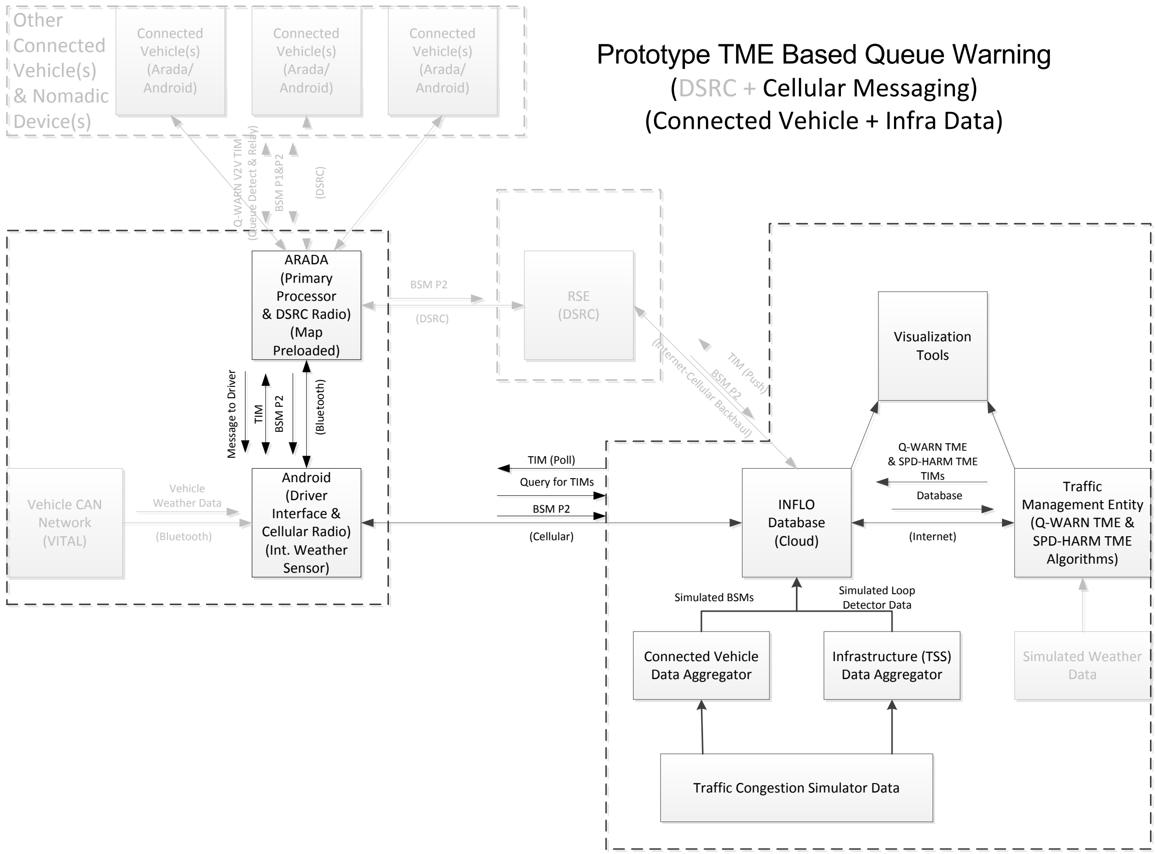
Appendix C details the INFLO System Requirements and the INFLO Application Acceptance test wherein each requirement is verified.

Requirements verified through TME-Based Q-WARN testing include 1.8.5, 1.9, 1.9.1, 1.9.2, 1.9.3, 1.9.5, 2.4, 2.5, 2.7, 3.1, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.16, 5.3, 8.14, 8.16, 8.17, 8.18, 8.22, 10.1, 10.2, 10.3, 10.5, 10.6, 10.7, 10.8, 10.10, 10.11, 10.12, 10.17, 10.18, 10.19, 10.20, 10.22, 14.2, 16.1, 16.2, 16.4, 17.1, and 17.2.

Requirements verified through TME-Based SPD-HARM with WRTM testing include: 1.1, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.8.1, 1.8.2., 1.8.3, 1.10, 1.11, 1.12, 1.13, 1.19, 2.1, 2.3, 2.7, 4.1, 4.3, 4.5, 4.6, 4.8, 4.11, 4.12, 5.4, 5.8, 6.1, 6.4, 6.6, 7.2, 8.5, 8.6, 8.7, 8.8.1, 8.8.2, 8.8.3, 8.8.4, 8.8.5, 8.8.6, 8.9, 8.9.6, 8.9.7, 8.12, 8.13, 8.15, 8.16, 8.17, 8.18, 8.19, 8.20, 8.21, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.12, 11.13, 11.14, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 12.6, 12.7, 12.10, 13.1, 13.2, 14.4, 14.5, 14.6, 14.7, 15.1, 15.2, 15.3, 16.1, 16.2, 17.1, and 17.2

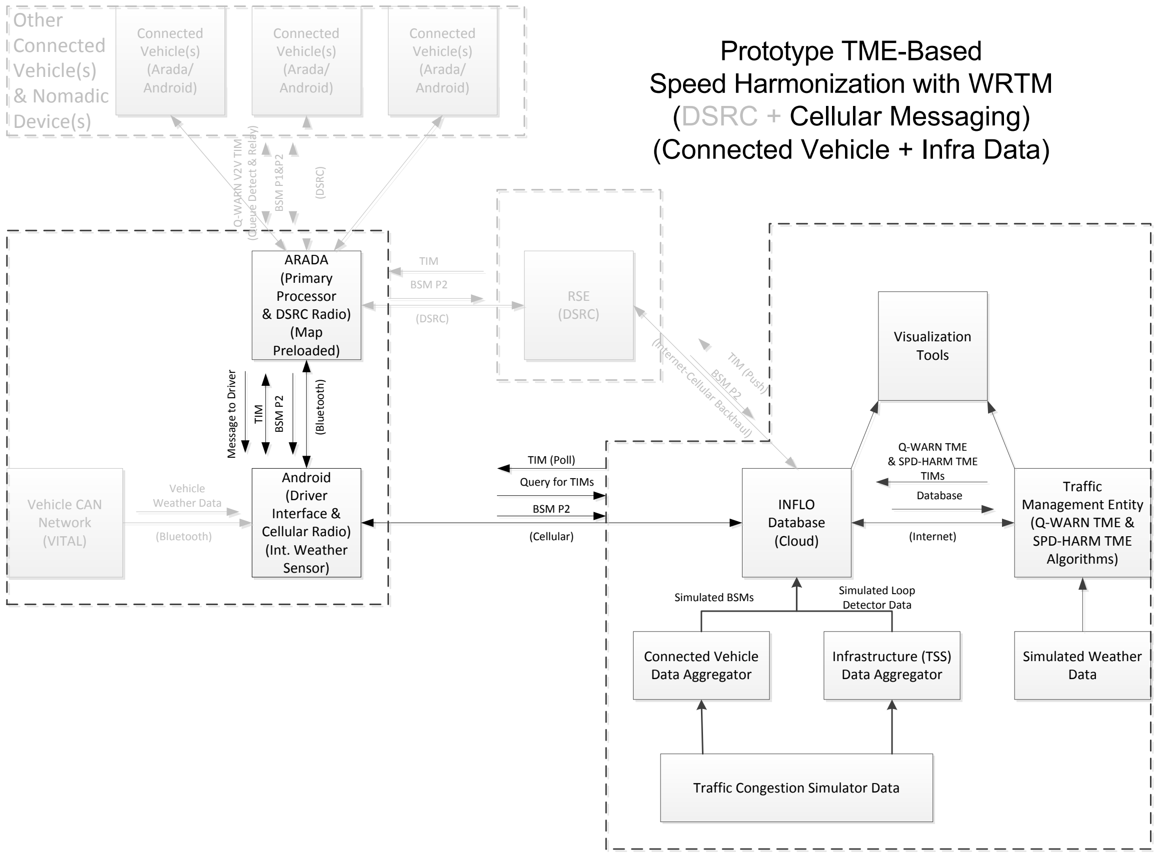
Test Case System Configuration

The INFLO System configuration for this Q-WARN and SPD-HARM Algorithm and System Test Case is shown in Figure 7-1 and Figure 7-2 below. Figure 7-3 illustrates the configuration for Cloud-Based Q-WARN in which no infrastructure data or infrastructure communications (DSRC) are utilized.



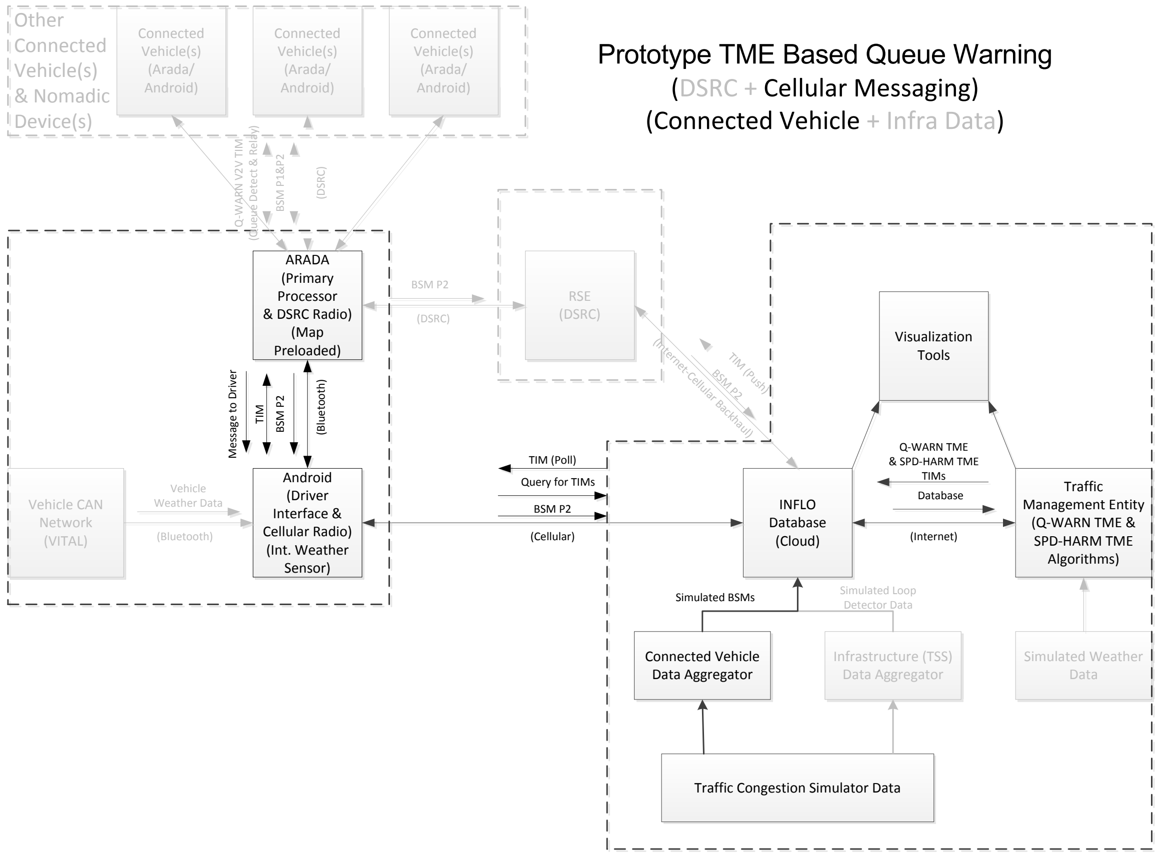
Source: Battelle

Figure 7-1. Prototype INFLO System Configuration Used in Laboratory TME-Based Queue Warning Testing



Source: Battelle

Figure 7-2. Prototype INFLO System Configuration Used in Laboratory TME-Based Speed Harmonization Testing



Source: Battelle

Figure 7-3. Prototype INFLO System Configuration Used in Laboratory Cloud-Based Queue Warning Testing

Test Case Location

TTI Connected Vehicle Laboratory. U.S. DOT Acceptance Test Demonstration conducted in Battelle Visitor Conference Room on May 6, 2014.

Test Case Setup (Route and Messaging)

The route is that described under Traffic Simulation Data in Chapter 4 Prototype Pilot System Test Components and Test Configuration. For the purposes of generating the data used for the testing, a seventeen mile section of two-lane freeway was coded into VISSIM. The section of freeway was coded as a two-lane freeway with no entrance and exit ramps. A land closure bottleneck was coded for the right lane at Mile marker 12.25. The capacity of the bottleneck was coded to be 1900 vehicles per hour. Traffic sensors were “installed” at half mile intervals, beginning at Mile marker 2.0 through Mile marker 13.0.

Test Case Pass/Fail Criteria

Researchers verify that the algorithm was successful at accomplishing the following:

- Obtaining and using traffic stream data from multiple sources (e.g., traffic sensor system, connected vehicles, and weather) in assessing the current operating state of a facility
- Detecting the formation and propagation of the queue upstream from a known bottleneck location
- Providing specific information about the queue such as the current location of the back of the queue, the estimated length of the queue, the average travel speed of vehicle in the queue, and the rate of growth of the queue,
- Providing recommended speeds upstream of the back of queue to provide a smooth reduction in speed to the queue
- Providing infrastructure-based and vehicle-based speed recommendation that were not in conflict with one another.
- Detecting the formation and presence of shockwaves in the traffic data stream
- Providing recommended speed reduction in response to the formation of a shockwave
- Providing recommended speed reduction in response to weather conditions (visibility and road surface conditions)
- Generating messages to be broadcast to the connected vehicles in order for the vehicle to generate queue warning messages specific to that vehicle.

Test Case Procedure Summary

Simulated traffic congestion data is fed into the INFLO Database as the rate that would be expected from Infrastructure-based and connected vehicle-based data collection systems. The algorithms are applied to detect and measure queue formation and evolution and to recommend speed harmonization results. The results are displayed visually through the TME Algorithm Queue Visualization Tool described in Chapter 4.

Test Case Results

The TTI research team demonstrated the following operation of the prototype algorithms:

- Queue warning with speed harmonization using TSS data and 100 percent connected vehicles.
- Queue warning with speed harmonization using TSS data only.
- Queue warning with speed harmonization using CV data only at 100 percent connected vehicles.
- Queue warning with speed harmonization using TSS data and 50 percent connected vehicles.
- Speed harmonization in response to the formation of a shockwave.

In each of the scenarios, the results of the demonstration showed that the algorithms were successful at meeting all Test Case Pass/Fail Criteria listed above.

The results of the Q-WARN and SPD-HARM Algorithm System Integration Test Case were captured and presented in AVI video files provided under separate cover.

Anomalies or Discrepancies Observed

No discrepancies or anomalies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This Q-WARN and SPD-HARM Algorithm System Acceptance Test Case was successfully demonstrated to U.S. DOT and stakeholder observers in the Conference Room Presentation on May 6, 2014.

Chapter 8 Phase III INFLO Prototype Pilot System Acceptance Test Summary

Phase III testing in this program focused on vehicle based on-road and closed-course testing and verification of functionality and performance of the system. This chapter describes the Phase III on-road system communications and message acceptance tests which test, verify, and demonstrate the functionality of interfaces, communications and transmission of messages between traveling mobile components and the INFLO Cloud Database. When combined with the results of the previous chapter demonstrating TME and INFLO Database functionality, these two chapters represent testing and verification of the functionality of the complete INFLO system, end-to-end using both DSRC and cellular communications.

The testing described in this chapter is organized in three test cases

- On-road Low Speed TME-Based Q-WARN and SPD-HARM Test Case
- On-road High Speed TME-Based Q-WARN and SPD-HARM Test Case
- V2V Queue Warning Test Case

The first two test cases test, verify and demonstrate the functionality of interfaces, communications and transmission of messages via cellular communications between all mobile components and the INFLO Cloud Database. The last test case demonstrates on-road communications and transmission of messages via DSRC between all mobile components. This testing also demonstrated mobile V2I DSRC communications between vehicles and the RSE.

On-road Low Speed TME-Based Q-WARN and SPD-HARM Test Case

Test Case Summary

In this Prototype Pilot Acceptance Test Case, the INFLO Database is prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route around Battelle operating in live traffic at speeds from 0 to 15 miles per hour, through multiple signalized intersections. Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Objective

This Acceptance Test demonstrates the functionality of TME-based Q-WARN and SPD-HARM messaging from the INFLO Database to the Nomadic Devices when traveling at low speeds. This test case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that the TME System Elements are operational
- Verifies that when a queue is created in the field, the following occurs:
    - TME-based Q-WARN is disseminating the queue strategies to connected vehicle network
    - TME-based SPD-HARM is disseminating target speed recommendations to connected vehicles

Requirements Verified

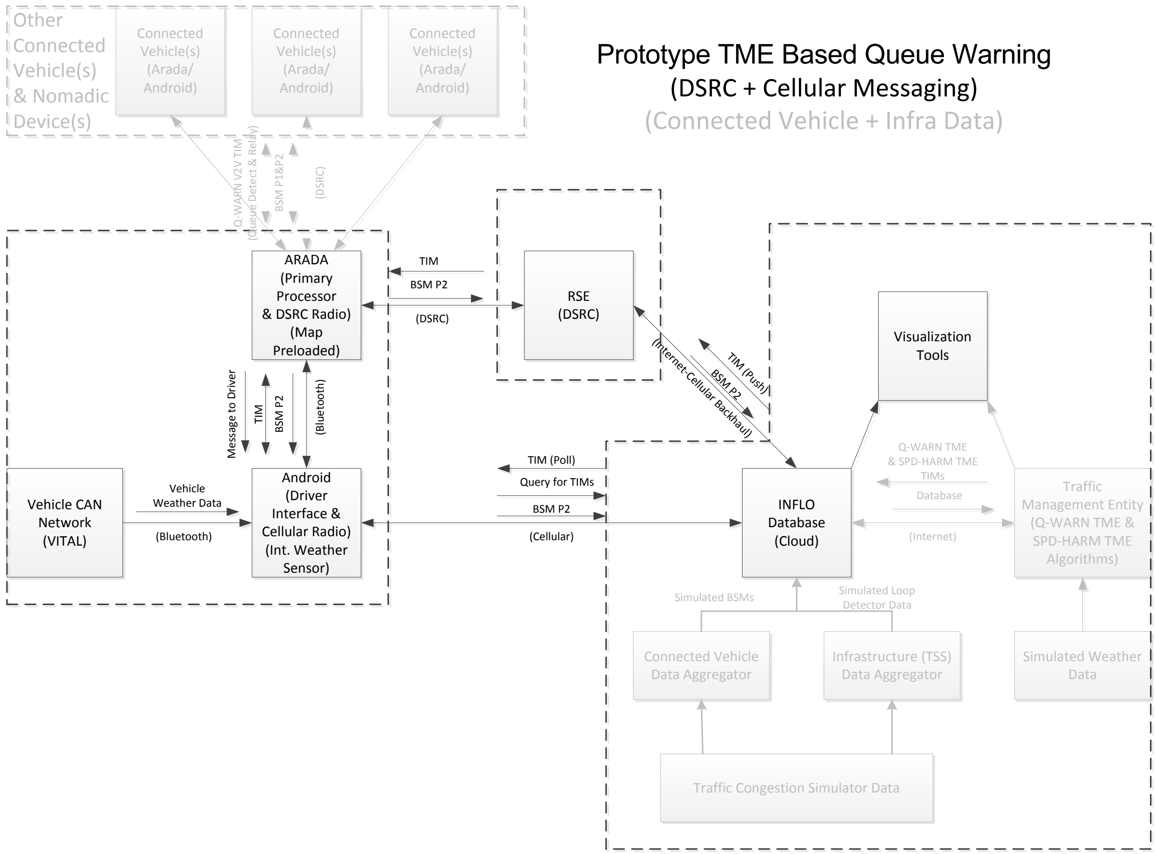
Appendix C details the INFLO System Requirements and the INFLO Application Acceptance test wherein each requirement is verified.

Requirements verified through TME-Based Q-WARN testing include 1.8.5, 1.9, 1.9.1, 1.9.2, 1.9.3, 1.9.5, 2.4, 2.5, 2.7, 3.1, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.16, 5.3, 8.14, 8.16, 8.17, 8.18, 8.22, 10.1, 10.2, 10.3, 10.5, 10.6, 10.7, 10.8, 10.10, 10.11, 10.12, 10.17, 10.18, 10.19, 10.20, 10.22, 14.2, 16.1, 16.2, 16.4, 17.1, and 17.2.

Requirements verified through TME-Based SPD-HARM with WRTM testing include: 1.1, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.8.1, 1.8.2., 1.8.3, 1.10, 1.11, 1.12, 1.13, 1.19, 2.1, 2.3, 2.7, 4.1, 4.3, 4.5, 4.6, 4.8, 4.11, 4.12, 5.4, 5.8, 6.1, 6.4, 6.6, 7.2, 8.5, 8.6, 8.7, 8.8.1, 8.8.2, 8.8.3, 8.8.4, 8.8.5, 8.8.6, 8.9, 8.9.6, 8.9.7, 8.12, 8.13, 8.15, 8.16, 8.17, 8.18, 8.19, 8.20, 8.21, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.12, 11.13, 11.14, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 12.6, 12.7, 12.10, 13.1, 13.2, 14.4, 14.5, 14.6, 14.7, 15.1, 15.2, 15.3, 16.1, 16.2, 17.1, and 17.2.

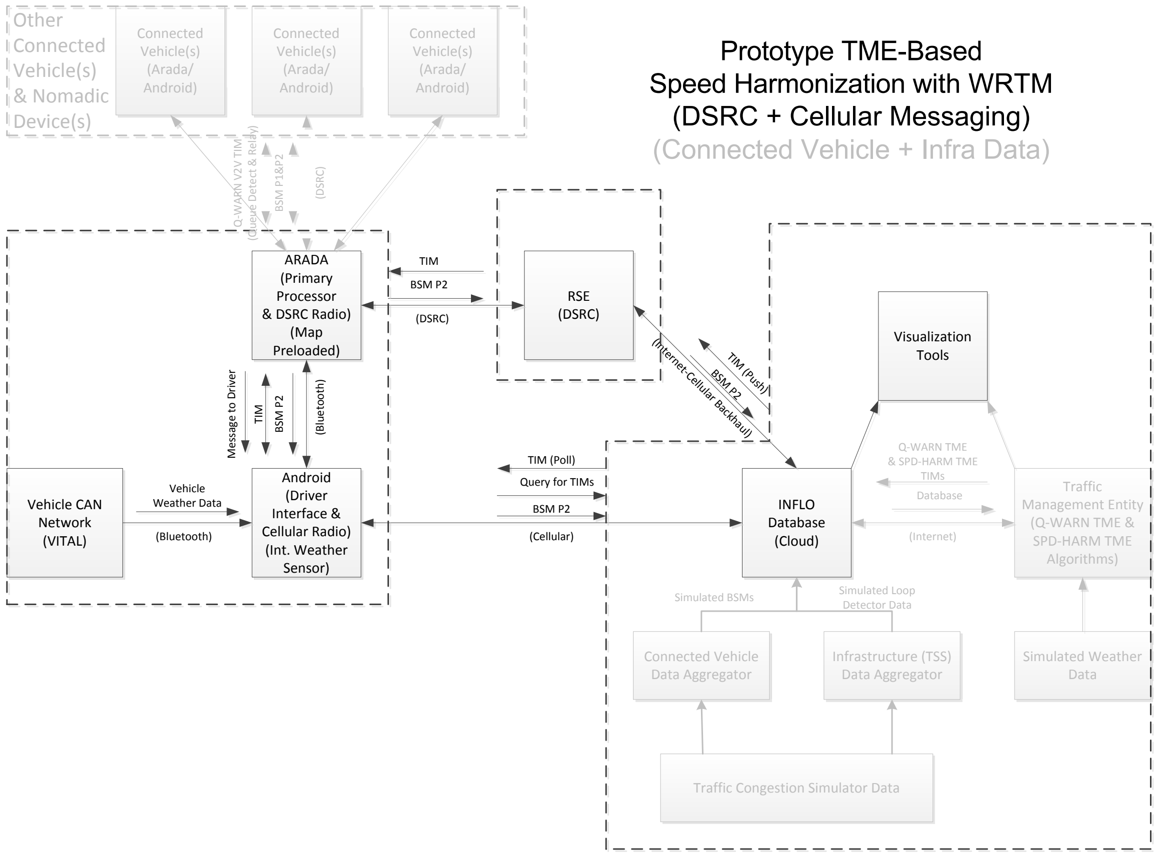
Test Case System Configuration

The INFLO System configuration for this Prototype Pilot Acceptance Test Case is shown in Figure 8-1, and Figure 8-2 below.



Source: Battelle

Figure 8-1. Prototype INFLO System Configuration Used in TME-Based Queue Warning On-road Testing



Source: Battelle

Figure 8-2. Prototype INFLO System Configuration Used in TME-Based Speed Harmonization On-road Testing

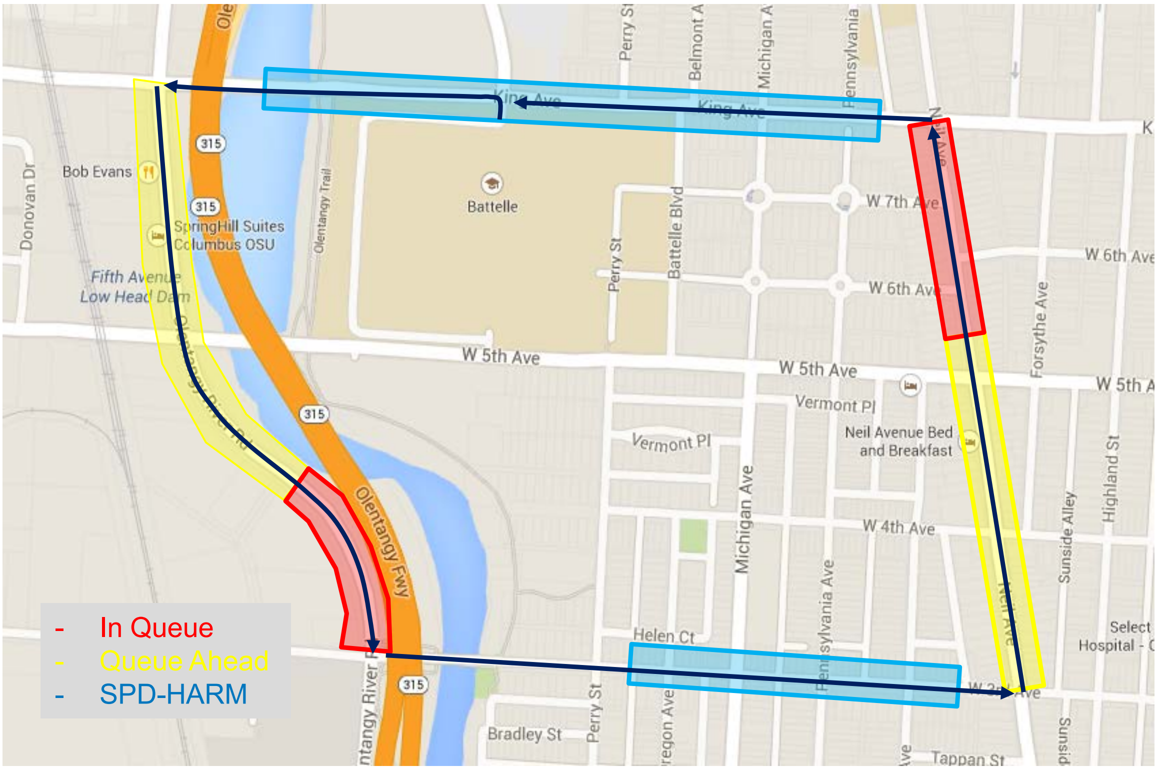
Test Case Location

This test case was conducted around the Battelle Connected Vehicle Test Loop described in Chapter 4. U.S. DOT Acceptance Test Demonstration was also conducted on the Battelle Connected Vehicle Test Loop.

Test Case Setup (Route and Messaging)

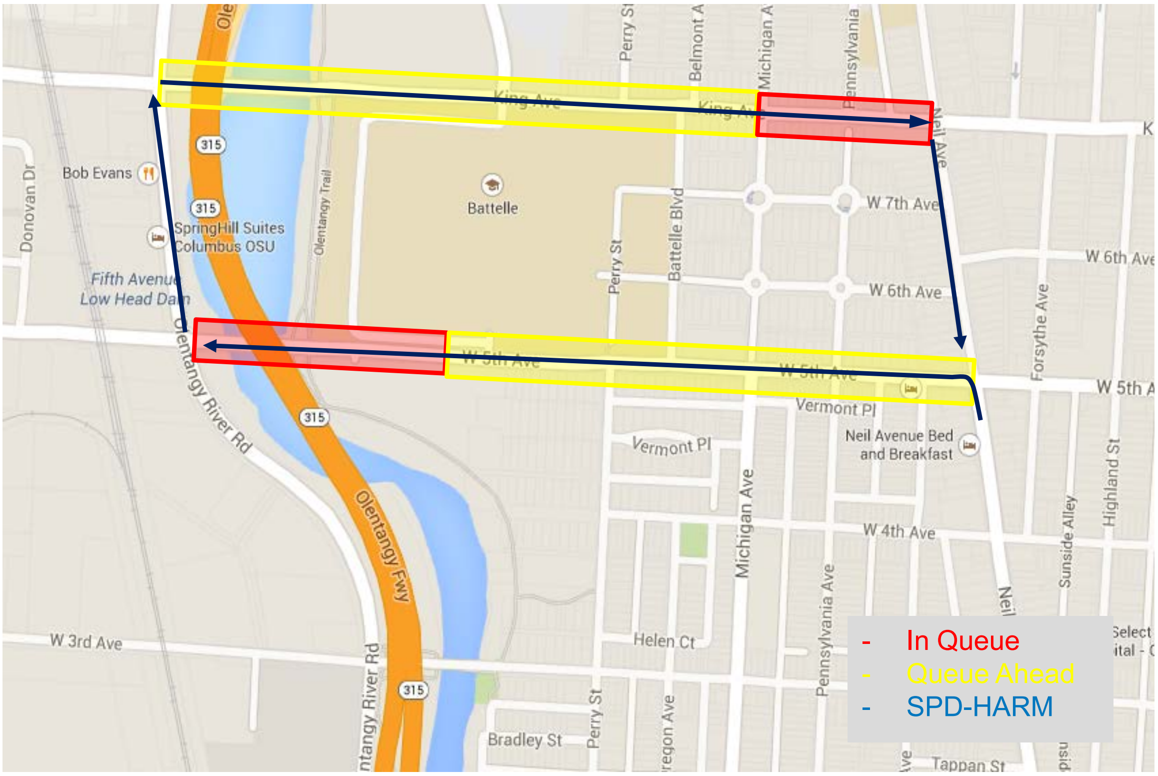
The Cloud Database was prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route around Battelle operating in live traffic. Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction.

The routes traveled during this Prototype Pilot Acceptance Test are illustrated in Figure 8-3 and Figure 8-4 below along with color coding to show the location of messages populated in the Cloud Database. Figure 8-3 shows the messages populated for “counter-clockwise travel” and Figure 8-4 shows the messages populated for “clockwise travel”.



Source: Battelle

Figure 8-3. Battelle Connected Vehicle Test Loop Counter Clockwise TME Messages



Source: Battelle

Figure 8-4. Battelle Connected Vehicle Test Loop Clockwise TME Messages

Test Case Pass/Fail Criterion

Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Procedure Summary

- The Cloud Database is prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route around Battelle operating in live traffic at speeds from 0 to 15 miles per hour, through multiple signalized intersections.
- Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction.
- They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Results

Researchers first confirmed that TME-based Q-WARN and SPD-HARM messages displayed correctly for both counter-clockwise and clockwise travel during at least ten circuits of each. The location of the message specification where displayed on both the INFLO Database Map Viewer and the Samsung User Interface.

Figure 8-5 through Figure 8-9 below show pictures of the driver messages displayed while traveling Battelle Connected Vehicle Test Loop.

Source: Battelle

Figure 8-5. Nomadic Device Mounted in Vehicle showing Android Samsung 4 Cellular Phone in Arada BackPack DSRC Radio

Source: Battelle

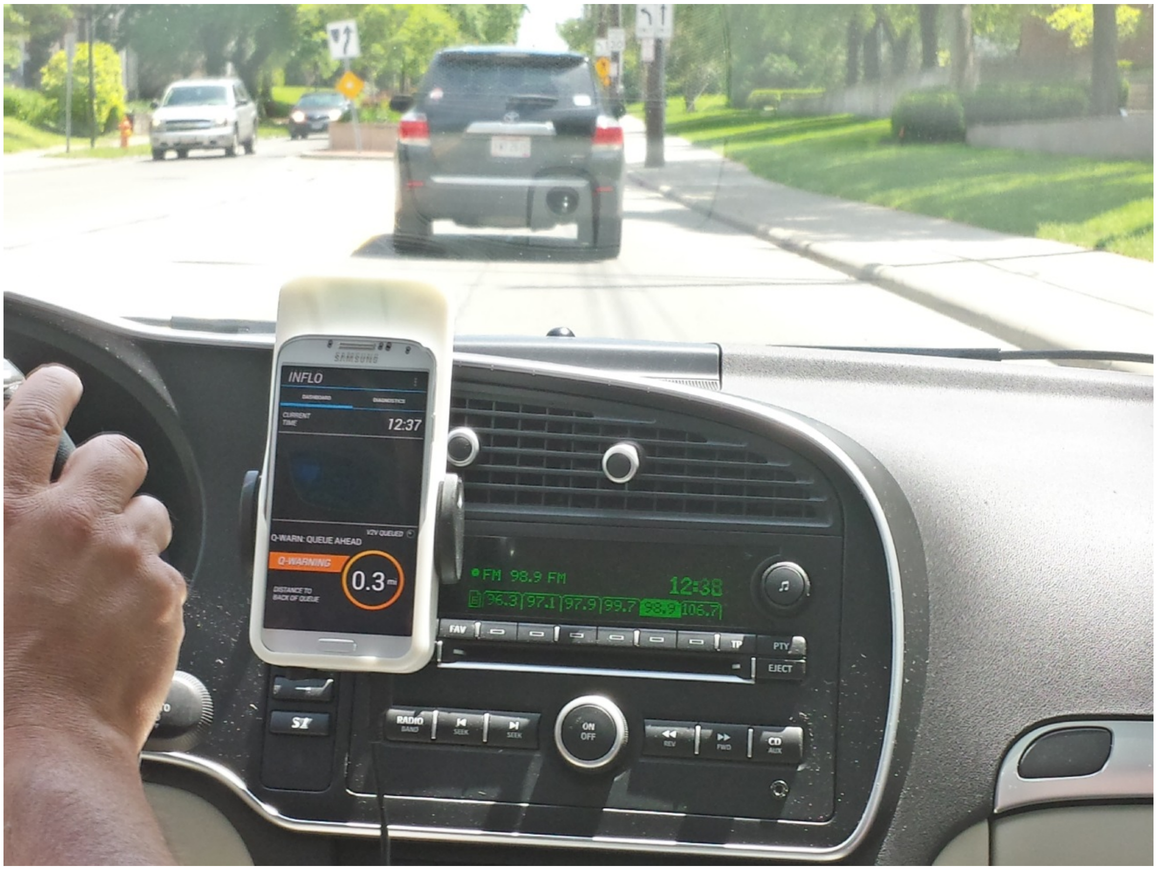
Figure 8-6. Queue Ahead Message Displayed Correctly on Battelle Connected Vehicle Test Loop

Source: Battelle

Figure 8-7. Queue Ahead Message Displayed Correctly on Battelle Connected Vehicle Test Loop

Source: Battelle

Figure 8-8. In-Queue Message Displayed Correctly on Battelle Connected Vehicle Test Loop



Source: Battelle

Figure 8-9. Queue Ahead Message Displayed Correctly on Battelle Connected Vehicle Test Loop

Source: Battelle

Figure 8-10. Display of Vehicle Location on INFLO Database Visualization Tool While Conducting Acceptance Test Demonstration on Battelle Loop

Anomalies or Discrepancies Observed

No discrepancies or anomalies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This Prototype Pilot Acceptance Test Case was successfully demonstrated to U.S. DOT and stakeholder observers on May 7, 2014.

On-road High Speed TME-Based Q-WARN and SPD-HARM Test Case

Test Case Summary

In this Prototype Pilot Acceptance Test Case, the Cloud Database is prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route northbound and southbound on State Highway 315 through a commonly congested area, at speeds from 30 to 60 miles per hour. Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Objective

This Acceptance Test demonstrates the functionality of TME-based Q-WARN and SPD-HARM messaging from the Cloud Database to the Nomadic Devices when at highway speeds. This test case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that the TME System Elements are operational
- Verifies that when a queue is created in the field, the following occurs:
  - TME-based Q-WARN is disseminating the queue strategies to connected vehicle network
  - TME-based SPD-HARM is disseminating target speed recommendations to connected vehicles

Requirements Verified

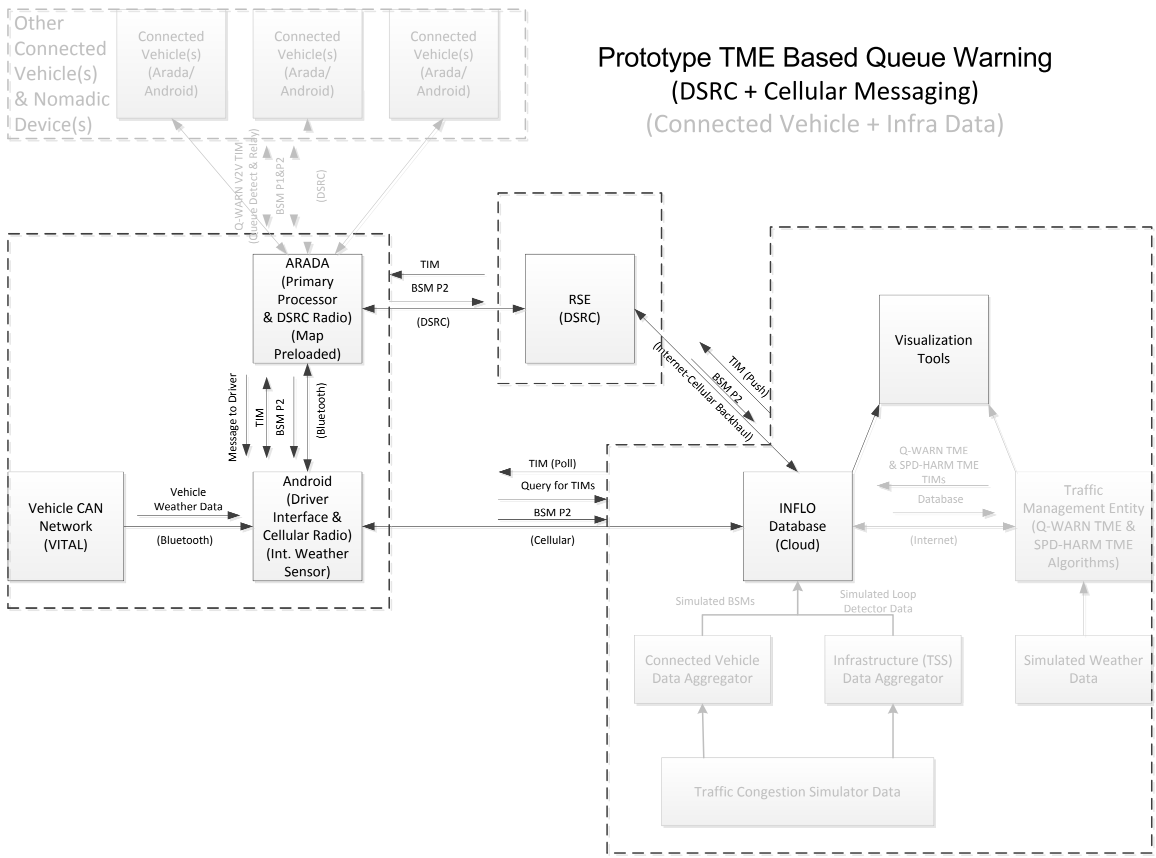
Appendix C details the INFLO System Requirements and the INFLO Application Acceptance test wherein each requirement is verified.

Requirements verified through TME-Based Q-WARN testing include 1.8.5, 1.9, 1.9.1, 1.9.2, 1.9.3, 1.9.5, 2.4, 2.5, 2.7, 3.1, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.16, 5.3, 8.14, 8.16, 8.17, 8.18, 8.22, 10.1, 10.2, 10.3, 10.5, 10.6, 10.7, 10.8, 10.10, 10.11, 10.12, 10.17, 10.18, 10.19, 10.20, 10.22, 14.2, 16.1, 16.2, 16.4, 17.1, and 17.2.

Requirements verified through TME-Based SPD-HARM with WRTM testing include: 1.1, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.8.1, 1.8.2., 1.8.3, 1.10, 1.11, 1.12, 1.13, 1.19, 2.1, 2.3, 2.7, 4.1, 4.3, 4.5, 4.6, 4.8, 4.11, 4.12, 5.4, 5.8, 6.1, 6.4, 6.6, 7.2, 8.5, 8.6, 8.7, 8.8.1, 8.8.2, 8.8.3, 8.8.4, 8.8.5, 8.8.6, 8.9, 8.9.6, 8.9.7, 8.12, 8.13, 8.15, 8.16, 8.17, 8.18, 8.19, 8.20, 8.21, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.12, 11.13, 11.14, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 12.6, 12.7, 12.10, 13.1, 13.2, 14.4, 14.5, 14.6, 14.7, 15.1, 15.2, 15.3, 16.1, 16.2, 17.1, and 17.2.

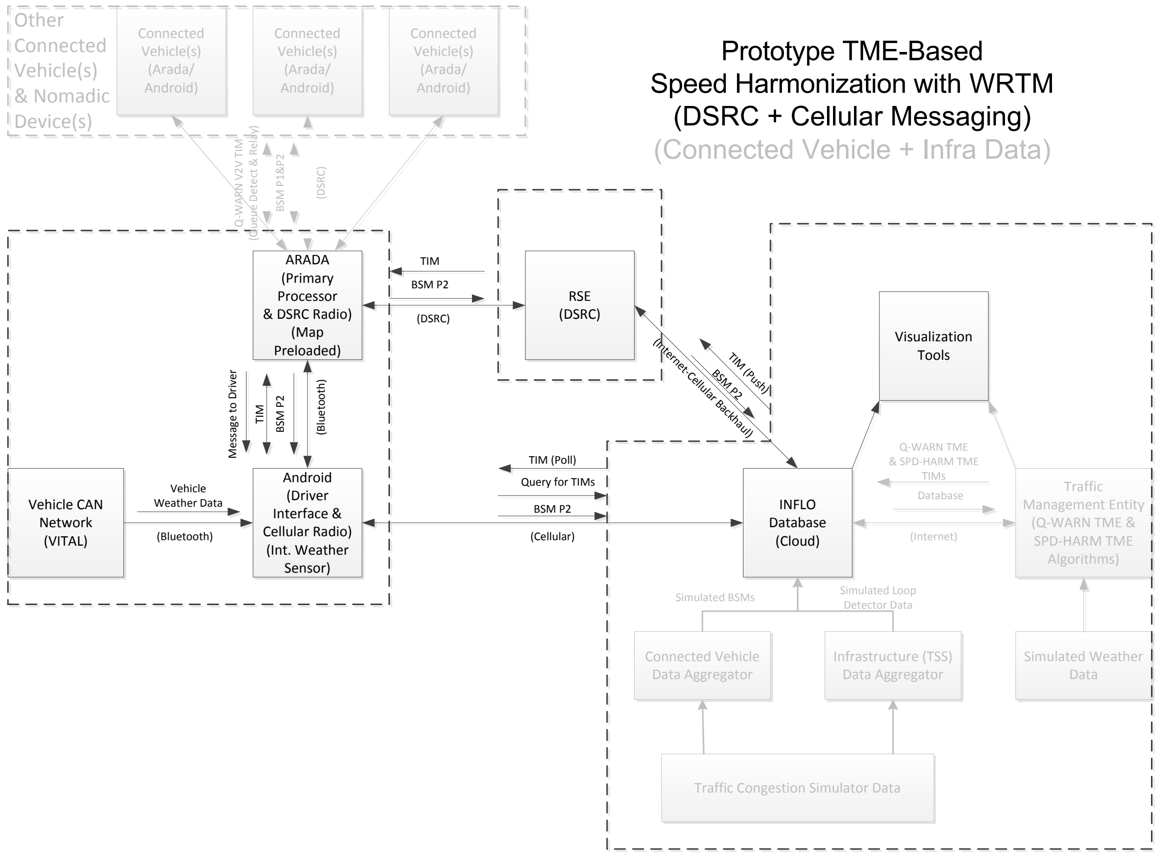
Test Case System Configuration

The INFLO System configuration for this Prototype Pilot Acceptance Test Case is shown in Figure 8-11 and Figure 8-12 below.



Source: Battelle

Figure 8-11. Prototype INFLO System Configuration Used in TME-Based Queue Warning On-road Testing



Source: Battelle

Figure 8-12. Prototype INFLO System Configuration Used in TME-Based Speed Harmonization On-road Testing

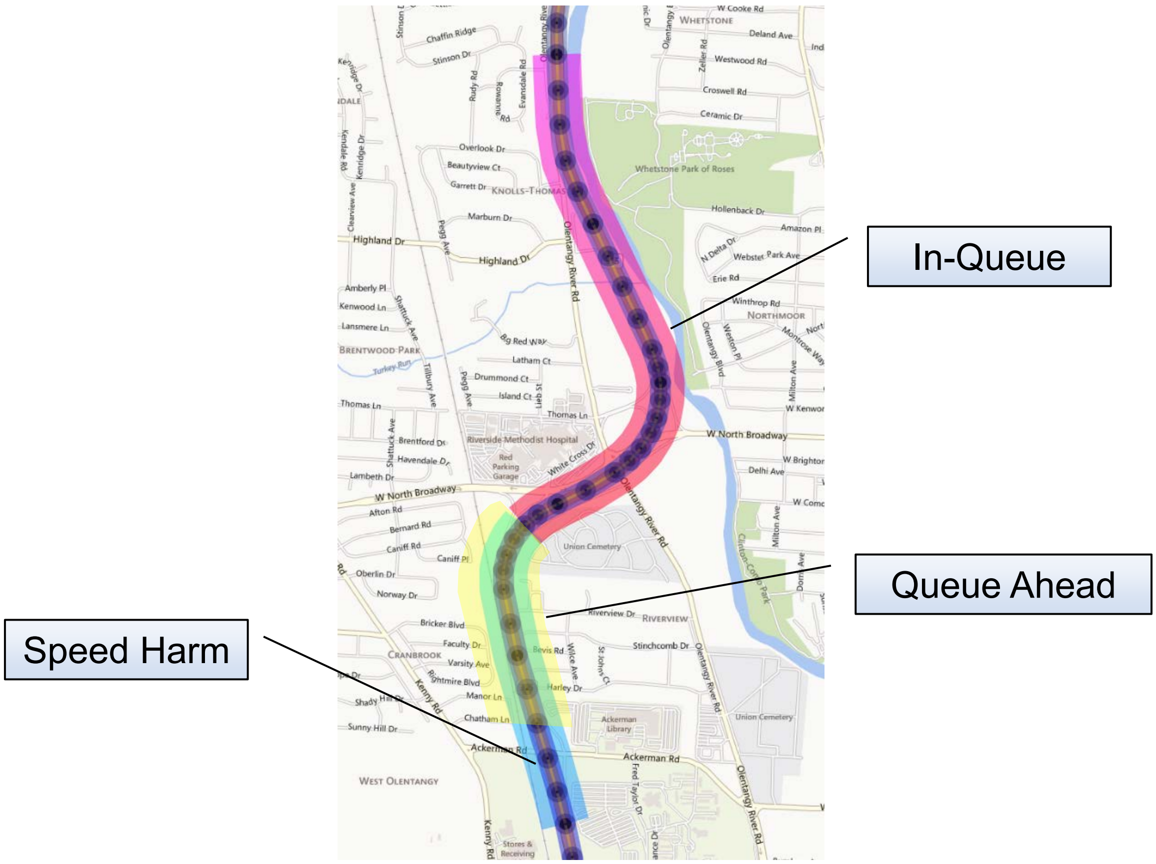
Test Case Location

This test case was conducted on State Route 315 (north of Battelle) described in Chapter 4. U.S. DOT Acceptance Test Demonstration was also conducted on the same State Route 315.

Test Case Setup (Route and Messaging)

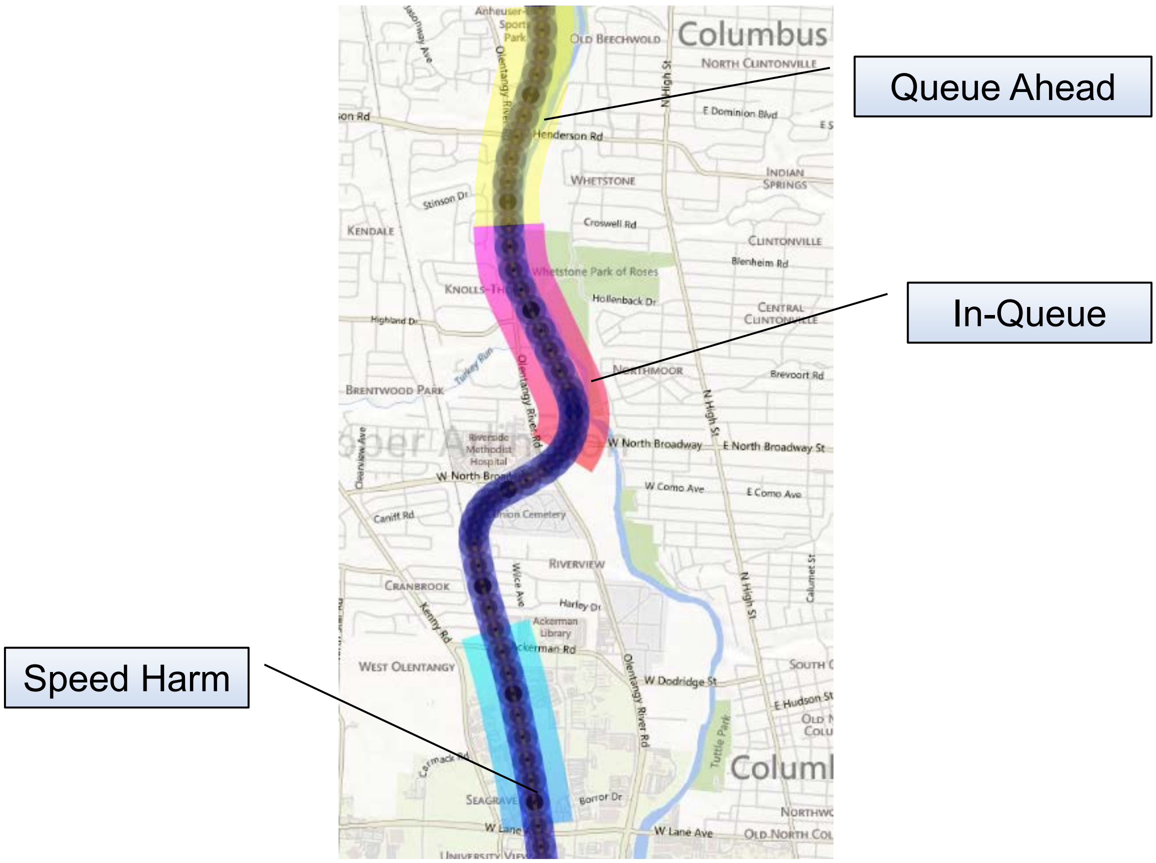
The Cloud Database was prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route around Battelle operating in live traffic. Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction.

The routes traveled during this Prototype Pilot Acceptance Test is illustrated in Figure 8-13 and Figure 8-14 along with color coding to show the location of messages populated in the Cloud Database. Figure 8-13 shows the messages populated for northbound travel and Figure 8-14 shows the messages populated for Southbound travel.



Source: Battelle

Figure 8-13. State Route 315 Northbound



Source: Battelle

Figure 8-14. State Route 315 Southbound

Test Case Pass/Fail Criterion

Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Procedure Summary

- The Cloud Database is prepopulated with TME-based Q-WARN and SPD-HARM messages on a predetermined route northbound and southbound on State Highway 315 through a commonly congested area, at speeds from 30 to 60 miles per hour.
- Researchers drive the route and verify that all Q-WARN and SPD-HARM messages are received and displayed to the driver at the proper locations when traveling the specified direction.
- They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Results

Researchers first confirmed that TME-based Q-WARN and SPD-HARM messages displayed correctly for both counter-clockwise and clockwise travel during at least ten circuits of each. The location of the message specification were displayed on both the INFLO Database Map Viewer and the Samsung User Interface.

Figure 8-15 through Figure 8-21 below show pictures of the driver messages displayed while traveling on State Route 315.

Source: Battelle

Figure 8-15. Nomadic Device Display Traveling on State Route 315

Source: Battelle

Figure 8-16. TME Unavailable Message While Traveling State Route 315

Source: Battelle

Figure 8-17. Speed Harmonization Message Display with Recommended Speed While Traveling on State Route 315

Source: Battelle

Figure 8-18. Queue Ahead Message While Traveling State Route 315 Indicating Back of Queue 0.1 mile Ahead

Source: Battelle

Figure 8-19. Queue Ahead and Speed Harmonization Recommended Speed Message While Traveling State Route 315

Source: Battelle

Figure 8-20. In-Queue Message While Traveling State Route 315 indicating Queue is 1 Mile in Length and Will Take 11 Minutes to Traverse

Source: Battelle

Figure 8-21. Queue Ahead Warning Displayed on Android Device and Laptop Visualization Tool while Traveling on SR 315

Anomalies or Discrepancies Observed

No discrepancies or anomalies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This Prototype Pilot Acceptance Test Case was successfully demonstrated to U.S. DOT and stakeholder observers on May 7, 2014.

V2V Queue Warning Test Case

Test Case Summary

In this on-road Prototype Pilot Acceptance Test Case, a single vehicle slows and stops on a test road. The second vehicle approaches the stopped vehicle, and determines that it is in a queue and issues a message indicating it is queued. A third vehicle approaches from the same direction and issues a Queue Ahead message to the driver. Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Objective

This Acceptance Test demonstrates the functionality of V2V DSRC based Queue detection and Queue warning in the on-road environment including all interfaces, communication and messaging. This test case

- Verifies that Connected Vehicle System Elements are operational
- Verifies that when a simulated queue is created, the following occurs:
  - CV-based Q-WARN is detecting roadway location and queue state and passing information to other connected vehicles and infrastructure
  - CV-based Q-WARN is receiving queue warnings and information from other connected vehicles and the TME-based Q-WARN application and using data to generate individualized queue response strategies
  - CV-based Q-WARN is providing recommendations to the User Interface which is communicating with driver
  - CV-based Q-WARN is disseminating queue status alerts and information to other connected vehicles

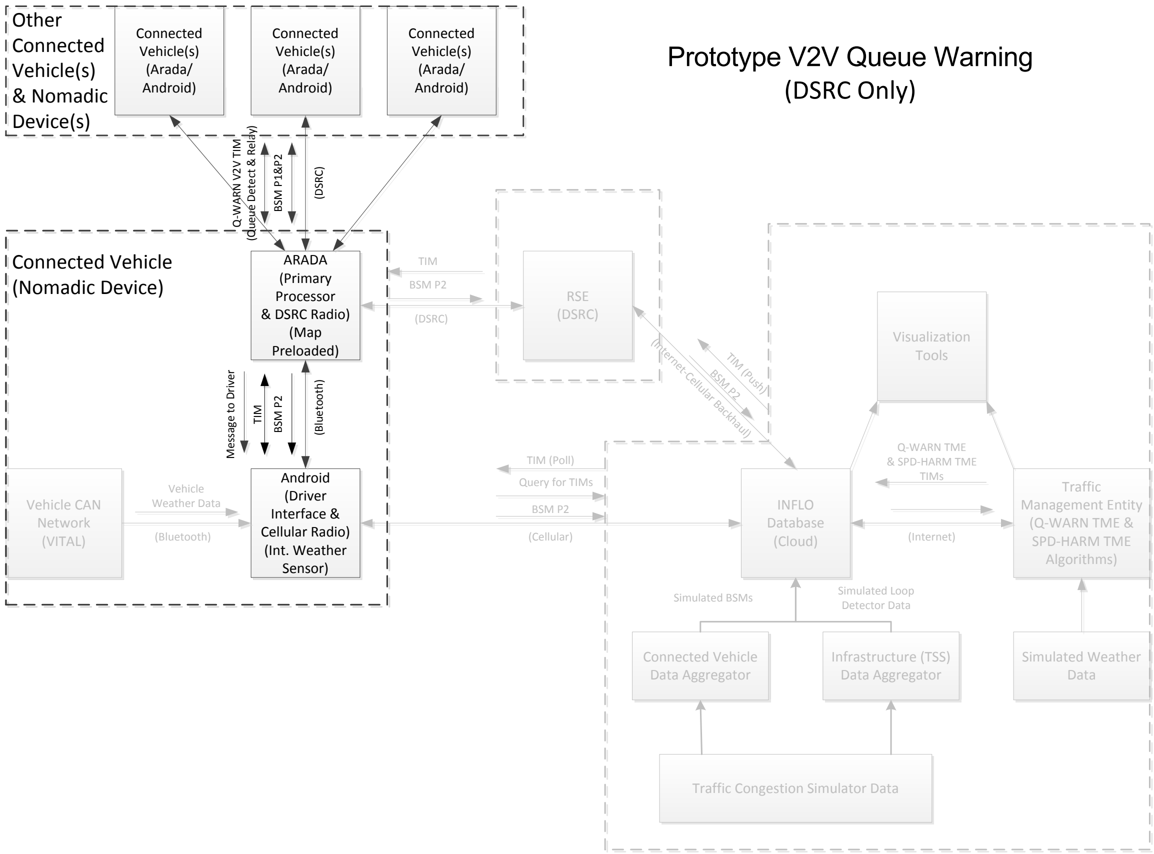
Requirements Verified

Appendix C details the INFLO System Requirements and the INFLO Application Acceptance test wherein each requirement is verified.

Requirements verified through V2V Q-WARN testing include 1.1, 1.4, 1.5, 2.4, 2.5, 2.7, 3.2, 3.4, 3.5, 3.7, 3.8, 3.10, 3.15, 5.1, and 5.2.

Test Case System Configuration

The INFLO System configuration for this Prototype Pilot Acceptance Test Case is shown in Figure 8-22 below.



Source: Battelle

Figure 8-22. Prototype INFLO System Configuration Used in V2V DSRC Queue Warning On-road Testing

Test Case Location

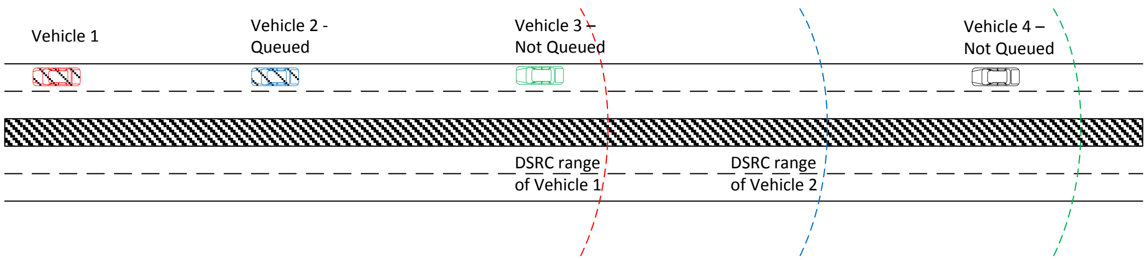
This test was conducted on the ODOT Delaware Test Pavement described in Chapter 4. U.S. DOT Acceptance Test Demonstration was also conducted on the same ODOT Delaware Test Pavement.

Test Case Setup (Route and Messaging)

The scenario for this Prototype Pilot Acceptance Test is illustrated in Figure 8-23 through Figure 8-24. The vehicles are color coded. The DSRC communication range for each vehicle is shown by a curved dotted line of the same color. (Vehicles 2 and 3 are within DSRC range of Vehicle 1. Vehicle 4 is within DSRC range of Vehicle 3, but not Vehicle 1 or 2). Figure 8-23 illustrates the configuration when Vehicle 2 approaches Vehicle 1 and determines that it is Queued. Vehicle 3 approaches, receives the vehicle queued message and delivers the Queue Ahead message to the driver. Vehicle 3 also rebroadcasts the Queue Ahead message, which is received and displayed by Vehicle 4. (Vehicle Queued messages are broadcast by Vehicle 2 at 1 Hz. Each Queue Ahead message received by Vehicle 3 is rebroadcast once.)

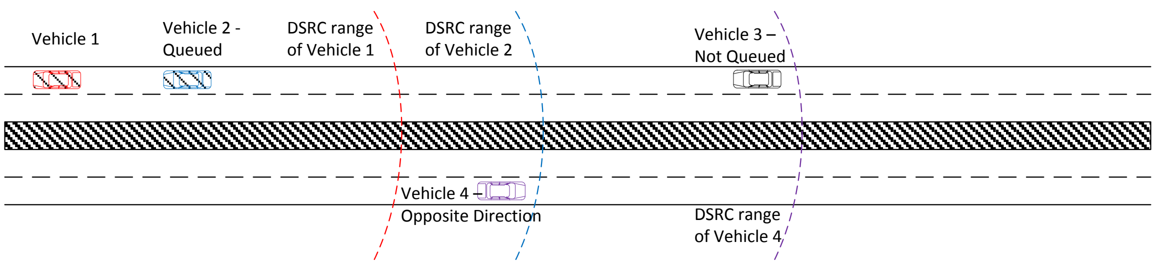
The scenario for V2V Message Relay through vehicles approaching from the opposite direction is illustrated in Figure 8-24. Figure 8-24 illustrates the configuration when Vehicle 2 approaches Vehicle 1 and determines that it is Queued. Vehicle 4 approaches from the opposite direction, receives the vehicle queued message, *does not* display it to the driver and rebroadcasts the Queue Ahead message. Vehicle 3 receives the Queue Ahead message from Vehicle 4 and displays it to the driver. Vehicle 3 is within DSRC range of Vehicle 4, but is not within DSRC range of Vehicle 2.

Figure 8-24 illustrates the configuration when vehicle/nomadic device 9 approaches from the opposite direction, receives the vehicle queued message and *does not* deliver the Queue Ahead message to the driver.



Source: Battelle

Figure 8-23. Q-WARN V2V Message Relay through Following Vehicles



Source: Battelle

Figure 8-24. Q-WARN V2V Message Relay with Opposing Vehicles

Test Case Pass/Fail Criterion

Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Procedure Summary

- A single vehicle slows and stops on a test road.
- The second vehicle approaches the stopped vehicle, and determines that it is in a queue and issues a message indicating it is queued.
- A third vehicle approaches from the same direction and issues a Queue Ahead message to the driver.
- Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Test Case Results

Researchers verify that all messages are received and displayed to the driver at the proper locations when travel is in the specified direction. They also confirmed that the messages are received, but not displayed to the driver when traveling in the opposite direction.

Figure 8-25 through Figure 8-30 below show vehicles and components used for testing and demonstration.

Source: Battelle

Figure 8-25. Stopped and Queued Vehicle on Delaware Frontage Road and RSU

Source: Battelle

Figure 8-26. Android Samsung Cellular Phone Being Inserted in Arada Backpack

Source: Battelle

Figure 8-27. External DSRC and GPS Antenna Used for V2V DSRC Communications

Source: Battelle

Figure 8-28. RSU to Demonstrate V2I Communications

Source: Battelle

Figure 8-29. Shuttle Bus Used as Subject Vehicle for Acceptance Test Demonstration

Source: Battelle

Figure 8-30. Test Vehicles at the Roadside

Anomalies or Discrepancies Observed

No discrepancies or anomalies were generated.

Test Case Pass/Fail

Pass

Verification of Results

This on-road Prototype Pilot Acceptance Test Case was successfully demonstrated to U.S. DOT and stakeholder observers on May 7, 2014.

APPENDIX A. Phase I: Component Acceptance Test Cases and Test Results

The following table summarizes the results of Component Acceptance Testing conducted in Phase I.

Table A-1. Phase I: Component Acceptance Test Results Summary

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-01	**Connected Vehicle Nomadic Device Functionality**	1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.8.1 1.8.2 1.8.3 1.8.4 1.8.5 1.9	1.9.1 1.9.2 1.9.3 1.9.4 1.9.5 1.10 1.11 1.12 1.13 1.14 1.15 1.16 1.17 1.19	To verify: • Operational Capabilities o Device's ability to operate as both a stand-alone portable device and as an installed in-vehicle device o Device's ability to operate on battery power (when stand-alone) and to operate and charge battery on voltage supplied by vehicle (when installed in-vehicle) • Data Detection, Retrieval and Transmission Capabilities o Device's ability to retrieve data via a data retrieval mechanism o Device's ability to access vehicle state data when installed in-vehicle o Device's ability to detect geographic location (road segment), vehicle location (direction of travel and heading), and vehicle speed characteristics o Device's ability to transmit vehicle data at regular intervals o Device's ability to transmit road and weather conditions at regular intervals • Data Logging Capabilities o Device's ability to log all alerts issued to driver and associated parameters o Device's ability to log all outbound messages generated by vehicle-based applications o Device's ability to log travel data (GPS position, timestamp, device and trip IDs) • Communication Capabilities o Device's ability to communicate with TME-based SPD-HARM applications via I2V communication to transmit target speed recommendations o Device's ability to communicate with TME-based Q-WARN applications via I2V communication to transmit target speed recommendations o Device's ability to communicate with TME-based WRTM applications via I2V communication to transmit target speed recommendations o Device's ability to communicate with TME-based Vehicle Message Generator via I2V Communication to transmit real-time weather and road conditions; target speed recommendations; queue location, growth, and speed data; and roadway reference information	Operational Capabilities • Tested in laboratory 3/12/2014 • Battery life 2-3 hours with radios running Data Detection, Retrieval and Transmission Capabilities • Tested in laboratory 3/15/2014 using TME, multiple radios and phones. Radios used simulated GPS position Data Logging Capabilities • Tested in laboratory 3/15/2014 using TME, multiple radios and phones. Radios used simulated GPS position Communication Capabilities • Tested in laboratory 3/15/2014 using TME, multiple radios and phones. Radios used simulated GPS position. Example logs are part of the 5/7/2014 testing.	Operational Capabilities **Passed** Data Detection, Retrieval and Transmission Capabilities **Passed** Data Logging Capabilities **Passed** Communication Capabilities **Passed**	Operational Capabilities **TME Q-WARN** **TME SPD-HARM** **V2V Q-WARN** Data Detection, Retrieval and Transmission Capabilities **TME Q-WARN** **TME SPD-HARM** **V2V Q-WARN** Data Logging Capabilities **TME Q-WARN** **TME SPD-HARM** **V2V Q-WARN** Communication Capabilities **TME Q-WARN** **TME SPD-HARM** **V2V Q-WARN**
TC 1-02	**Connected Vehicle Nomadic Device User Interface System (UI) Functionality**	2.1 2.2 2.3 2.4	2.5 2.6 2.7	To verify: • UI's ability to communicate speed, speed justification, and lane recommendations from CV-based SPD-HARM application to driver • UI's ability to communicate individualized queue warnings, characteristics, and response strategies from CV-based Q-WARN application to driver • UI's latency is under acceptable threshold from receipt of event to driver display • UI's ability to provide operational application notification to driver when no alerts/warnings present	Verification • Tested in laboratory 4/14/2014 using static GPS simulation • UI can be seen in Section Figure 4-4 through Figure 4-13 • Latency is subjective but no discernable delay between the receipt of an alert and the display of the alert.		

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-03	**Connected Vehicle Q-WARN Application Functionality**	0.1 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8	3.9 3.10 3.11 3.12 3.13 3.14 3.15 3.16 3.17 17.2	To verify: • Application is developed in accordance with practices allowing for its open-source use • Time sensitive data used in application shall be timestamped using a common time reference • Communication with Integrated Vehicle Network Access System (INVAS) o CV-based Q-WARN's ability to communicate with INVAS to obtain real-time vehicle state data and weather and road surface data from the vehicle network • Data Detection, Retrieval, and Transmission Capabilities o CV-based Q-WARN's ability to determine location on roadway o CV-based Q-WARN's ability to detect when vehicle is in a queue state o CV-based Q-WARN's ability to communicate back of queue position to driver interface o CV-based Q-WARN's ability to communicate back of queue position to other connected vehicles. o CV-based Q-WARN's ability to use secure data transmission methods when disseminating personally identifiable information (PII) • Receipt of Queue Warning Messages o CV-based Q-WARN's ability to receive TME-based Q-WARN warning messages o CV-based Q-WARN's ability to receive queue warning messages from other connected vehicles • Development of Queue Messages/Responses o CV-based Q-WARN's ability to generate appropriate queue response strategies o CV-based Q-WARN's ability to develop individualized queue warning messages based on vehicle position and distance to the back of queue • Transmittal of Queue Data and Messages o CV-based Q-WARN's ability to pass queue warnings and queue characteristics received from TME to the driver interface o CV-based Q-WARN's ability to pass individualized queue strategies to driver interface o CV-based Q-WARN's ability to disseminate queue status alerts to other connected vehicles via V2V communication o CV-based Q-WARN's ability to disseminate queue status alerts to infrastructure via V2I communication	Open Source and Time Stamp • Open Source verified by inspection. All developed applications have source code in the build with no closed third party libraries used. • Time stamps verified by inspection. All time stamps are UTC or local time with UTC offset included. Communication with Integrated Vehicle Network Access System (INVAS) • Tested in laboratory 4/15/2014 using VITAL module and ECU simulator. • Temperature, humidity and barometric pressure read from vehicle and transmitted in a BSM part 2 Data Detection, Retrieval and Transmission Capabilities • Tested in laboratory 4/28/2014 using TME, multiple radios and phones. Radios used simulated GPS position • We do not transmit any PII information from CV –based Q-WARN Receipt of Queue Warning Messages • Tested in laboratory 4/28/2014 using TME, multiple radios and phones. Radios used simulated GPS position. Development of Queue Messages/Responses • Tested in laboratory 4/28/2014 using TME, multiple radios and phones. Radios used simulated GPS position. Transmittal of Queue Data and Messages • Tested in laboratory 4/28/2014 using TME, multiple radios and phones. Radios used simulated GPS position.	Open Source and Time Stamp **Passed** Communication with Integrated Vehicle Network Access System (INVAS) **Passed** Data Detection, Retrieval and Transmission Capabilities **Passed** Receipt of Queue Warning Messages **Passed** Development of Queue Messages/Responses **Passed** Transmittal of Queue Data and Messages **Passed**	Open Source and Time Stamp **N/A** Communication with Integrated Vehicle Network Access System (INVAS) **Parking Lot Demonstration** Data Detection, Retrieval and Transmission Capabilities **V2V Q-WARN** Receipt of Queue Warning Messages **TME Q-WARN** **V2V Q-WARN** Development of Queue Messages/Responses **TME Q-WARN** **V2V Q-WARN** Transmittal of Queue Data and Messages **TME Q-WARN** **V2V Q-WARN**

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-04	**Connected Vehicle SPD-HARM Application Functionality**				Because final implementation of SPD-HARM does not have a component resident on the vehicle, TC 1-04 – Connected Vehicle SPD-HARM Application Functionality was not performed.		
TC 1-05	**Connected Vehicle Communication (CVC) System Functionality**	5.1 5.2 5.3 5.4 5.5	5.6 5.7 5.8 5.9	To verify: • <u>CV-based Q-WARN Application Communication</u> o CVC System's ability to disseminate queued status alerts to other connected vehicles via V2V communication o CVC System's ability to receive queue warning messages from other connected vehicles via V2V communication o CVC System's ability to receive messages from TME-based Q-WARN applications via I2V communication • <u>CV-based SPD-HARM Application Communication</u> o CVC System's ability to receive messages from TME-based SPD-HARM applications via I2V communication • <u>Generation and Transmission of Messages</u> o CVC System's ability to generate basic safety messages in compliance with SAE standards o CVC System's ability to transit basic safety messages under acceptable threshold • <u>Interoperability</u> o CVC System's ability to interoperate with other equipped vehicles and roadside equipment based on SAE and IEEE standards • <u>Cellular and DSRC Communication</u> o CVC System's ability to communicate with the TME using cellular infrastructure when DSRC is not needed or not available o CVC System's ability to switch from cellular infrastructure to DSRC under acceptable threshold	<u>CV-based Q-WARN Application Communication</u> • Tested in laboratory 4/28/2014 using TME, multiple radios and phones. Radios used simulated GPS position <u>CV-based SPD-HARM Application Communication</u> • Tested in laboratory 4/28/2014 using radio and phone. <u>Generation and Transmission of Messages</u> • Tested in laboratory 4/28/2014 using radio and phone. • Verified using 3M packet sniffer and verified decoding of messages. <u>Interoperability</u> • This was not specifically tested but all code was implemented using the Arada API. The Arada units are approved for use in the Safety Pilot and based on this they are interoperable. Fields in some standard messages were used for other values but do not change the structure of the messages. <u>Cellular and DSRC Communication</u> • Tested in laboratory 4/28/2014 using Arada RSU, TME, Arada ME and phone. • Verified switching between cellular and DSRC based on the RSSI level. The transition RSSI level was tested and calculated to be 15.	<u>CV-based Q-WARN Application Communication</u> **Passed** <u>CV-based SPD-HARM Application Communication</u> **Passed** <u>Generation and Transmission of Messages</u> **Passed** <u>Interoperability</u> **Not Tested** <u>Cellular and DSRC Communication</u> **Passed**	<u>CV-based Q-WARN Application Communication</u> **TME Q-WARN** **V2V Q-WARN** <u>CV-based SPD-HARM Application Communication</u> **TME SPD-HARM** <u>Generation and Transmission of Messages</u> **V2V Q-WARN** <u>Interoperability</u> **N/A** <u>Cellular and DSRC Communication</u> **RSU Test**
TC 1-06	**Connected Vehicle Weather System Functionality**	0.1 6.1 6.2 6.3 6.4	6.5 6.6 6.7 6.8	To verify: • Time sensitive data used in application shall be time stamped using a common time reference • <u>Transmittal and Range of Temperature Data</u> o CV Weather Systems' ability to measure ambient temperature and transmit data to the TME o CV Weather Systems' ability to measure ambient temperature and transmit data to CV-based Q-WARN application o CV Weather Systems' ability to provide ambient temperature between -50 to 50C • <u>Transmittal and Range of Air Pressure Data</u> o CV Weather Systems' ability to measure air pressure and transmit data to the TME o CV Weather Systems' ability to measure air pressure and transmit data to CV-based Q-WARN application • <u>Transmittal and Range of Humidity Data</u> o CV Weather Systems' ability to measure humidity and transmit data to the TME o CV Weather Systems' ability to measure humidity and transmit data to CV-based Q-WARN application o CV Weather Systems' ability to provide humidity data between 0 and 100%	<u>Time Stamp</u> • Time stamps verified by inspection. All time stamps are UTC or local time with UTC offset included. <u>Transmittal and Range of Temperature Data</u> • Tested in laboratory 4/15/2014 using Arada ME Radio, Galaxy S4 Phone, VITAL module and ECU simulator. • Temperature tested from simulated vehicle • Verified ability to transmit temperatures in range but actual ability to measure that temperature range is CV dependent. <u>Transmittal and Range of Air Pressure Data</u> • Tested in laboratory 4/15/2014 using Arada ME Radio, Galaxy S4 Phone, VITAL module and ECU simulator. • Air pressure data tested from simulated vehicle • Air pressure was not part of database schema so was not stored in database. Transmission and receipt of values verified. <u>Transmittal and Range of Humidity Data</u> • Tested in laboratory 4/15/2014 using Arada ME Radio, Galaxy S4 Phone, VITAL module and ECU simulator. • Humidity data tested from simulated vehicle • Humidity was not part of database schema so was not stored in database. Transmission and receipt of values verified.	<u>Time Stamp</u> **Passed** <u>Transmittal and Range of Temperature Data</u> **Passed** <u>Transmittal and Range of Air Pressure Data</u> **Passed – Not stored in the database** <u>Transmittal and Range of Humidity Data</u> **Passed – Not stored in the database**	<u>Transmittal and Range of Temperature Data</u> **Parking Lot Demonstration**

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-07	**Integrated Vehicle Network Access System (INVAS) Communication**	7.1 7.2	7.3 7.4	To verify: • CV's ability to communicate with INVAS to gather vehicle movement data from vehicle network • CV's ability to communicate with INVAS to gather weather data form vehicle network • CV's ability to communicate with INVAS to gather road surface data from vehicle network • Communications use standard data sets and communication protocols	INVAS Communications • Tested in laboratory 4/15/2014 using Arada ME Radio, Galaxy S4 Phone, VITAL module and ECU simulator. • Android Phone communicated through Battelle's VITAL module to collect data for BSM part 2s. • Data collected can be seen in Figure 11 – INVAS Data	INVAS Communications **Partial – Surface data not gathered**	INVAS Communications **Parking Lot Demonstration**
TC 1-08	**Traffic Management Entity (TME) Functionality**	8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.8.1 8.8.2 8.8.3 8.8.4 8.8.5 8.8.6 8.8.7 8.8.8 8.8.9 8.8.10 8.9 8.9.1 8.9.2 8.9.3	8.9.4 8.9.5 8.9.6 8.9.7 8.10 811 8.11.1 8.11.2 8.11.3 8.11.4 8.12 8.13 8.14 8.15 8.16 8.17 8.18 8.19 8.20 8.21 8.22 8.23 16.2	To verify: • Data Collection Capabilities o TME's ability to collect real-time traffic, road surface, and weather data from multiple sources o TME's ability to receive real-time traffic, road surface, and weather data from infrastructure-based systems o TME's ability to obtain traffic conditions, and vehicle flow data from infrastructure-based traffic sensors (on user-defined intervals) o TME's ability to determine which traffic sensors apply to which segment of roadway o TME's ability to obtain weather forecast information (type, time, severity and duration) from external weather providers • Data Analysis and Transmission Capabilities o TME's ability to aggregate lane detector data into station-level detector data o TME's ability to verify quality of data before applying it to algorithms o TME's ability to dynamically configure freeway detection zones based on results of data quality verification o TME's ability to combine recommended traffic management strategies from various applications to determine appropriate responses to provide to traveler o TME's ability to recommend traffic management strategies for sharing with other dynamic mobility applications o TME's ability to make shockwave, queue, and road condition information available for sharing with other dynamic mobility applications o TME's ability to communicate traffic, road condition, and weather data to connected vehicles via I2V communication • TME-based Applications o TME has application to mitigate impacts of shockwaves (TME-based SPD-HARM app) o TME has application to mitigate impacts of queues (TME-based Q-WARN app) o TME has application to mitigate travel conditions due to adverse weather (TME-based WRTM)	Traffic Management Entity • Tested in the Laboratory 4/30/14 using Simulated Traffic Congestion Data • Tested in the Laboratory 4/30/14 using Simulated Weather Data	Data Collection Capabilities **Passed** (using simulated traffic congestion data and simulated weather data) Data Analysis and Transmission Capabilities **Passed** TME-based Applications **Passed**	Data Collection Capabilities **TME Q-WARN** **TME SPD-HARM** Data Analysis and Transmission Capabilities **TME Q-WARN** **TME SPD-HARM** TME-based Applications **TME Q-WARN** **TME SPD-HARM**

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-09	**TME Q-WARN Application Functionality**	0.1 10.1 10.2 10.3 10.4 10.5 10.6 10.7 10.8 10.9 10.10 10.11 10.12 10.13	10.14 10.15 10.16 10.17 10.18 10.19 10.20 10.21 10.22 10.23 10.24 10.25 17.1 17.2	To verify: • Application is developed in accordance with practices allowing for its open-source use • Application will use input data obtained from fixed-point detection equipment • INFLO Prototype will use real or simulated data to represent traffic, weather, and road conditions • Time sensitive data used in application shall be timestamped using a common time reference • <u>Data Collection Capabilities</u> o TME Q-WARN's ability to interface with the data environment to obtain data from multiple sources including infrastructure-based systems and connected vehicles • <u>Data Analysis and Transmission Capabilities for Queues</u> o TME Q-WARN's ability to fuse and process data from various sources to detect queues in real-time and generate warning information o TME Q-WARN's ability to determine sections of freeway operating in a queue state, and other queue characteristics (length, travel speed, direction of queue and estimated number of cars) o TME Q-WARN's ability to fuse and process data from various sources to perform queue prediction o TME Q-WARN's ability to update estimates for queues (speed etc.) under an acceptable threshold o TME Q-WARN's ability to predict queues (speed etc.) under an acceptable threshold o TME Q-WARN's ability to provide false positive queue identification and missed queues below an acceptable threshold o TME Q-WARN's ability to interface with TME-based SPD-HARM app to generate appropriate reduced speed o TME Q-WARN's ability to share queue information with other DMAs via the TME • <u>Queue Detection and Response Capabilities</u> o TME Q-WARN's capability to generate queue response strategies (including speeds and warning messages) o TME Q-WARN's capability to disseminate queue warning and information o TME Q-WARN's capability to identify, track, and analyze unidentified and incorrectly identified queue formation events	<u>TME Q-WARN</u> • Tested in the Laboratory 4/30/14 using Simulated Traffic Congestion Data	<u>Data Collection Capabilities</u> **Passed** (using simulated traffic congestion data and simulated weather data) <u>Data Analysis and Transmission Capabilities</u> **Passed** <u>Queue Detection and Response Capabilities</u> **Passed**	<u>Data Collection Capabilities</u> **TME Q-WARN** <u>Data Analysis and Transmission Capabilities</u> **TME Q-WARN** <u>Queue Detection and Response Capabilities</u> **TME Q-WARN**

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-10	**TME SPD-HARM Application Functionality**	0.1 11.1 11.2 11.3 11.4 11.5 11.6 11.7 11.8 11.9 11.10 11.11 11.12	11.13 11.14 11.15 11.16 11.17 11.18 11.19 11.20 11.21 11.22 17.1 17.2	To verify: • Application will use input data obtained from fixed-point detection equipment • INFLO Prototype will use real or simulated data to represent traffic, weather, and road conditions • Time sensitive data used in application shall be timestamped using a common time reference • <u>Data Collection Capabilities</u> o TME SPD-HARM's ability to interface with the data environment to obtain real-time traffic data, road conditions and weather data from connected vehicles and other data sources • <u>Data Analysis Capabilities</u> o TME SPD-HARM's ability to fuse and process data from various sources to calculate speed target recommendations utilizing real-time and historic traffic data, real-time and forecasted weather data, and real-time and predicted road surface data o TME SPD-HARM's ability to use real-time traffic data in shockwave detection algorithm • <u>Shockwave Detection and Response Capabilities</u> o TME SPD-HARM's capability to detect shockwaves o TME SPD-HARM's capability to generate target speed strategies o TME SPD-HARM's capability to detect shockwaves at an acceptable threshold o TME SPD-HARM's false positive detection of shockwaves falls below an acceptable threshold o TME SPD-HARM's ability to detect segments of roadway impacted by shockwave as well as location, speed, direction, and length of shockwave o TME SPD-HARM's ability to update shockwave information at an acceptable threshold	<u>TME SPD-HARM</u> • Tested in the Laboratory 4/30/14 using Simulated Traffic Congestion Data	<u>Data Collection Capabilities</u> **Passed** (using simulated traffic congestion data and simulated weather data) <u>Data Analysis and Transmission Capabilities</u> **Passed** <u>Shockwave Detection and Response Capabilities</u> **Passed**	<u>Data Collection Capabilities</u> **TME SPD-HARM** <u>Data Analysis and Transmission Capabilities</u> **TME SPD-HARM** <u>Shockwave Detection and Response Capabilities</u> **TME SPD-HARM**
TC 1-11	**TME WRTM Application Functionality**	0.1 12.1 12.2 12.3 12.4 12.5 12.6	12.7 12.8 12.9 12.10 12.11 17.1 17.2	To verify: • Application will use input data obtained from fixed-point detection equipment • INFLO Prototype will use real or simulated data to represent traffic, weather, and road conditions • Time sensitive data used in application shall be time stamped using a common time reference • TME-based WRTM's capability of fusing weather information from multiple sources to determine the location of potential hazardous conditions • TME-based WRTM's capability includes providing weather-related travel warning message based on measured conditions and weather-related alerts and/or warnings based on forecasted conditions	<u>TME WRTM</u> • Tested in the Laboratory 4/30/14 using Simulated Traffic Congestion Data • Tested in the Laboratory 4/30/14 as a subset of SPD-HARM using Simulated Weather Data	**Passed** (using simulated traffic congestion data and simulated weather data)	**TME SPD-HARM w/WRTM**
TC 1-12	**TME-Based Information Dissemination Sub-system (IDS) Functionality**	13.1 13.2 13.3 13.4	13.5 13.6 13.7 16.1 16.3 16.4	To verify: • TME-based IDS's ability to receive real-time data from all TME-based applications • TME-based IDS's ability to approximate travel speeds based on criteria provided by TMO • TME-based IDS's ability to generate target speed strategies which consider traffic, weather, and road surface conditions • TME-derived target speed and shockwave information and TME-derived queue warning information will be shared with other DMAs via the TME • TME will disseminate queue warnings and information to traveler information systems	Not Tested in the Laboratory	Not Tested in the Laboratory	**TME Q-WARN** **TME SPD-HARM**

Test Case Number	Test Case Title	Requirements Addressed (Number)		Test Case Objectives	Test Case Results Summary	Test Case Pass/Fail Results	System Level Validation (INFLO Application)
TC 1-13	**TME-based Communication System (CS) Functionality**	14.1 14.2 14.3 14.4 14.5	14.6 14.7 14.8 14.9	To verify: • TME-based CS's ability to disseminate queue warnings and information to connected vehicles, traveler information systems and DMS locations • TME-based CS's ability to receive near real-time data from the Nomadic Device and Roadside Equipment over the cellular infrastructure • TME-based CS's ability to send messages to the Nomadic Device or for transmission over DSRC to the Roadside Equipment over the cellular infrastructure • TME-based CS's ability to generate messages conveying recommended speeds and queue/weather warning information for display on DMS	Communication System • Tested in laboratory 4/28/2014 using Arada RSU, TME, Arada ME and phone. • Did not test ability to disseminate warnings to DMS locations	Communication System **Passed Partial – Did not disseminate to DMS**	**Conference Room** **TME Q-WARN** **TME SPD-HARM**
TC 1-14	**Roadside Equipment (RSE) Functionality**	15.1 15.2 15.3	15.4 15.5 15.6	To verify: • RSE's ability to utilize V2I communication between connected vehicle applications and infrastructure systems to disseminate vehicle-collected data (speed, location, weather, road conditions etc.) • RSE's ability to utilize V2I communication between connected vehicle applications and infrastructure systems to send target speed and lane recommendations and justifications to connected vehicle applications • RSE's ability to disseminate target speed recommendations and queue warnings and information to DMS locations • RSE's interoperability with equipped vehicles according to IEEE and SAE standards	• Tested in laboratory 4/28/2014 using Arada RSU, TME, Arada ME and phone. • Verified using 3M packet sniffer and verified decoding of messages. • This was not specifically tested but all code was implemented using the Arada API. The Arada units are approved for use in the Safety Pilot and based on this they are interoperable. Fields in some standard messages were used for other values but do not change the structure of the messages.	**Passed**	**Conference Room** **TME Q-WARN** **TME SPD-HARM**

APPENDIX B. Example Android Log Files

Log Files Created on Android Phone

The following log files are created on the Android device and can be accessed from the SD card on the phone. Additional examples can be seen in the log files included with the test package.

1. TME Requests
    a. File name (timetag)_tme-requests.txt
    b. Tab separated file
    c. These are the request to the TME for any current alerts
    d. Requests contain Roadway ID and Mile Marker
    e. File also contains latency and return alerts
    f. Returned Alerts are BER encoded TIM messages
2. Radio Signals
    a. File name (timetag)_radio-signal.txt
    b. Tab separated file
    c. Contains information concerning the radio signals of remote vehicles
3. Received BSMs
    a. File name (timetag)_received-bsms.txt
    b. Tab separated file
    c. BER encoded BSM messages that are sent to the TME
4. Queue Alerts
    a. File name (timetag)_qwarn.txt
    b. Tab separated file
    c. Contains all queue alerts received from the Arada Radio

Timestamp	BOQ	FOQ	Length	Time-FOQ	Recommended Action
2014-05-07T07:42:33.045-04:00	0.04341	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:33.696-04:00	0.041228	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:33.898-04:00	0.04042	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:34.569-04:00	0.03798	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:35.185-04:00	0.035443	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:36.011-04:00	0.032	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:36.720-04:00	0.028058	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:36.898-04:00	0.027009	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:37.643-04:00	0.022598	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:38.266-04:00	0.020272	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:38.461-04:00	0.017833	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:39.075-04:00	0.013988	-1.0	-1.0	-1	Q-WARN: Queue Ahead
2014-05-07T07:42:40.014-04:00	-1.0	0.168454	-1.0	12	Q-WARN: In Queue
2014-05-07T07:42:40.159-04:00	-1.0	0.168454	-1.0	12	Q-WARN: In Queue
2014-05-07T07:42:40.611-04:00	-1.0	0.168454	-1.0	12	Q-WARN: In Queue
2014-05-07T07:42:41.694-04:00	-1.0	0.168105	-1.0	11	Q-WARN: In Queue
2014-05-07T07:42:41.802-04:00	-1.0	0.166719	-1.0	11	Q-WARN: In Queue
2014-05-07T07:42:42.101-04:00	-1.0	0.163956	-1.0	11	Q-WARN: In Queue
2014-05-07T07:42:43.140-04:00	-1.0	0.156581	-1.0	11	Q-WARN: In Queue
2014-05-07T07:42:43.302-04:00	-1.0	0.155079	-1.0	11	Q-WARN: In Queue
2014-05-07T07:42:43.633-04:00	-1.0	0.153578	-1.0	10	Q-WARN: In Queue
2014-05-07T07:42:44.723-04:00	-1.0	0.146542	-1.0	10	Q-WARN: In Queue
2014-05-07T07:42:45.107-04:00	-1.0	0.142388	-1.0	10	Q-WARN: In Queue
2014-05-07T07:42:46.421-04:00	-1.0	0.133964	-1.0	9	Q-WARN: In Queue
2014-05-07T07:42:46.558-04:00	-1.0	0.132461	-1.0	9	Q-WARN: In Queue
2014-05-07T07:42:46.713-04:00	-1.0	0.131076	-1.0	9	Q-WARN: In Queue
2014-05-07T07:42:47.839-04:00	-1.0	0.123687	-1.0	8	Q-WARN: In Queue
2014-05-07T07:42:48.031-04:00	-1.0	0.122188	-1.0	8	Q-WARN: In Queue
2014-05-07T07:42:48.192-04:00	-1.0	0.12069	-1.0	8	Q-WARN: In Queue
2014-05-07T07:42:49.437-04:00	-1.0	0.111919	-1.0	7	Q-WARN: In Queue
2014-05-07T07:42:49.660-04:00	-1.0	0.110534	-1.0	7	Q-WARN: In Queue
2014-05-07T07:42:49.902-04:00	-1.0	0.110534	-1.0	7	Q-WARN: In Queue
2014-05-07T07:42:50.903-04:00	-1.0	0.10004	-1.0	7	Q-WARN: In Queue
2014-05-07T07:42:51.047-04:00	-1.0	0.098542	-1.0	7	Q-WARN: In Queue
2014-05-07T07:42:51.413-04:00	-1.0	0.097041	-1.0	6	Q-WARN: In Queue
2014-05-07T07:42:52.281-04:00	-1.0	0.089543	-1.0	6	Q-WARN: In Queue

Figure B-1. Example Queue Warning Log File

5. Speed Harmonization Alerts
    a. File name (timetag)_spdharm.txt
    b. Tab separated file
    c. Contains all speed harmonization alerts received from the Arada Radio

Timestamp	Speed	Justification
2014-05-07T07:33:51.057-04:00	5	Slow Traffic
2014-05-07T07:33:52.556-04:00	5	Slow Traffic
2014-05-07T07:33:53.150-04:00	5	Slow Traffic
2014-05-07T07:33:53.628-04:00	5	Slow Traffic
2014-05-07T07:33:54.073-04:00	5	Slow Traffic
2014-05-07T07:33:54.495-04:00	5	Slow Traffic
2014-05-07T07:33:55.283-04:00	5	Slow Traffic
2014-05-07T07:33:55.660-04:00	5	Slow Traffic
2014-05-07T07:33:56.231-04:00	5	Slow Traffic
2014-05-07T07:33:56.760-04:00	5	Slow Traffic
2014-05-07T07:33:57.150-04:00	5	Slow Traffic
2014-05-07T07:33:58.275-04:00	5	Slow Traffic
2014-05-07T07:33:58.646-04:00	5	Slow Traffic
2014-05-07T07:33:59.158-04:00	5	Slow Traffic
2014-05-07T07:34:00.057-04:00	5	Slow Traffic
2014-05-07T07:34:00.188-04:00	5	Slow Traffic
2014-05-07T07:34:00.824-04:00	5	Slow Traffic
2014-05-07T07:34:01.684-04:00	5	Slow Traffic
2014-05-07T07:34:02.314-04:00	5	Slow Traffic
2014-05-07T07:34:02.659-04:00	5	Slow Traffic
2014-05-07T07:34:03.049-04:00	5	Slow Traffic
2014-05-07T07:34:03.199-04:00	5	Slow Traffic
2014-05-07T07:34:03.825-04:00	5	Slow Traffic
2014-05-07T07:34:04.685-04:00	5	Slow Traffic
2014-05-07T07:34:05.277-04:00	5	Slow Traffic
2014-05-07T07:34:06.226-04:00	5	Slow Traffic
2014-05-07T07:34:06.384-04:00	5	Slow Traffic
2014-05-07T07:34:06.870-04:00	5	Slow Traffic
2014-05-07T07:34:07.672-04:00	5	Slow Traffic
2014-05-07T07:34:07.861-04:00	5	Slow Traffic
2014-05-07T07:34:08.460-04:00	5	Slow Traffic
2014-05-07T07:36:40.681-04:00	-1	
2014-05-07T07:39:05.694-04:00	-1	Road
2014-05-07T07:39:37.522-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:37.955-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:38.969-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:39.241-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:39.371-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:40.433-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:40.683-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:40.874-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:41.976-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:42.278-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:42.459-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:43.604-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:43.743-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:45.014-04:00	15	Speed-Harm: 3rd Ave East
2014-05-07T07:39:45.452-04:00	15	Speed-Harm: 3rd Ave East

Figure B-2. Example Speed Harmonization Log File

6. Console output from the Application
    a. File name (timetag).txt
    b. Tab separated file
    c. Contains logcat output from the Android device

APPENDIX C. Requirements Traceability Matrix for INFLO Prototype Acceptance Testing

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
0.1	Common	All time sensitive data used in the applications shall be timestamped using a common time reference.		A	Not Tested at this Level.					Not verified during this level of testing.
1.1	CV 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	Demonstrate by showing that warnings specified for a particular road segment were indeed displayed when the vehicle traversed this road segment, and similarly, did not display warnings when traveling in the opposite direction along the same road segment.	☑			☑	
1.2	CV 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.	Lane specific detection requires an accuracy of equipment greater than what U.S. 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.	D	Not Tested					Not a feature included in the Prototype. Lane level accuracy not reliable.
1.3	CV 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).		D	Verify the reported speed of the vehicle as captured by BSM are consistent with the speed measured by the onboard speedometer.	☑				
1.4	CV 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).		D	Demonstrate by showing that warnings specified for a particular road segment were indeed displayed when the vehicle traversed this road segment, and similarly, did not display warnings when traveling in the opposite direction along the same road segment.	☑			☑	
1.5	CV 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.	Revised requirement to ensure point of view is consistent with the stated subsystem. Revised real-time to put an achievable and measureable constraint.	A	Demonstrate by showing vehicle position information on a map. Also showed the configuration file that enabled this setting.	☑			☑	
1.6	CV 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.	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.	A	Demonstrate ability of system to include vehicle-based data in the outgoing data (BSM) stream.	☑				
1.7	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall receive target speed recommendations from the TME-based SPD-HARM application via I2V communications.	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.	D	Demonstrate receipt of target speed information via both DSRC and LTE paths.	☑				
1.8	CV 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.	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.	A	Demonstrate ability of the Nomadic Device to receive information supporting the target speed recommendation.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
1.8.1	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall receive target speed recommendations from the TME-based Vehicle Message Generator via I2V communication subsystems.	This would be either regulatory or advisory speed recommendations.	D	Demonstrate receipt of target speed information via both DSRC and LTE paths.	☑				
1.8.2.	CV 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.	E.g., "Congestion", "queue" "Limited Visibility" , "Icy Conditions", etc.	D	Demonstrate ability of the Nomadic Device to receive information supporting the target speed recommendation.	☑				
1.8.3	CV 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.		A	Demonstrate display of user information for a specific segment of roadway as configured in the TME database.	☑				
1.8.4	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall receive target lane recommendations from the TME-based Vehicle Message Generator via the I2V communication subsystems.			Not Tested					Not a feature included in the Prototype. Lane level accuracy not reliable.
1.8.5	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall receive roadway reference information from the TME-based Vehicle Message Generator via I2V communication subsystems.	We need something that allows the vehicle to locate itself on a mile-maker referencing systems.	D	Demonstrate display of user information for a specific segment of roadway as configured in the TME database.		☑			
1.9	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall receive queue warnings and queue information from the TME-based Vehicle Message Generator via I2V communications.	Revised requirement to ensure point of view is consistent with the stated subsystem.	D	Demonstrate display of queue ahead and in-queue messages on the Nomadic Device		☑			
1.9.1	CV 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	Demonstrate display of the position of the front of the queue on the nomadic device.		☑			
1.9.2	CV 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	Demonstrate the display of Distance to queue, which is derived from the nomadic device knowing both its position and the back of queue.		☑			
1.9.3	CV 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	Demonstrate the display of the rate of growth of the queue on the nomadic device.		☑			
1.9.4	CV 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.			Not Tested					Not a feature included in the Prototype.
1.9.5	CV 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	Demonstrate display of the speed in queue information, as received from the TME, on the nomadic device.		☑			
1.10	CV 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	Demonstrate ability of Nomadic device to operate as a fully battery-operated unit, sending and receiving both DSRC and LTE information. Also demonstrate ability to do same with vehicle-powered DSRC, and device that includes In-Vehicle Network Access.	☑				
1.11	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall be able operate on battery power when not installed in a vehicle.		D	Demonstrate operation of nomadic device when powered by battery-only.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
1.12	CV Nomadic Device	The vehicle installed Connected Vehicle (Nomadic Device) equipment shall not obstruct the vehicle driver's field of view.		D	Demonstrate how mounting of device in vehicle is similar to that of traditional GPS navigation unit and does not obstruct field of view, while maintaining necessary operational characteristics.	☑				
1.13	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall operate and charge the battery on the voltage supplied by the Test Vehicle.		D	Demonstrate charging and operating functions while installed in a vehicle.	☑				
1.14	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall log all alerts issued to the driver including the parameters that triggered the alerts.		A	Not Tested at this Level.					Not verified during this level of testing.
1.15	CV 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.	Requirement exists for prototype testing and data gathering. Use of Device ID for real-world implementation must deal with PII issues.	A	Not Tested at this Level.					Not verified during this level of testing.
1.16	CV Nomadic Device	The Connected Vehicle (Nomadic Device) shall log all outbound messages generated by the vehicle-based applications.		A	Not Tested at this Level.					Not verified during this level of testing.
1.17	CV 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	Not Tested at this Level.					Not verified during this level of testing.
1.19	CV Nomadic Device	The Connected Vehicle (Nomadic device) shall have access to vehicle state data when installed in the vehicle.	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.	D	Demonstrate ability of Nomadic Device to pair with a vehicle-installed OBD-II adapter and to retrieve example data via this interface.	☑				
2.1	CV User Interface System	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.	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.	D	Demonstrate display of target speed recommendations using on-screen messages.	☑				
2.2	CV User Interface System	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.	Lane Specific detection requires an accuracy of equipment greater than what U.S. 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.	D	Not Tested at this Level.					Not verified during this level of testing.
2.3	CV User Interface System	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	Demonstrate display of speed change justification information using on-screen messages. Typical message might be 'queue ahead'.	☑				
2.4	CV User Interface System	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.	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.	D	Demonstrate display of queue ahead and in-queue messages, along with distance to back of queue, on the Nomadic Device.		☑		☑	Lanes was not demonstrated, but is a matter of having scenario where TME would issue recommendation that includes lane guidance. Nomadic Device is not expected to discern lanes at this time.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
2.5	CV User Interface System	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.	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.	D	Demonstrate display of 'reduce speed' in response to q-warn response strategies.		☑		☑	
2.6	CV User Interface System	The UI latency from receipt of event to aural and visual display shall be less than 500 milliseconds.		T	Not Tested at this Level.					Not verified during this level of testing.
2.7	CV User Interface System	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.		D	Demonstrate Nomadic device has indication that it is operating (i.e. powered-on and communicating) even when no active alerts or warnings are in progress.	☑	☑		☑	
3.1	CV-based Q-WARN App	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	Demonstrate Nomadic Device receives TME-based information necessary to notify drivers of current condition.		☑			
3.2	CV-based Q-WARN App	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	Demonstrate the Nomadic Device receives Queue related information from other DSRC-equipped vehicles				☑	
3.3	CV-based Q-WARN App	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	Not Tested					Not a feature included in the Prototype.
3.4	CV-based Q-WARN App	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.	Needs to determine its position in terms of roadway mile markers.	D	Demonstrate by showing that warnings specified for a particular road segment were indeed displayed when the vehicle traversed this road segment, and similarly, did not display warnings when traveling in the opposite direction along the same road segment.				☑	
3.5	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall have the ability to detect when the vehicle is in a queued state.		D	Demonstrate ability of Nomadic Device to identify when it is below the stated threshold for being considered 'queued', and to include this indicator in the BSM II message.		☑		☑	
3.6	CV-based Q-WARN App	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	Demonstrate ability of Nomadic Device to identify when it is below the stated threshold for being considered 'queued', and to include this indicator in the BSM II message.		Partial			Current response strategy does not consider diversion recommendations, nor as previously discussed, lane changes.
3.7	CV-based Q-WARN App	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	Demonstrate ability to calculate and update distance to back of queue as vehicle approaches the queue.		☑		☑	

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
3.8	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall pass vehicle's calculated distance to back of queue to the driver interface system.		D	Demonstrate ability to calculate and update distance to back of queue as vehicle approaches the queue.		☑		☑	
3.9	CV-based Q-WARN App	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.		D	Demonstrate ability of CV-based Q-WARN application to generate distance to back of queue, queue-ahead and in-queue information to the user.		☑			Lanes impacted is not presently available.
3.10	CV-based Q-WARN App	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).		D	Demonstrate ability of CV-based Q-WARN application to generate distance to back of queue, queue-ahead and in-queue information to the user.		Partial		☑	Current response strategy does not consider diversion recommendations, nor as previously discussed, lane changes.
3.11	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall utilize secure data transmission methods when disseminating any personally identifiable information.	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.	A	Not Tested at this Level.					Not Verified during this level of testing.
3.12	CV-based Q-WARN App	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.	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.	D	Not Tested					Not a feature included in the Prototype.
3.13	CV-based Q-WARN App	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.	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.	D	Not Tested					Not a feature included in the Prototype.
3.14	CV-based Q-WARN App	Communications between the Connected Vehicle-based Q-WARN application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	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.	A	Not Tested at this Level.					Not verified during this level of testing.
3.15	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.		D	Demonstrate ability of the CV-based Q-WARN application to include the 'queued' state in the BSM II message				☑	
3.16	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to infrastructure systems via V2I communication.		D	Demonstrate receipt of BSM II with 'queued' state by the TME		☑	☑		
3.17	CV-based Q-WARN App	The Connected Vehicle-based Q-WARN application shall be developed in accordance with practices allowing for open-source use of the application.		I	Not Tested at this Level.					Not verified during this level of testing.
4.1	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall pass target speed recommendations to the driver interface system.		D	Demonstrate display of target speed recommendations on the Nomadic Device.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
4.2	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall pass target lane recommendations to the driver interface system.	Lane specific detection requires an accuracy of equipment greater than what U.S. 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.		Not Tested					Not a feature included in the Prototype. Lane level accuracy not reliable.
4.3	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall pass speed change justification information to the driver interface system.		D	Demonstrate display of speed justification information, such as Queue Ahead, on the Nomadic Device.	☑				
4.4	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall utilize secure data transmission methods when disseminating any personally identifiable information.		A	Not Tested at this Level.					Not verified during this level of testing.
4.5	CV-based SPD-HARM App	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	Demonstrate inclusion (and absence) of vehicle-based as received by the cloud-based database.	☑				
4.6	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall have access to following data: time, location, velocity, heading, barometric pressure, lateral and longitudinal acceleration.	When available, this data will be collected from the IVNA. However, this specific data (as listed) may also be collected from the Nomadic Device.	D	Demonstrate receipt of vehicle-based data, as shown, in the cloud-based database.	☑				
4.7	CV-based SPD-HARM App	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.	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.	D	Not Tested at this Level.					Not verified during this level of testing.
4.8	CV-based SPD-HARM App	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.	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.	D	Demonstrate receipt of vehicle-based data, as shown, in the cloud-based database.	☑				
4.9	CV-based SPD-HARM App	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.	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.	D	Not Tested at this Level.					Not verified during this level of testing.
4.10	CV-based SPD-HARM App	Communications between the Connected Vehicle-based SPD-HARM application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.		A	Not Tested at this Level.					Not verified during this level of testing.
4.11	CV-based SPD-HARM App	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.		D	Demonstrate receipt of vehicle-based data, as shown, in the cloud-based database.	☑				Partial. Not all data is available from the tested vehicle.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
4.12	CV-based SPD-HARM App	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.		D	Demonstrated display of information on the nomadic device based on information received from the infrastructure	☑				
4.13	CV-based SPD-HARM App	The Connected Vehicle-based Q-WARN application shall interface with the Connected Vehicle-based SPD-HARM application to generate appropriate speed reduction targets.	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.		Not Tested					Not a feature included in the Prototype.
4.14	CV-based SPD-HARM App	The Connected Vehicle-based SPD-HARM application shall be developed in accordance with practices allowing for open-source use of the application.		A	Not Tested at this Level.					Not verified during this level of testing.
5.1	CV Comm. System	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to other connected vehicles via V2V communication.	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.	D	Demonstrate receipt of BSM II with 'queued' state from known 'queued' vehicle.				☑	
5.2	CV Comm. System	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via V2V communication channels.	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.	D	Demonstrate receipt of BSM II and TIM from known 'queued' vehicle.				☑	
5.3	CV Comm. 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.	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.	D	Demonstrated receipt of TIM with Queue information from infrastructure.		☑			
5.4	CV Comm. 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.	The current J2735 message set is sufficient. Some local content will need to be defined within current messages for status.	D	Demonstrate display of messages received form the TMS-based SPD-HARM application on the Nomadic device.	☑				
5.5	CV Comm. System	The Connected Vehicle Communications System shall generate and transmit Basic Safety Messages in compliance with SAE standard J2735 version 2009-11.		I	Not Tested at this Level.					Not verified during this level of testing.
5.6	CV Comm. 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	Not Tested at this Level.					Not verified during this level of testing.
5.7	CV Comm. System	The Connected Vehicle Communications System shall be able to transmit a SAE J2735 Basic Safety Message (BSM) at 10 times per second.		D	Not Tested at this Level.					Not verified during this level of testing.
5.8	CV Comm. 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).		D	Demonstrate transition between use of RSU and LTE communications when RFFI falls below 10db and that communications resume when value exceeds 10db. There is a X second duration of current level before the switch occurs to prevent 'bounce' between the two.	☑				Signal strength (aka power levels) were used as the determining factors to switch between cellular and DSRC, not latency.
5.9	CV Comm. System	The Connected Vehicle Communications System shall be able to switch between use of cellular infrastructure to DSRC within 1 second.			Not Tested					Not a feature included in the Prototype. Use RFII as switching point.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
6.1	CV-based Weather System App	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	Demonstrate receipt of temperature data from the vehicle by reviewing in the cloud database as visualized on a dynamic map.	☑				
6.2	CV-based Weather System App	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.			Not Tested					Not a feature included in the Prototype.
6.3	CV-based Weather System App	The Weather System should provide an ambient temperature range of -50 to 50°C +/- 2°.		A	Not Tested at this Level.					Not verified during this level of testing.
6.4	CV-based Weather System App	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	Demonstrate receipt of air pressure data from the vehicle by reviewing in the cloud database as visualized on a dynamic map.	☑				
6.5	CV-based Weather System App	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.		A	Not Tested					Not a feature included in the Prototype.
6.6	CV-based Weather System App	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	Demonstrate receipt of humidity data from the vehicle by reviewing in the cloud database as visualized on a dynamic map.	☑				
6.7	CV-based Weather System App	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.		A	Not Tested					Not a feature included in the Prototype.
6.8	CV-based Weather System App	The weather system will provide a humidity range of 0 to 100% relative humidity +/-10%.		A	Not Tested at this Level.					Not verified during this level of testing.
7.1	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.	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.	D	Not Tested at this Level.					Not verified during this level of testing.
7.2	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.	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.	D	Demonstrate capture and persistence of available vehicle-based data in the cloud-based database.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
7.3	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.	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.	D	Not Tested at this Level.					Not verified during this level of testing.
7.4	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.		A	Not Tested at this Level.					Not verified during this level of testing.
8.1	Traffic Management Entity	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.		I	Not tested during this phase of the prototype.					Task 3
8.2	Traffic Management Entity	The Traffic Management Entity shall use secure transmission methods for disseminating target speed and lane recommendations and justification for speed changes.		A	Not Tested at this Level.					Not verified during this level of testing.
8.3	Traffic Management Entity	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.		A	Not Tested at this Level.					Not verified during this level of testing.
8.4	Traffic Management Entity	The Traffic Management Entity shall ensure data is authenticated.		A	Not Tested at this Level.					Not verified during this level of testing.
8.5	Traffic Management Entity	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)		D	Demonstrate injection of simulated data representing real-time traffic and other conditions into the database via data aggregation capability.	☑				
8.6	Traffic Management Entity	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.		D	Demonstrate capture and persistence of vehicle-collected movement data in the database.	☑				
8.7	Traffic Management Entity	The TME shall receive vehicle-collected weather data from the Connected Vehicle-based applications utilizing V2I communication.		D	Demonstrate capture and persistence of vehicle-collected weather data in the database.	☑				
8.8	Traffic Management Entity	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	Not tested during this phase of the prototype.					This demonstrates the capability. Actual implementation of this interface is limited to Task 3.
8.8.1	Traffic Management Entity	The TME shall have the capability to obtain traffic condition information for each lane from infrastructure-based traffic sensors.		A	Review the data captured in the database from the simulation model.	☑				
8.8.2	Traffic Management Entity	The TME shall have the capability to obtain average speed for each lane from the infrastructure-based traffic sensors.		A	Review the data captured in the database from the simulation model.	☑				
8.8.3	Traffic Management Entity	The TME shall have the capability to obtain average lane occupancy for each lane from the infrastructure-based traffic sensors.		A	Review the data captured in the database from the simulation model.	☑				
8.8.4	Traffic Management Entity	The TME shall have the capability to obtain vehicle flow rate for each lane from the infrastructure-based traffic sensors.		A	Review the data captured in the database from the simulation model.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
8.8.5	Traffic Management Entity	The TME shall have the capability to obtain data from the traffic sensor on a user-defined interval (e.g. every 20 seconds).		D	Verify the system has a configuration setting to allow for setting this value.	☑				
8.8.6	Traffic Management Entity	The TME shall have the capability to aggregate lane detector data to station-level detector data.		I	Review the data captured in the database from the simulation model.	☑				
8.8.7	Traffic Management Entity	The TME shall be able to determine which traffic sensor station apply to each segment of the freeway.		I	Review the configuration database table that shows the linkage between the traffic sensor stations and the segments of freeway	☑				
8.8.8	Traffic Management Entity	The TME shall be able to determine the operational state of each detector station.			Not Tested					Not a feature included in the Prototype.
8.8.9	Traffic Management Entity	The TME shall be able to verify the quality of the data before it is applied in the algorithms.			Not Tested					Not a feature included in the Prototype.
8.8.10	Traffic Management Entity	The TME shall be able to dynamically configure freeway detection zones to use based on the results of the data quality verification.			Not Tested					Not a feature included in the Prototype.
8.9	Traffic Management Entity	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	Demonstration that the algorithm was capability of receiving simulated data inputs from an ESS.	Partial				Simulated sensor data were used to emulate connection to an actual WRTM.
8.9.1	Traffic Management Entity	The TME shall communicate with ESSs using the most current version on the NTCIP 1204 Environmental Sensor Station Interface Standards.		I	Not Tested					Not a feature included in the Prototype.
8.9.2	Traffic Management Entity	The rate at which the TME obtains weather information from ESSs shall be configurable and consistent with the ESS contributor.	This will most likely be done through a configuration file.	I	Not Tested					Not a feature included in the Prototype.
8.9.3	Traffic Management Entity	The TME shall be able to associate one or more environmental sensor station with the freeway segment.	This will most likely be done through a configuration file.	I	Not Tested					Not a feature included in the Prototype.
8.9.4	Traffic Management Entity	The TME shall determine the operational state of all available environmental sensor stations.			Not Tested					Not a feature included in the Prototype.
8.9.5	Traffic Management Entity	The TME shall obtain information about wind conditions from each ESS that supports this measurement.	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		Not Tested					Not a feature included in the Prototype.
8.9.6	Traffic Management Entity	The TME shall obtain information about precipitation conditions from each ESS that supports this measurement.	Note: The specific data objects likely to be used include the following: 5.8.6 Precipitation Indicator 5.8.9 Precipitation Situation	I	Demonstrate inclusion of road surface co-efficient of friction, an outcome of precipitation, can affect speed harmonization.	Partial				Simulated

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
8.9.7	Traffic Management Entity	The TME shall obtain information about the prevailing visibility conditions from each ESS that supports this measurement.	Note: The specific data objects likely to be used include the following: 5.10.1 Visibility 5.10.2 Visibility situation	I	Demonstrate inclusion of a visibility variable can and does affect speed harmonization calculations.	Partial				Simulated
8.10	Traffic Management Entity	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.	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	I	Not Tested					Not a feature included in the Prototype.
8.11	Traffic Management Entity	The TME shall have the capability to obtain weather forecast information from external weather provider(s).		I	Not Tested					Not a feature included in the Prototype.
8.11.1	Traffic Management Entity	The TME shall obtain forecasted type weather event from external weather provider.		I	Not Tested					Not a feature included in the Prototype.
8.11.2	Traffic Management Entity	The TME shall obtain forecasted start time of weather event from external weather provider.		I	Not Tested					Not a feature included in the Prototype.
8.11.3	Traffic Management Entity	The TME shall obtain forecasted duration of weather event from external weather provider.		I	Not Tested					Not a feature included in the Prototype.
8.11.4	Traffic Management Entity	The TME shall obtain forecasted severity/intensity of weather event from external weather provider.		I	Not Tested					Feature not implemented as part of the prototype.
8.12	Traffic Management Entity	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.		D	Demonstrate capture and persistence of data from the vehicle in the cloud-based database.	☑				As available. Must revisit.
8.13	Traffic Management Entity	The TME shall have an application to mitigate the impacts of shockwaves in the freeway traffic stream. (TME-based SPD-HARM)		D	Demonstrate that the algorithm can identify shockwaves in the traffic stream and provide speed harmonization messages in response to the shockwave.	☑				Per instructions from Noblis, our demonstration was only intended to test the data flow and was not intended to gauge the effectiveness of the recommendation. In order to do this, a feedback mechanism that would feed recommended speeds back into the simulation model would need to be developed. This was beyond the scope of this prototype development.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
8.14	Traffic Management Entity	The TME shall have an application to mitigate the impacts of recurring queues in the freeway traffic stream. (TME-based Q-WARN)		D	Demonstrate that the algorithm can identify the location of the back of the queue at a known bottleneck location as the freeway changes from an uncongested to a congested state.		Partial			Per instructions from Noblis, our demonstration was only intended to test the data flow and was not intended to gauge the effectiveness of the recommendation. In order to do this, a feedback mechanism that would feed recommended speeds back into the simulation model would need to be developed. This was beyond the scope of the this prototype development.
8.15	Traffic Management Entity	The TME shall have an application to mitigate the impacts of travel conditions caused by adverse weather on the freeway. (TME-based WRTM)		D	Demonstrate that the algorithm can provide a recommending travel speed based on input weather data.	Partial				WR SPD HARM Per instructions from Noblis, our demonstration was only intended to test the data flow and was not intended to gauge the effectiveness of the recommendation. In order to do this, a feedback mechanism that would feed recommended speeds back into the simulation model would need to be developed. This was beyond the scope of the this prototype development.
8.16	Traffic Management Entity	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	Demonstrate how a recommended speed change is the result of a detected Queue.	☑	☑			
8.17	Traffic Management Entity	The TME shall have the ability to formulate recommended traffic management strategies for display on infrastructure-based traveler information systems.		A	Demonstrate that the algorithm can produce a recommended speed for each location where an infrastructure sign would be installed.	Partial	Partial			Need DMS emulator
8.18	Traffic Management Entity	The TME shall communicate recommended traffic management strategies to the connected Vehicle utilizing I2V communication.		D	Demonstrate the display of the recommended strategy on the Nomadic Device display	☑	☑			
8.19	Traffic Management Entity	The TME shall make recommended traffic management strategies available for sharing with other dynamic mobility applications.	Will require definition of the interface with these applications and frequency of sharing data and decisions made.	I	Demonstrate the capture and persistence of the recommended strategy in the cloud-based database, which is accessible from other applications.	☑				
8.20	Traffic Management Entity	The TME shall make the shockwave/breakdown, queuing, and roadway condition information available for sharing with other dynamic mobility applications.	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.	I	Demonstrate the capture and persistence of the recommended strategy in the cloud-based database, which is accessible from other applications.	☑				
8.21	Traffic Management Entity	The TME shall communicate traffic, road condition, and weather data to connected vehicles/devices via I2V communications systems.	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.	D	Demonstrate the display of TME-based communications on the Nomadic Device display	☑				
8.22	Traffic Management Entity	The TME shall have a Data Environment to collect, aggregate, and disseminate queue warning related data to freeway traffic management entities.		D	Demonstrate the capture and persistence of queue-warning related data in the cloud-based database, which is accessible from other external applications.		☑			
8.23	Traffic Management Entity	The TME shall have the ability to communicate recommended traffic management strategy data to a Performance Measures Subsystem.		A	Not Tested at this Level.					Not verified during this level of testing.
10.1	TME-based Q-WARN App	The Traffic Management Entity (TME)-based Q-WARN application shall interface with the data environment to obtain the data collected from multiple sources.		I	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of collected data from multiple sources.		☑			

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
10.2	TME-based Q-WARN App	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	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of simulated traffic and road weather data.		Partial			Simulated
10.3	TME-based Q-WARN App	The TME-based Q-WARN application shall have the capability to access real-time traffic conditions from connected vehicles.	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.	D	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of collected data from collected BSM messages.		☑			
10.4	TME-based Q-WARN App	The TME-based Q-WARN application shall have the capability to access real-time pavement conditions from connected vehicles.			Not Tested					Not a feature included in the Prototype.
10.5	TME-based Q-WARN App	The TME-based Q-WARN application shall have a queue detection capability for known fixed queue generation locations.		D	Demonstrate that the algorithm can identify the location of the back of the queue at a known bottleneck location as the freeway changes from an uncongested to a congested state.		☑			
10.6	TME-based Q-WARN App	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.		I	Review the database to show that the location of the back of queue as identified by various source and the final recommended back of queue.		☑			
10.7	TME-based Q-WARN App	The TME-based Q-WARN application shall determine the sections of freeway which are operating in the queued state.	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.	D	Demonstrate the ability of the applications to determine the sublinks of the freeway which are operating in a queued state using the visualization tool developed to validate the algorithm		☑			
10.8	TME-based Q-WARN App	The TME-based Q-WARN application shall determine the length of the formed queue.	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.	D	Demonstrate the ability of the applications to determine the length of the queue using the visualization tool developed to validate the algorithm		☑			
10.9	TME-based Q-WARN App	The TME-based Q-WARN application shall estimate the number of vehicles in the formed queue.	Can provide estimate both determine length of roadway in queue state, and then assuming vehicle length to estimate number of vehicles in queue.		Not Tested					Not a feature included in the Prototype.
10.10	TME-based Q-WARN App	The TME-based Q-WARN application shall determine the traveling speed and direction of the formed queue.	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.	D	Demonstrate the ability of the applications to determine the traveling speed and direction of the formed queue using the visualization tool developed to validate the algorithm		☑			
10.11	TME-based Q-WARN App	The TME-based Q-WARN application shall provide an estimate of average speed of vehicles traveling in the congested state.		I	Demonstrate the ability of the applications to calculate an estimate of average speed of vehicles traveling in the congested state. using the visualization tool developed to validate the algorithm		☑			
10.12	TME-based Q-WARN App	The TME-based Q-WARN application shall update the estimation of the traveling speed of the queue once per second.	The periodicity of collected data, whether from fixed-infrastructure or from a connected vehicle will not support this performance requirement.	A	Demonstrate the ability of the applications to update the estimation of the traveling speed of the queue once every 5 seconds using the visualization tool developed to validate the algorithm		☑			Implemented as 5 Seconds
10.13	TME-based Q-WARN App	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue prediction.	Need to define specifically what data is to be fused and processed.		Not Tested					Not a feature included in the Prototype.
10.14	TME-based Q-WARN App	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	Not Tested at this Level.					Not verified during this level of testing.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
10.15	TME-based Q-WARN App	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	Not Tested at this Level.					Not verified during this level of testing.
10.16	TME-based Q-WARN App	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	Not Tested at this Level.					Not verified during this level of testing.
10.17	TME-based Q-WARN App	The TME-based Q-WARN application shall have a queue warning response strategy generation capability.		D	Demonstrate the resulting response strategies presented to the user via the Nomadic Device.		☑			
10.18	TME-based Q-WARN App	The TME-based Q-WARN strategies shall include recommended target speeds, characteristics about queues and queue warning messages for the infrastructure.		D	Demonstrate the resulting response strategies presented to the user via the Nomadic Device.		Partial			
10.19	TME-based Q-WARN App	The TME-based Q-WARN application shall interface with the TME-based SPD-HARM application to generate appropriate speed reduction targets.		D	Demonstrate that travel speeds are recommended for each link and sublink approaching the back of the queue.		☑			
10.20	TME-based Q-WARN App	The TME-based Q-WARN application shall generate upstream recommended target speed strategies that consider distance to back of queue.		D	Demonstrate that the recommended travel speed propagate upstream from the back of queue location.		☑			
10.21	TME-based Q-WARN App	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.	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.		Not Tested					Not a feature included in the Prototype.
10.22	TME-based Q-WARN App	The TME-based Q-WARN application shall have a queue warning and queue information dissemination capability.		D	Demonstrate the resulting response strategies presented to the user via the Nomadic Device.		☑			
10.23	TME-based Q-WARN App	The TME-based Q-WARN application shall provide a means to identify, track, and analyze unidentified or mis-identified queue formation events.	The prototype type will log all data inputs, process results, and messaging to assist in assessment of unidentified or miss-identified queue information events.	I	Not tested during this phase of the prototype.					Not implemented for this Phase of testing. Expected to be demonstrated in Task 3.
10.24	TME-based Q-WARN App	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	Data will be logged in the data environment. It is assumed that this is sufficient to satisfy this requirement.	D	Not Tested at this Level.					Not verified during this level of testing.
10.25	TME-based Q-WARN App	The TME-based Q-WARN Application shall be developed in accordance with practices allowing for open-source use of the application.		I	Not tested at this level.					Not verified during this level of testing.
11.1	TME-based SPD-HARM App	The TME-based SPD-HARM application shall have the capability to receive real-time traffic (including location and speed) from connected vehicles.		I	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of collected data from multiple sources.	☑				
11.2	TME-based SPD-HARM App	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.	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.	I	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of simulated traffic and road weather data.	☑				

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
11.3	TME-based SPD-HARM App	The TME-based SPD-HARM application shall be capable of fusing and processing data from various sources to make target speed recommendations.		I	Demonstrate the existence and functionality of a cloud-based data environment which serves as the source of simulated traffic and road weather data.	☑				
11.4	TME-based SPD-HARM App	The TME-based SPD-HARM application shall utilize real-time traffic data when calculating the recommended target speed.		I	Demonstrate the existence and functionality of a cloud-based data environment which intakes near real time connected vehicle data.	☑				
11.5	TME-based SPD-HARM App	The TME-based SPD-HARM application should utilize historical traffic data when calculating the recommended target speed.	See comment for requirement 11.3 above.		Not Tested					Not a feature included in the Prototype.
11.6	TME-based SPD-HARM App	The TME-based SPD-HARM application should utilize real-time and forecasted weather data when calculating the recommended target speed.	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.	D	Demonstrate capability of applications to current weather when calculating the recommended target speed.	Partial				Forecasted weather data is not currently being used by the algorithm.
11.7	TME-based SPD-HARM App	The TME-based SPD-HARM application should utilize real-time and predicted road surface data when calculating the recommended target speed.	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.	I	Demonstrate capability of applications to current road conditions when calculating the recommended target speed.	Partial				Predicted road surface conditions are not currently being used by the algorithm.
11.8	TME-based SPD-HARM App	The TME-based SPD-HARM application shall have a shockwave detection capability for known fixed bottleneck locations.		D	Demonstrate that the algorithm can identify shockwaves in the traffic stream and provide speed harmonization messages in response to the shockwave that forms at a known bottleneck location.	☑				
11.9	TME-based SPD-HARM App	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.	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.	I	Not Tested at this Level.					Not verified during this level of testing.
11.10	TME-based SPD-HARM App	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.	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.	I	Not Tested at this Level.					Not verified during this level of testing.
11.11	TME-based SPD-HARM App	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.	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.	A	Not Tested at this Level.					Not verified during this level of testing.
11.12	TME-based SPD-HARM App	The TME-based SPD-HARM application shall determine the segment(s) impacted by the formed shockwave.	We will include a method of capturing and retaining the defined data requirements to allow for post-processing and analysis.	D	Demonstrate the identification of segments impacted by formed shockwaves using the algorithm visualization tool.	☑				
11.13	TME-based SPD-HARM App	The TME-based SPD-HARM application shall determine the location of the formed shockwave.		D	Demonstrate the identification and display of the location of the formed shockwave utilizing the algorithm visualization tool.	☑				
11.14	TME-based SPD-HARM App	The TME-based SPD-HARM application shall determine the speed and direction of the formed shockwave.		D	Demonstrate the identification and display of the speed and direction of the formed shockwave utilizing the algorithm visualization tool.	☑				
11.15	TME-based SPD-HARM App	The TME-based SPD-HARM application shall update the current shockwave length estimation once per second.	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.		Not Tested					Not a feature included in the Prototype. Shockwaves don't have length. They are a boundary between flow regimes.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
11.16	TME-based SPD-HARM App	The TME-based SPD-HARM application shall utilize real-time traffic data in shockwave detection algorithms.		I	Demonstrate the use of simulated, but real-time data in the shockwave detection algorithms using the algorithm visualization tool.	Partial				Uses simulated data as input.
11.17	TME-based SPD-HARM App	The TME-based SPD-HARM application shall have a recommended target speed generation capability.		D	Demonstrate the display of information on the nomadic device based on information received from the TME.	☑				
11.18	TME-based SPD-HARM App	The TME-based SPD-HARM application shall generate recommended target speed strategies for different segments of the roadway.		D	Demonstrate the determination of the recommended target speed strategies of the formed shockwave utilizing the algorithm visualization tool.	☑				
11.19	TME-based SPD-HARM App	The Traffic Management Entity (TME)-based SPD-HARM application shall have a data collection capability for receiving real-time data from multiple sources.		D	Demonstrate the capture and persistence of both simulated and real-time data in the cloud-based database.	Partial				Realtime infrastructure data is not currently demonstrated, however same aggregator used for simulated data has been developed.
11.20	TME-based SPD-HARM App	The TME-based SPD-HARM application shall have a target speed recommendation dissemination capability.		D	Demonstrate the display of information on the nomadic device based on information received from the TME.	☑				
11.21	TME-based SPD-HARM App	The TME-based SPD-HARM application shall disseminate target speed recommendations to SPD-HARM enabled connected vehicles on the facility via I2V communications.	Standard messages to be utilized need to be identified.	D	Demonstrate the display of information on the nomadic device based on information received from the TME.	☑				
11.22	TME-based SPD-HARM App	The TME-based SPD-HARM application shall disseminate target speed recommendations to DMS locations.		I	Not tested during this phase of the prototype.					Task 3 DMS
12.1	TME-Based WRTM App	The TME-based WRTM application shall obtain road weather information from infrastructure-based environmental sensing stations (ESS) (aka RWIS).		D	Not tested during this phase of the prototype.					Not implemented for this Phase of testing. Expected to be demonstrated in Task 3.
12.2	TME-Based WRTM App	The TME-based WRTM application shall obtain road weather information from mobile weather monitoring devices.		I	Not tested during this phase of the prototype.					Not implemented for this Phase of testing. Expected to be demonstrated in Task 3.
12.3	TME-Based WRTM App	The TME-based WRTM application shall obtain weather forecast information from external weather service providers.			Not Tested					Not a feature included in the Prototype.
12.4	TME-Based WRTM App	The TME-based WRTM application shall obtain road condition information from connected vehicles.			Not Tested					Not a feature included in the Prototype.
12.5	TME-Based WRTM App	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.			Not Tested					Not a feature included in the Prototype.
12.6	TME-Based WRTM App	The TME-based WRTM application shall identify traffic management strategies for low visibility conditions.		D	Demonstrate the identification and display of the location of traffic management strategies for low visibility conditions utilizing the algorithm visualization tool.	☑				
12.7	TME-Based WRTM App	The TME-based WRTM application shall identify traffic management strategies for road surface conditions that impact travel speeds.		D	Demonstrate the identification and display of the location of traffic management strategies for road surface conditions that impact travel speeds utilizing the algorithm visualization tool.	☑				
12.8	TME-Based WRTM App	The TME-based WRTM application shall identify traffic management strategies for high wind conditions.			Not Tested					Not a feature included in the Prototype.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
12.9	TME-Based WRTM App	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.			Not Tested					Not a feature included in the Prototype.
12.10	TME-Based WRTM App	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	Demonstrate the generation and dissemination of weather-related traffic management strategies via the nomadic device display.	☑				
12.11	TME-Based WRTM App	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.			Not Tested					Not a feature included in the Prototype.
13.1	TME-Based Information Dissemination Sub-system	The Traffic Management Entity (TME)-based Information Dissemination application shall have the capability for receiving real-time data from all the TME-based applications.		I	Demonstrate the timely display of information on the nomadic device based on information received from the TME.	☑				
13.2	TME-Based Information Dissemination Sub-system	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	Demonstrate the timely display of segment specific travel speed information on the nomadic device based on information received from the TME.	☑				
13.3	TME-Based Information Dissemination Sub-system	The TME-based Information Dissemination application shall generate target speed strategies that consider downstream traffic conditions, weather, and local roadway surface conditions.		D	Not Tested					The requirement is incorrectly worded as this is not a capability of this subsystem.
13.4	TME-Based Information Dissemination Sub-system	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.	Will require definition of the interface with these applications and frequency of sharing data and decisions made.	A	Not Tested at this Level.					Not verified during this level of testing.
13.5	TME-Based Information Dissemination Sub-system	The TME-based Information Dissemination application shall generate target speed strategies that consider distance to back of queue.		I	Not Tested					The requirement is incorrectly worded as this is not a capability of this subsystem.
13.6	TME-Based Information Dissemination Sub-system	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.			Not Tested					Not a feature included in the Prototype.
13.7	TME-Based Information Dissemination Sub-system	Q-WARN-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	Data will be logged in data environment, but that is the extent of how this requirement will be satisfied.	A	Not Tested at this Level.					Not verified during this level of testing.
14.1	TME-based Comm System	The TME-based application shall disseminate queue warnings and queue information to DMS locations.		I	Not tested during this phase of the prototype.					Task 3 DMS
14.2	TME-based Comm System	The TME-based application shall disseminate queue warnings and queue information to connected vehicles.		D	Demonstrate the ability of the system to disseminiate queue warnings and information to the connected vehicle via the nomadic device display.		☑			

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
14.3	TME-based Comm System	The TME-based application shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	The prototype will generate a generic queue warning message that other applications can use.	A	Not Tested at this Level.					Not verified during this level of testing.
14.4	TME-based Comm 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	Demonstrate the capture of information in the cloud database as received from the nomadic device when no DSRC RSU is available.	☑				
14.5	TME-based Comm 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.		D	Demonstrate the capture of information in the cloud database as received from the nomadic device when DSRC RSU communications are available	☑				
14.6	TME-based Comm System	The TME-based Communications System shall have the capability to send messages to the Nomadic Device over the cellular infrastructure.		D	Demonstrate the display of information on the nomadic device based on information received from the infrastructure when outside of DSRC range.	☑				
14.7	TME-based Comm 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.		D	Demonstrate the display of information on the nomadic device based on information received from the infrastructure when within DSRC range.	☑				
14.8	TME-based Comm System	The TME shall have the ability to generate messages conveying the recommended target speeds for display on dynamic speed control signs.			Not Tested					Not a feature included in the Prototype.
14.9	TME-based Comm System	The TME shall have the ability to generate messages conveying the queue/weather warning information for display on dynamic message signs.			Not Tested					Not a feature included in the Prototype.
15.1	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).		D	Demonstrate ability of Nomadic Device to use DSRC communications to provide vehicle-collected data in the form of the BSM II message.	☑				
15.2	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).		D	Demonstrate ability of Nomadic Device to use DSRC communications to provide vehicle-collected data in the form of the BSM II message.	☑				
15.3	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.		D	Demonstrate ability of Nomadic Device to receive information from the DSRC RSU.	☑				Not Lanes
15.4	Roadside Equipment	The TME-based applications shall disseminate target speed recommendations to DMS locations.			Not Tested					Not a feature included in the Prototype.
15.5	Roadside Equipment	The TME-based applications shall disseminate queue warnings and queue information to DMS locations.			Not Tested					Not a feature included in the Prototype.

Rqmt No.	System / SubSystem	Requirement	Prototype-Specific Rqmts Notes	Method	Test Description	SPD-HARM (TME) w/ WRTM	Q-WARN (TME)	Q-WARN (Cloud)	Q-WARN (V2V)	Verification Notes
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.		A	Not Tested at this Level.					Not verified during this level of testing.
16.1	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.	Will require definition of the interface with these applications and frequency of sharing data and decisions made.	A	Demonstrate the ability of the system to generate and persist the necessary target speed info and shockwave/breakdown formation information to enable use by third party applications.	☑	☑			Need documentation
16.2	Enable ATIS Application, FRATIS Application	The TME application shall generate queue warning response strategies that include recommended target speeds reduction, and lane(s) queued.		A	Demonstrate the ability of the system to generate and persist the necessary response strategies to enable use by third party applications.	☑	☑			Not lanes.
16.3	Traveler Information Systems	The TME shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	Prototype develop will generate a generic queue warning message that other applications can use.	A	Not Tested					Not a feature included in the Prototype.
16.4	DMAs	TME-derived queue warning information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	Data will be logged in the data environment. It is assumed that this is sufficient to satisfy this requirement.	A	Demonstrate the existence of logged data in the cloud database that may be used by other DMA applications.		☑			
17.1	Legacy Detection Equipment	The TME-based applications shall use as an input, data that is obtained from traditional, fixed-point detection equipment.		A	Demonstrate using simulated data representing traditional link speed detectors.	Partial	Partial			Simulated
17.2	Legacy Detection Equipment	The INFLO Prototype shall use either real or simulated data to represent traffic, weather and road conditions.		D	Demonstrate using simulated data to trigger both SPD-HARM and queueing activities.	☑	☑			

APPENDIX D. Acronyms and Abbreviations

CV	Connected Vehicle
CVC	Connected Vehicle Communication
DMA	Dynamic Mobility Application
DMS	Dynamic Message Sign
DSRC	Dedicated Short-Range Communications
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
I2V	Infrastructure-to-Vehicle
IDS	Information Dissemination Sub-system
IEEE	Institute of Electrical and Electronics Engineers
INFLO	Intelligent Network Flow Optimization
IVNA	Integrated Vehicle Network Access
PII	Personally Identifiable Information
Q-WARN	Queue Warning application
RSE	Roadside Equipment
RSSI	Received Signal Strength Indicator
SAE	Society of Automotive Engineers
SPD-HARM	Speed Harmonization application
TC	Test Case
TME	Traffic Management Entity
TMO	Traffic Management Operator
TTI	Texas Transportation Institute
UI	User Interface
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WRTM	Weather Responsive Traffic Management

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