Intelligent Network Flow Optimization (INFLO) Prototype Seattle Small-Scale Demonstration Plan

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16. Abstract

This report describes the INFLO Prototype Small-Scale Demonstration to be performed in Seattle Washington. This demonstration is intended to demonstrate that the INFLO Prototype, previously demonstrated in a controlled environment, functions well in an operating highway traffic environment and can provide a basis for planning a more comprehensive field deployment and test of the technology. The purpose of the small-scale demonstration is to deploy the INFLO system to demonstrate its functionality and performance in an operational traffic environment and to capture data that can help assess hypotheses pertaining to INFLO system functionality, INFLO system performance, INFLO algorithm performance, measured driver behaviors, and driver feedback. This document is organized into two key components and deliverables for the project:

- INFLO Prototype Small-Scale Demonstration Site Plan
- INFLO Prototype Small-Scale Demonstration Experimental Plan

The Site Plan describes the plans, logistics and schedule for conducting the small-scale demonstration and the Experimental Plan describes the plan for data capture and analysis.

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Chapter 1 Introduction

Following the successful demonstration of the INLFO Queue-Warning (Q-WARN) and Speed Harmonization (SPD-HARM) applications under Task 2 of the Intelligent Network Flow Optimization (INFLO) Prototype Development Project, the U.S. DOT authorized Battelle to proceed with a Small-Scale Demonstration of the applications under Task 3.1. With the support of the Washington State Department of Transportation (WSDOT) Battelle has proposed and the U.S. DOT has approved conducting this demonstration in Seattle, Washington in conjunction with the WSDOT Active Traffic Management System (ATM). Following is a description of the demonstration as currently envisioned and planned by Battelle, with the support of its subcontractor Texas A&M Transportation Institute (TTI), and WSDOT.

Chapter 2 INFLO Prototype Small-Scale Demonstration Objectives

The Battelle Team has developed prototype INFLO QWARN and SPD-HARM applications and demonstrated the functionality and performance of these applications to U.S. DOT as part of controlled environment tests conducted on roadways around Battelle offices in Columbus, Ohio in May 2014. Battelle demonstrated the system that:

- Collects location and heading data from connected vehicle Basic Safety Messages (BSMs) using both cellular and DSRC communications
- Populates that data in a Cloud database
- Processes the data to determine the beginning and end of congestion[1] zones
- Processes the data to determine recommended harmonization speeds
- Delivers Queue Ahead, In-queue and Speed Harmonization messages to drivers on a smart-phone interface.

As described in the Intelligent Network Flow Optimization (INFLO) Prototype Acceptance Test Summary, Battelle demonstrated the functionality of the system on roads around Battelle and demonstrated the performance characteristics using simulated traffic congestion data.

The next step in verifying the viability of applying connected vehicle technology for INFLO applications is to conduct a small-scale demonstration under operational conditions. Battelle has recommended conducting this demonstration in Seattle, Washington along a seven mile corridor of I-5 south of downtown Seattle. The northbound side of this corridor has an Active Traffic Management (ATM) system in place and the adjacent southbound corridor does not. In this small-scale demonstration, Battelle and TTI (The Team) will work with WSDOT to deploy connected vehicle systems in approximately 25 vehicles in a scripted driving scenario circuiting this corridor northbound and southbound during morning rush hour on multiple days. The Team will collect vehicle speed data from both the WSDOT infrastructure-based speed detectors and the connected vehicles during the driving scenario. The Team will process the data in real time and deliver Q-WARN and SPD-HARM messages to drivers. The Team will capture system performance data as well as driver behavior and feedback to demonstrate the INFLO system in a fully operational highway traffic environment and examine potential benefits of connected vehicle technology. The team will also compare speed harmonization recommendations based upon connected vehicle data with those recommended by WSDOT system to help refine the INFLO algorithms.

The Seattle I-5 corridor south of downtown is an advantageous location to deploy and assess connected vehicle technology in parallel with infrastructure-based technology because it has:

- Recurring congestion
- Existing infrastructure-based queue detection

[1] "Congestion" in this document is used to refer to "Recurring Congestion" or congestion that forms when routine traffic volumes exceed the available capacity of a known bottleneck location.

- Existing Variable Speed Limit (VSL) policy and accompanying signage on the northbound side
- An installed inventory of Dynamic Message Signs
- WSDOT is a highly supportive leader in Intelligent Transportation Systems (ITS) research.

The purpose of the small-scale demonstration is to deploy the INFLO system to demonstrate its functionality and performance in an operational traffic environment and to capture data that can help assess hypotheses pertaining to:

- INFLO system functionality
- INFLO system performance
- INFLO algorithm performance
- Measured driver behaviors
- Driver feedback.

The first set of objectives for the demonstration focus on demonstrating functionality, including:

- Demonstration of the basic functionality of the INFLO Prototype System in an operational highway traffic environment, including its ability to;
  - Capture current location and telematics data from connected vehicles and vehicle speed data from infrastructure
  - Analyze the data to detect congestion and determine the beginning and end of congestion queues
  - Formulate recommendations
  - Communicate those recommendations to drivers.
- Demonstration of connected vehicle data capture and dissemination using both cellular communications and DSRC communications.

The second set of objectives is to demonstrate that the INFLO Prototype System has the latency, processing speed and bandwidth to support this functionality in an operational traffic environment.

The third set of objectives is to develop data that can help assess:

- The integration of connected vehicle-based speed data with infrastructure-based speed sensor data to improve resolution of estimates of the location of the back of the queue and the length of the queue.
- Using connected vehicle-based speed data by itself to provide estimates of the location of the back of the queue and the length of the queue that are comparable to that provided by infrastructure-based speed sensors only.

The small scale demonstration will capture speed, acceleration, and deceleration data on selected vehicles as they travel through the route to provide a quantitative measure of driver behavior.

Finally, the Team will capture driver impressions and feedback concerning the system, its performance and its benefits through a written survey.

The Small-Scale Demonstration is intended to be an interim step between controlled environment demonstrations and a full-scale field test deployment of the application in highway traffic. It is intended to demonstrate that the controlled environment system can function in an operating environment and can provide a basis for planning a more comprehensive field deployment and test of the technology.

This document is organized into two key components and deliverables for the project:

- INFLO Prototype Small-Scale Demonstration Site Plan
- INFLO Prototype Small-Scale Demonstration Experimental Plan

The Site Plan describes the logistics and schedule for the small-scale demonstration and the Experimental Plan describes the plan for data capture and analysis.

Chapter 3 INFLO Prototype Small-Scale Demonstration Site Plan

This section of the Small-Scale Demonstration Plan outlines the plans and logistics for the demonstration including:

- Seattle ATM System Overview and Site Plan Layout
- INFLO Prototype System Description
- Recruitment and Identification of Test Participants
- Conducting the Demonstration
- Small-Scale Demonstration Schedule

This section of the document addresses the Small Scale Demonstration Site Plan deliverable requirement for the project.

Source: Washington State Department of Transportation

Figure 1. Locations of VMS and VSLS Devices in the Seattle, WA Area.

Seattle ATM System Overview and Site Plan Layout

The Battelle Team suggests conducting the demonstration on the stretch of I-5 between Tukwila, WA and Northgate. This section of freeway, located in King County, is already equipped with Variable Message Signs (VMS) and Variable Speed Limit Signs (VSLS) on the northbound lanes (see Figure 1 and Figure 2; see also http://www.wsdot.wa.gov/smarterhighways/default.htm).

The small scale demonstration is expected to consist of 15 to 24 vehicles, each of which will be equipped with the connected vehicle system designed, built and successfully tested and demonstrated in Task 2. The participants will be recruited from individuals local to the area. According to the U.S. Census Bureau in 2013, King County's population stood at 2,044,449 while the city of Seattle's population was 634,535[2]. These same statistics show that greater than approximately 66 percent of the King County population is of working age, and that over 46 percent are college graduates.

[2] http://quickfacts.census.gov/qfd/states/53000.html, retrieved 5/15/2014.

As a study site, the city of Seattle offers some additional unique advantages to this important research. According to U.S. DOT's Bureau of Transportation Statistics publication National Transportation Statistics (Tables 1-69 & 1-70), Seattle, Washington is 12th in the nation in terms of annual person-hours of delay on the highway, and is ranked 4th in terms of the travel time index. Very recently, TomTom ranked Seattle traffic 4th in the nation in their roadway congestion index[3].

To date, three corridors in the Seattle area, branded "Smarter Highways," include ATM signage, which is used for incident management and automatically posts regulatory variable speed limits to smooth traffic flow. The first corridor to begin ATM operations in Seattle was a seven-mile segment of Interstate 5 (I-5) northbound from the Boeing Access Road to Interstate 90 (I-90) in downtown Seattle. This corridor is part of the planned route for demonstration of the INFLO applications. Operations began on this corridor in August 2010 with 97 new electronic signs on 15 new sign bridges spaced roughly every half-mile. Along this segment, I-5 is reduced from five lanes to two lanes as it enters downtown Seattle. Further, with significant construction on the parallel State Route 99 (SR 99)-Alaskan Way Viaduct, ATM signage was implemented to help alleviate increased traffic on the corridor. Prior to deployment, this corridor averaged 434 crashes per year, 296 of which were congestion related. WSDOT intends that the ATM deployment will reduce property damage only (PDO) crashes by 15 percent and injury crashes by 30 percent.

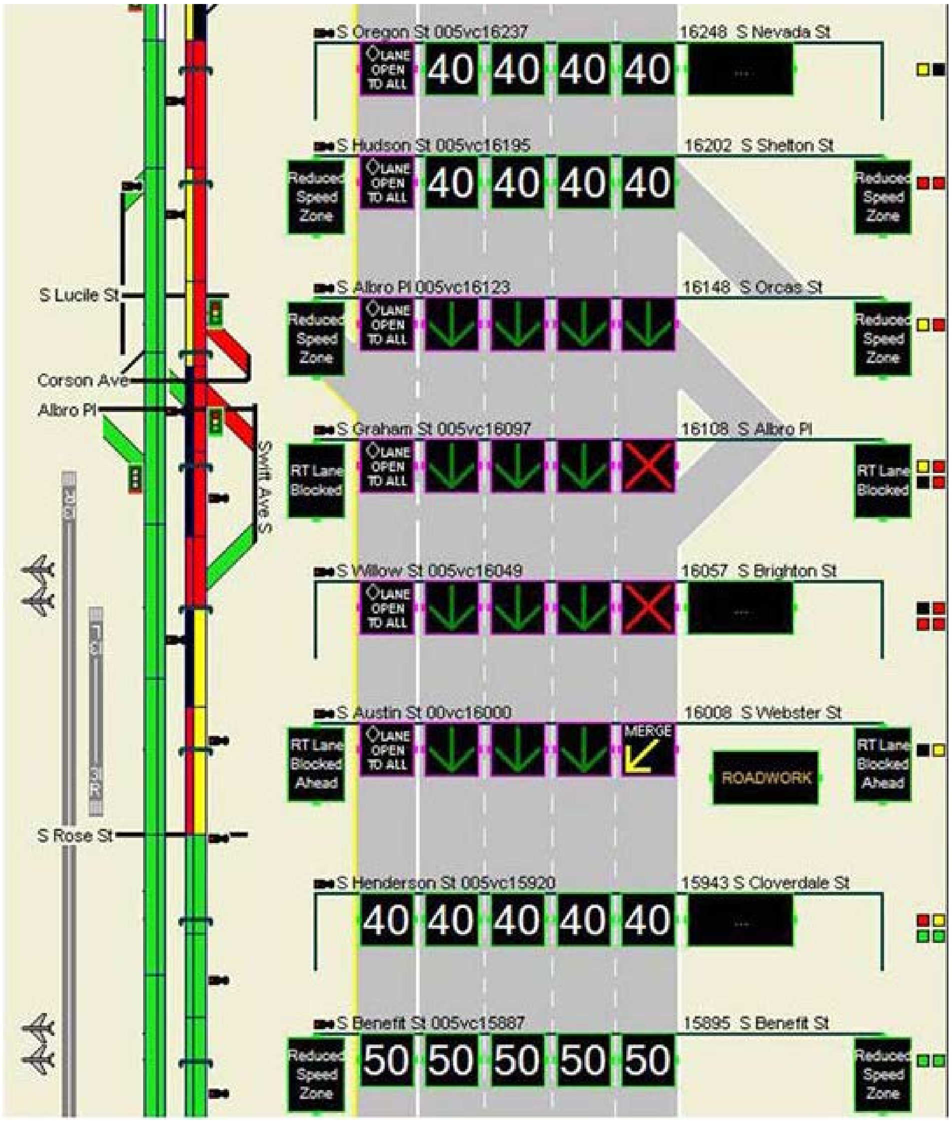
In general for this deployment, WSDOT gathers real-time traffic information to support ATM operations using existing inductive loop detectors and fills the gaps with additional Wavetronix detectors. Side-mounted dynamic message signs (DMS) are typically on every other gantry on both the left and right side of the highway, with remaining gantries having a standard, larger overhead DMS.

The ATM signage system is operated from the WSDOT Northwest Regional Traffic Management Center in Shoreline, Washington just north of Seattle. The software user interface (shown in Figure 3) has a control view showing current displays and a preview view on which the operator clicks signs manually based on incident location. In Seattle, the ATM signage is actively managed 24 hours a day.

Source: Washington State Department of Transportation

Figure 2. Example of Combined VMS and VSLS just South of Seattle, WA.

3 (http://www.tomtom.com/lib/doc/congestionindex/2012-0704-TomTom-Congestion-index-2012Q1namerica-mi.pdf)



Source: Washington State Department of Transportation

Figure 3. Seattle ATM Software User Interface showing Variable Speed Limits and Lane Closures Due to Roadwork.

Variable Speed Limits

In the Seattle region, ATM signage displays regulatory variable speed limits. As shown in Figure 4, these signs are displayed in the configuration of a typical speed limit sign. Variable speed limits are entirely automated and are activated by the system in advance of congested areas, including those caused by incidents. The variable speed limit algorithm uses 20-second averages of current speed to assess congestion levels on the corridor at stations ¼- and ½-mile downstream, and posts speeds roughly based on 85th percentile speed. Thus, operators need not deploy the variable advisory speeds, although they can manually override the signs if needed to better reflect current speed on the highway. WSDOT notes that the system automatically detects slowing traffic and posts a lower speed limit roughly 5 minutes before the slowdown would be manually detected.

Source: Washington State Department of Transportation.

Figure 4. ATM Signs Displaying Variable Speed Limits on I-5 Northbound to Downtown Seattle.

As the system has evolved, changes have been made to the maximum and minimum posted variable speed limits. The maximum posted variable speed limit was 50 miles per hour (mph). However, the system automatically displays the normal 60 mph speed limit on the ATM signs immediately upstream and also downstream of the reduced speed zone. Originally, WSDOT restricted the lower limit of the automatic variable speed limit to a 40 mph minimum because of data instability at lower speeds, which resulted in frequent changes in posted variable speed limits under stop-and-go conditions. After adjustments to the algorithm, the automatic variable speed limit minimum was lowered to 35 mph, and with additional refinements will likely be further reduced to 30 mph. The operating procedures currently allow for a manual input of the speed limit as low as 30 mph.

WSDOT posts speeds on a single gantry that differ up to 15 mph between the general purpose and HOV lanes. However, note that speeds never vary between individual general purpose lanes at a single gantry. Between gantries, the maximum drop in speed is 15 mph.

Variable speed limits work in groups of three gantries to reduce speeds for a smooth speed transition. However, variable speeds are displayed through the congested area and there is no limit to the number of consecutive gantries that display variable speed limits. In fact, WSDOT has adapted the system since deployment to automatically activate additional signs in advance of congestion to begin reducing speeds sooner. Remember that WSDOT also has the system automatically post a 60 mph speed on the ATM signage on the gantries immediately upstream and downstream of the reduced speed zone.

Note, because each gantry in the Seattle area contains either an overhead or a set of side-mounted DMS, WSDOT typically posts messages to supplement the variable speed limits. WSDOT posts a specific message about speed reductions due to a work zone or incident, instead of a generic “CONGESTION AHEAD” message for heavy traffic conditions. The message will typically read “REDUCED SPEED ZONE.”

Although the variable speed limits posted on the ATM signage are technically enforceable, the highway patrol generally does not tightly enforce minor speeding infractions of individual variable speed postings, lest the congestion become worse. Instead, the highway patrol focuses almost exclusively on reckless driving with speeds greatly exceeding the posted speed. Thus, WSDOT describes the variable speed limits in the Seattle region as essentially “self-enforcing.” Automated speed enforcement has not been discussed as a complement to ATM signage, however it has been used for work zones in Washington.

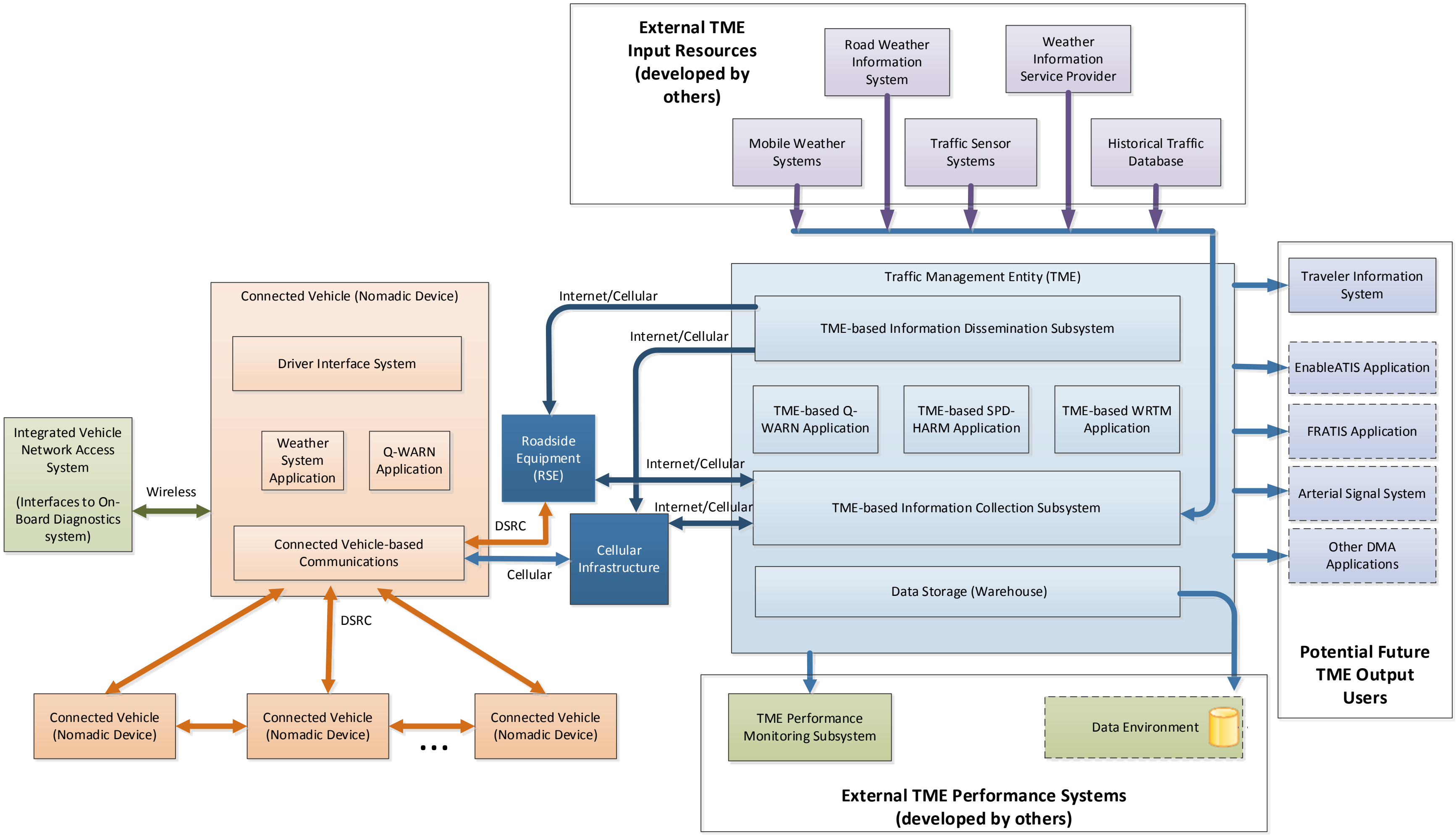
No changes to the operations of the current ATM system are planned as a result of this demonstration test. However, up to four (4) specific gantry locations along this proposed corridor will be equipped with the roadside version of the Dynamic Short Range Communications (DSRC) radio. The roadside units (RSUs) will be completely independent of the WSDOT ATM system including their own separate backhaul connectivity.

INFLO Prototype System Description

The INFLO Prototype System consists of multiple components, which exchange data through messages using DSRC or cellular communication. Figure 5 shows a comprehensive INFLO system-level diagram, which identifies the components, 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 6 is a simplified view of the *Prototype* INFLO System as it has been implemented for the purposes of this project and as it is tested and demonstrated to the U.S. DOT. It includes the messages that are exchanged between components necessary to support the multiple INFLO scenarios and applications. This system has the functionality and capabilities necessary to support the Seattle small-scale demonstration and future potential pilot tests under consideration by the U.S. DOT.

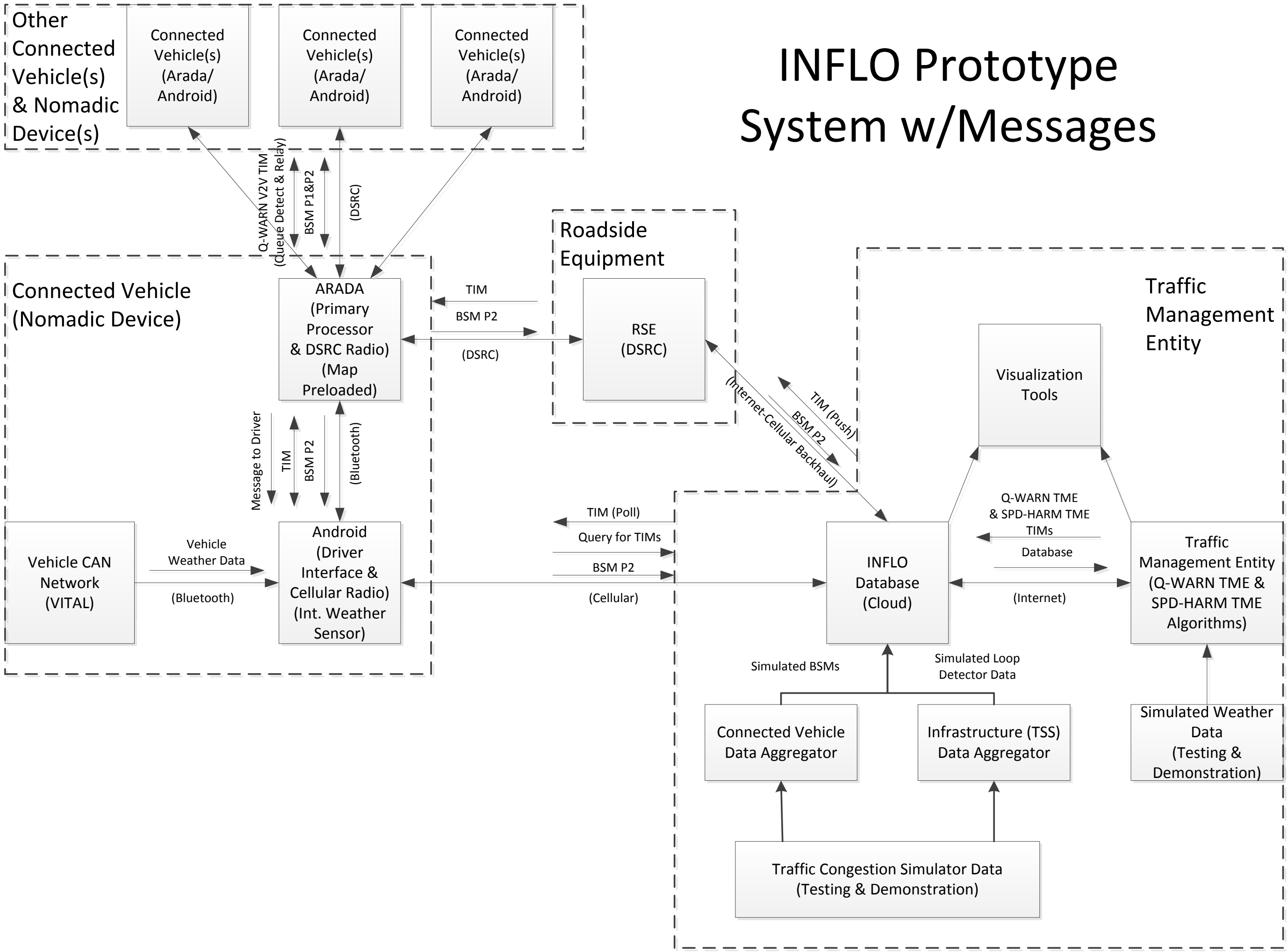
The remainder of this section of the plan provides background and an overview of the components under test and the implemented INFLO Prototype System. This section is organized under the following headings:

- INFLO Prototype System Components
- Connected Vehicle Messages Types
- INFLO Applications.



Source: Battelle

Figure 5. INFLO Prototype System Diagram from INFLO Design Report.



Source: Battelle

Figure 6. 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.[4] A brief synopsis is provided here for completeness and clarity of this demonstration description.

The primary functional components of the implemented INFLO Prototype System, shown in Figure 6 are the following:

- Connected vehicle system consisting of
    1. User Interface Module (Android User Interface and Cellular Radio),
    2. DSRC Radio Module (ARADA Processor and DSRC Radio),
    3. In Vehicle Network Access System (Vehicle CAN Network)
- Roadside Unit (RSU)
- Virtual Traffic Management Entity (TME) consisting of
    1. INFLO database
    2. TME-based Q-WARN application
    3. TME-based SPD HARM application

Connected Vehicle System User Interface Module

The connected vehicle system user interface module shown in Figure 8 is a mobile device (cell phone) running the Android operating system. The features of this component are:

- 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, and
- 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,
- Connected vehicle system state,
- SPD-HARM messages (e.g. recommended speed), and
- Q-WARN messages (e.g. distance to back of queue, length of queue).

The mobile device interfaces with the DSRC radio module in the connected vehicle system via Bluetooth connections to send ambient weather data to the DSRC radio module and to exchange TME bound messages.

[4] FHWA-JPO-14-TBD, Battelle Report 100030614-202A, March 28, 2014, System Design Document for the INFLO Prototype.

DSRC Radio Module

The DSRC Radio Module shown in Figure 7 is a small portable unit that can run on vehicle power[5]. The unit is the main computational processor for the connected vehicle system. 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 sends and receives both vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V) communications. The DSRC radio transmits BSMs (Part 1 only and combined Part 1 and Part 2) to other DSRC radios that are in range and to the roadside unit. 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.

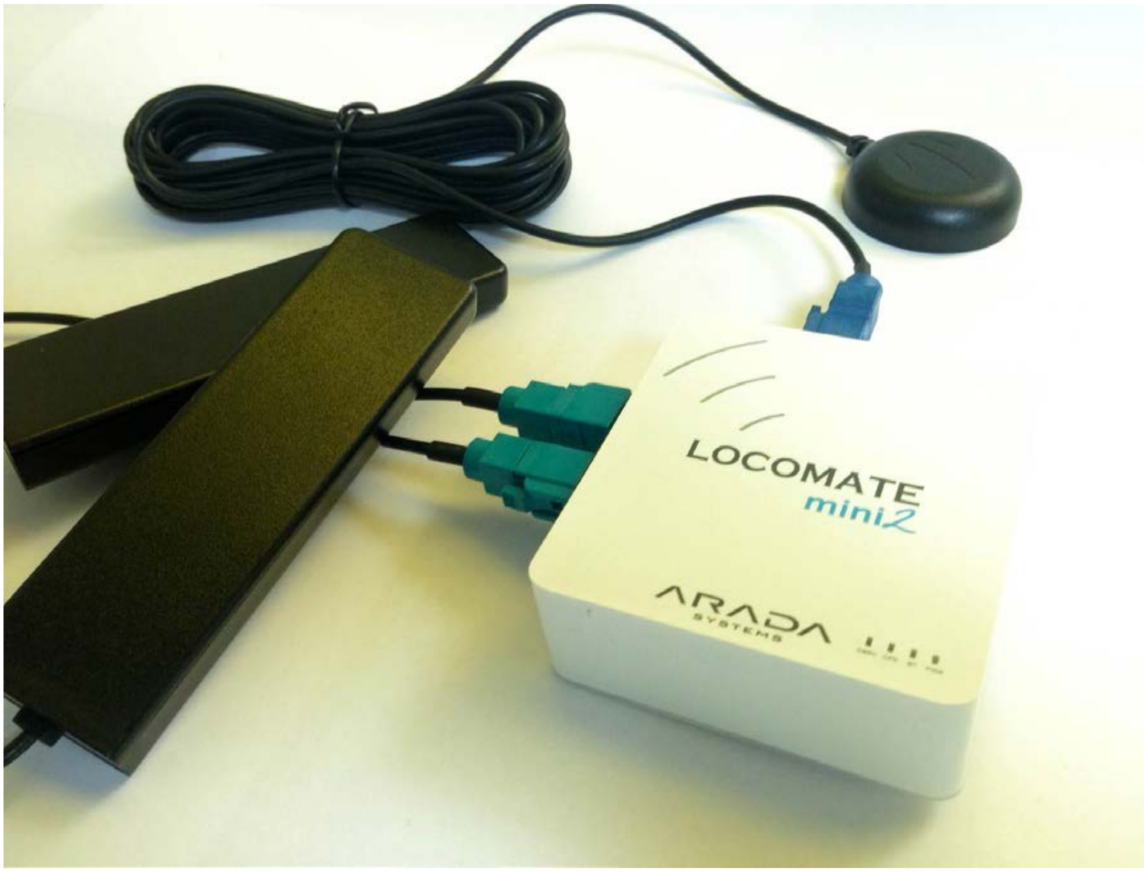
The BSM Part 1 and 2 data is populated by data from the vehicle, data from the onboard GPS and data collected by weather sensors. The BSM Part 1 is transmitted at 10 Hz and the combined BSM Part 1 and Part 2 is transmitted at 1HZ. The connected vehicle system also transmits Q-WARN indicators calculated by the onboard Q-WARN application (such as “this Vehicle Queued”) as part of the BSM Part 2.

The connected vehicle system DSRC Radio Module receives messages from other vehicles (V2V) and from the infrastructure (V2I). The connected vehicle system will receive and process any BSMs from surrounding vehicles and supply the data to the onboard Q-WARN application. The connected vehicle system 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 connected vehicle systems within radio range and “relay” of vehicle queue information.

The connected vehicle system DSRC Radio Module also determines if there is an RSU is nearby and if the DSRC signal strength (Received Signal Strength Indication, RSSI) is sufficient to support V2I communications. If the signal strength is strong enough, based on field test experience, (RSSI≥15), the BSM Part 1 and 2 is sent to the INFLO database via the RSU DSRC. If not, the BSM Part 1 and 2 is sent to the Android device and forwarded to the database via cellular communication.

Along with TIMs, the connected vehicle system 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 connected vehicle system.

[5] Battelle has elected to use the same DSRC radio as that used in the Task 2 Demonstration, but in a different form factor that permits the use of an external antenna for both GPS and DSRC.



Source: Arada

Figure 7. DSRC Radio Module Compact form Factor for Use with the ANDROID Mobile Device.

Source: Battelle

Figure 8. Android-based Cellular Phone Displaying Queue Ahead and Speed Harmonization Recommended Speed Message while Traveling State Route 315 in Columbus, OH.

In Vehicle Network Access System

The In Vehicle Network Access System (IVNAAS) is used to obtain data from the vehicle Controller Area Network (CAN) bus through the OBD-II interface. The connected vehicle system 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 9). This module allows the DSRC radio to receive vehicle dynamics to populate the BSM Part 2. The availability of specific data elements is dependent upon the vehicle. Battelle can readily access telematics data on 2004 and later Ford, GM and Toyota vehicles and many others.

Source: Battelle

Figure 9. VITAL™ OBD-II Module.

Road Side Unit

The Road Side Unit used in testing and demonstration is the Arada LocoMate™ RSU shown in Figure 10 which handles all DSRC communications from the TME to vehicles and connected vehicle systems and DSRC communications from the vehicles to the TME. The Road Side Unit forwards any warnings from the TME to all devices within its range. The RSE also collects BSM Part 1 and 2 messages and subsequently forwards these messages to the TME for use by the infrastructure-based algorithms.

Source: Arada

Figure 10. Road Side Unit. Arada LocoMate™ RSU.

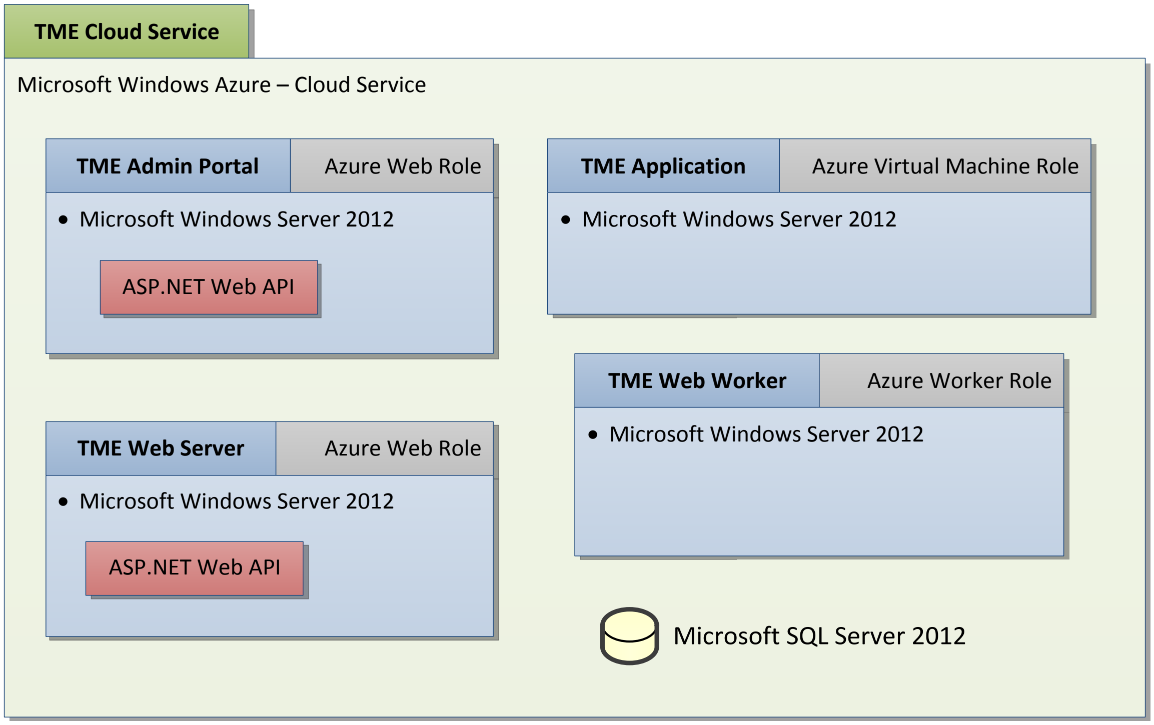
INFLO Cloud Services

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 are structured as shown in Figure 11.

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 use by the development team.



Source: Battelle

Figure 11. Cloud Service Computing Platforms.

Virtual Traffic Management Entity (TME)

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. 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. 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.

Connected Vehicle Message Types

Two primary SAE J2735 messages are transmitted and used to communicate data between components in the system, the BSM (combined Part 1 and Part 2) and the TIM.

The BSM Part 1 and Part 2 is used to communicate the following data, where available, from vehicle's time, location, velocity (speed), heading, lateral acceleration, longitudinal acceleration, external air temperature and others. As shown in Figure 6, the BSM message is primarily communicated from the connected vehicle system to the INFLO Database to capture an individual vehicle's speed and congestion related data. The BSM 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 connected vehicle systems 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

Two INFLO Application scenarios, described in more detail in the Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design[6], 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).

These applications correspond to the Seattle ATM system. Data collected will be used to compare connected vehicle results infrastructure based recommendations. Following is a brief description.

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 TME. The connected vehicles are not required

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

to process any data other than generating queue warning displays for the driver, where appropriate, 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 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.

Driver Display during Demonstration

As drivers traverse the northbound and southbound sides of the demonstration corridor, Q-WARN Q-Ahead and In-Queue messages will be displayed to drivers when warranted by the Q-WARN algorithm. SPD-HARM messages will be displayed to drivers when traveling southbound when warranted by the SPD-HARM algorithm. SPD-HARM messages will not be displayed to drivers when traveling northbound to avoid conflict or confusion with ATM VSLS messages[7].

System Readiness Acceptance Criteria

Battelle is acquiring and assembling connected vehicle installation kits that will be provided to system installers. As part of the kit assembly process the appropriate firmware and applications will be installed on each component. They will then be placed in a benchtop acceptance test system in which their functionality will be verified, before they are placed in the kit for installation. Upon installation in a

[7] ATM VSLS message display data are not currently available in real time to support real-time coordination with INFLO messaging, but are available after the fact for post-demonstration analysis.

participant's vehicle, a test application will be run to verify that the system is functional and is sending and receiving appropriate messages via DSRC and via cellular communications.

Prior to conducting the demonstration, TTI will conduct a comparison of the SPD-HARM recommendation messages to WSDOT ATM VSLS speed recommendations and refine the SPD-HARM algorithms for consistency and to provide a baseline for comparison.

Recruitment and Identification of Test Participants

Participant recruitment will be guided by the Experimental Plan discussed later in this document. The recruiting will begin approximately 3 weeks prior to the planned start date of vehicle installation and data collection. The recruiting materials are a key component of the Institutional Review Board (IRB) approval process, so those will be developed as soon as we begin work on the IRB submission.

Participants will be recruited using internet classified advertisements. We will also coordinate with WSDOT to advertise for recruits using WSDOT's Twitter account. In addition, and if necessary, we will also use targeted newspaper advertisements and/or flyers. The classified advertisements will direct interested participants to an informational website that will contain detailed information about the demonstration in general, participant eligibility requirements, contact information and what they can expect to do during the demonstration. Battelle has previously used these procedures successfully for recruiting participants for an on-road naturalistic study for NHTSA (164 participants) as well as for the Strategic Highway Research Program Naturalistic Driving Study (800 participants) in the Seattle region. Our past experiences indicate that these approaches should be adequate for getting a sufficient number of participants for the demonstration. Although the project does not include a parametric analysis of driving with regard to age or gender, we will attempt to recruit a reasonably balanced population demographically in order to achieve a representative sample of drivers in the Seattle area.

The website will provide potential participants with a phone number that they can call if they are eligible and interested in participating. A trained administrative staff person will field these calls (in addition to handling e-mail inquiries), and use a pre-designed screener questionnaire to identify eligible participants. The initial list of screening variables is shown in Table 1 below. The screening questions below will be updated to reflect additional constraints dictated by the Experimental Design, in addition to other requirements identified as we complete the Institutional Review Board process.

Table 1. Proposed Variables to be Included in the Participant Screening Questionnaire.

Proposed Variable	Type	Purpose
Driver age	Continuous	Used for filling experimental groups
Driver gender	M / F	Used for filling experimental groups
Own and / or regularly drive an insured vehicle?	Yes / No	Participant Requirement
Available to drive during specified demonstration periods?	Yes / No	Participant Requirement
Commuting Vehicle is a 2004 or later Ford, GM or Toyota?	Yes / No	Desirable for obtaining vehicle telematics data, but not required
Is the primary driver of this vehicle?	Yes / No	Participant Requirement
Is the vehicle in good operating condition?	Yes / No	Participant Requirement
Able to complete questionnaire?	Yes / No	Participant Requirement
Have and regularly use internet and e-mail?	Yes / No	Participant Requirement

Source: Battelle

Participant Intake and Institutional Review Board Approval (IRB)

Once recruited, the Battelle staff will schedule an appointment with the participants at the Battelle Seattle Research Center. On arrival, the participants will be provided with the informed consent form that describes the demonstration, participant requirements and actions and the risks associated with the demonstration. In addition, participants will also be given specific instructions about the demonstration and will fill out a demographic questionnaire. All participants will also receive a demonstration check-list that would serve as a reach-back tool throughout the demonstration period. The demonstration check-list will contain specific instructions for events such as “What to do if you are in an accident?” or “How do you know if your equipment is working?” and other such topics. The Battelle staff will assist the participant with the intake process and answer any questions/concerns that they may have about the demonstration and/or the check-lists that are provided.

Battelle’s IRB reviews and approves all human subjects research in accordance with the provisions of 45 CFR Part 46 and maintains a Federal wide Assurance, FWA00004696 (approval to 25 February 2018) with the Department of Health and Human Services’ (DHHS) Office of Human Research Protections (OHRP)

We will work to obtain IRB approval as soon as practical. In order to submit an application for IRB approval, we need to have final versions of the participant screener and informed consent forms. Details about how we intend to develop recruiting materials and screen participants are provided in other sections in this plan.

Protecting driver privacy and confidentiality will be a key requirement in the current project because we may potentially record behavior that is in violation of law, and risk to participants (i.e., being subject to prosecution because of recorded behavior) needs to be minimized. Another reason for focusing on confidentiality is to discourage participants from changing their behavior and responses to make them more socially acceptable (e.g., by driving slower than they normally would), thus impairing our ability to answer the key research questions.

To address the issue of driver privacy, the identifying elements are deleted from the BSMs when they are uploaded into the cloud. Other measures will include using an anonymous code to link material from the demographic questionnaires or other participant material (if any).

We will also provide full disclosure to participants about what data are being collected, including speed data, during the recruiting and informed consent process. They will also be informed of all potential risks, which is a requirement for IRB approval. All these necessary considerations will be covered in the informed consent form that will be used to obtain participant consent prior to their participating in the study. This approach, combined with advance consultation with IRB representatives at Battelle will ensure that we can obtain IRB approval with the minimum amount of delay necessary.

Another issue that requires special consideration is that the installed equipment must not pose a safety risk to drivers. We will address this by ensuring that the device is positioned well outside of the driver’s normal field of view, and it is fastened securely to the vehicle so that it does not cause undue distraction by sliding around the driver’s dashboard. Additional details about equipment installation are provided in the previous sections.

A final important concern is what happens with the data if drivers are involved in a crash. Because speed information is being collected, it could potentially be subpoenaed and used against the participant in a trial, which represents a separate additional risk to drivers. The most appropriate course of action to address this issue may be to obtain a Certificate of Confidentiality through the National Institute of Health (NIH) to protect collected data from being used against participants, should they be involved in a crash. This could take additional time to obtain (we estimate around 6-8 weeks after IRB approval). However, given that the experiment-wide number of driver is low (just 25 participants), and the time and locations in which the data is being collected is expected to be relatively short (just between 7 am – 9 am between mile post 157 -164 on I-5), we do not expect any test vehicle crashes to occur during this study and might not require a Certificate of Confidentiality. We will consult with Battelle’s IRB representatives to discuss the appropriate ways to deal with this issue. Full disclosure of this litigation risk to participants during the recruiting and the informed consent processes is certain to be required but may be sufficient to address this issue.

Driver Support during the Demonstration

This section addresses:

- Onboarding of Participants and System Installation
- Monitoring and Operational Support
- Equipment De-installation and Closeout.

Onboarding of Participants and System Installation

Prior to the data collection period, Battelle will develop written procedures for participant intake and installation and testing the equipment installation.

The participant consent, participant briefing and equipment installation will be done at the Battelle Seattle Research Center. Once the participant has completed the intake process, the installer will accompany the participant to his or her vehicle for installing the connected vehicle equipment. The installer will discuss the installation procedure with the participant, and they will mutually decide on the best placement of the device. The placement of the connected vehicle equipment will be based on criteria such as dashboard configuration, available mounting hardware, location of the vehicle's accessory power port (APP), placement for optimum GPS signal availability, routing of power cables from the APP to the connected vehicle equipment, ease of inserting and removing the device, and participant concerns. Once the best location has been determined, the installer will install the mounting hardware and instruct the participant on how to insert and remove the device. It is important the driver be able to remove the device when the vehicle is not moving in order to minimize the risk of break-in and theft of the device.

After installing the device, the installer will perform a testing procedure that will exercise the connected vehicle equipment, in order to ensure that the device is working before leaving the installation facility. The testing protocol will include verifying that the connected vehicle equipment is operational, the DSRC communications are functional and cellular communication is working. The test will also include a check of the power adapter and cable to ensure that the device is charging when it is plugged into the APP and active.

For quality control purposes, a checklist will be developed to facilitate documentation of the installation. The installer will mark each step of the installation and testing procedure to make sure the device is properly installed and the participant has received all instructions and materials.

Monitoring and Operational Support

Consistent engagement with test participants and continual monitoring of the connected vehicle equipment that support the applications will be necessary during the operational period. The status of the installed devices will be monitored regularly to determine if the device is functioning as designed, identifying why it is not functioning properly and taking corrective actions to ensure proper functionality during each driver's period of participation.

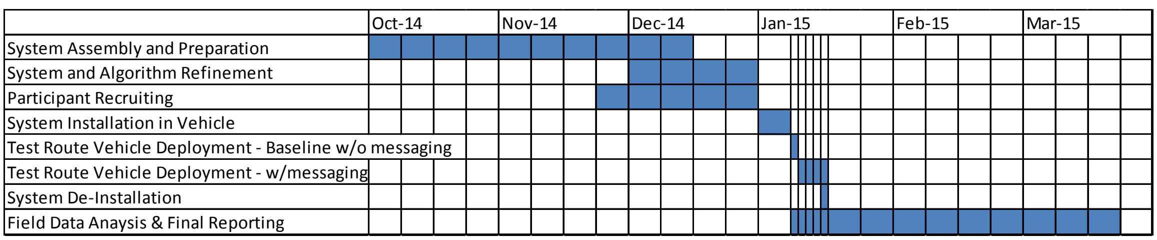
The Battelle Team currently has a dedicated e-mail address for users to report issues with their web and mobile applications and will provide a 24-hour turnaround for requests. Similarly, interfaces with agency systems will be monitored and a separate email set up for agency requests. We will also organize and host a weekly status briefing and update to provide the U.S. DOT and internal members of the Battelle Team with a routine coordination point for exchanging information, discussing issues, and resolving problems. Discussions and action items identified during these meetings would be documented and would become part of the permanent project record.

Equipment De-installation and Closeout

At the conclusion of the data collection, a staff from Battelle will contact the participant to schedule the closeout appointment at the Battelle Seattle Research Center. Upon arrival for closeout, the Battelle staff will accompany the participant to their car, de-install the connected vehicle equipment and answer any questions that the participants have. Finally, the participants will be compensated for their participation in the study.

Small-Scale Demonstration Schedule

Figure 12 below outlines the planned schedule for conducting the INFLO Prototype Small-Scale Demonstration. Components will be acquired and assembled into installation kits and tested during October and November 2014. Pre-demonstration system and algorithm refinement will take place in December. Participant recruiting will take place in late November through December 2014. Onboarding of participants and system installation in vehicles will occur the week of January 5, 2015 (the first week of January). Vehicles will be deployed as discussed in the following experimental plan the week of January 12, the second week of January. Vehicles will be deployed on the Test Route, described later, on each of the five week days during morning rush hour beginning at 6:30 am. A single set of drivers will be recruited that can support all five days. On the first, Monday, deployment Q-WARN and SPD-HARM messages will not be displayed, in order to capture baseline behavior without driver messaging. Q-WARN and SPD-HARM messages will be displayed during the Tuesday through Friday Test Route deployments. The connected vehicle system will be removed the last day while participants fill out the driver questionnaire.



Source: Battelle

Figure 12. Planned Schedule for INFLO Prototype Implementation and Small-Scale Demonstration.

Chapter 4 INFLO Small-Scale Demonstration Experimental Plan

This section of the Small-Scale Demonstration Plan describes the data to be collected, the hypotheses to be examined and the data analysis to be performed. This section of the document addresses the Small Scale Demonstration Experimental Plan deliverable requirement for the project.

Hypotheses To Be Tested During The Demonstration

The purpose of the small-scale demonstration is to deploy the INFLO system to demonstrate its functionality and performance in an operational traffic environment and to capture data that can help assess hypotheses pertaining to system functionality and performance, measured driver behaviors and driver feedback.

The test vehicles and drivers are expected to travel the deployment corridor as part of a loosely organized platoon of vehicles. The vehicles will capture and send vehicle telematics data wirelessly to the INFLO Database. The data will be analyzed with INFLO Q-WARN and SPD-HARM algorithms and appropriate messages delivered to drivers. The research team will then compare the output of the INFLO algorithm queue warning alerts and speed harmonization recommendations with and without connected vehicles. The research team will also examine driver acceleration and deceleration behavior as well as driver feedback.

The data resulting from this analysis will be analyzed to assess the following hypotheses. Data collection is described under Data to Be Collected below. The corresponding data analyses are described under Data Analysis below.

System Functionality and Performance

1. INFLO DSRC only and cellular only communications capture 98% of broadcast BSMs.
2. INFLO communications capture BSM data when switching between DSRC and cellular communications with less than 4% loss of data.
3. INFLO system delivers Q-WARN and SPD-HARM messages to the drivers at least 1 mile in advance of congestion.
4. INFLO system delivers messages to drivers within 5 seconds of detection of congestion (using both DSRC and cellular communications).

Algorithm Performance

5. Integrating connected vehicle data with infrastructure data will result in improved time of detection/notification that queues are present in the deployment corridor when compared to infrastructure data only.
6. Integrating connected vehicle data with infrastructure data will result in improved resolution in the location of the back of queue when compared to infrastructure data only.

7. Integrating connected vehicle data with infrastructure data will result in improved precision in estimating vehicle speeds in the queue when compared to infrastructure data only.
8. Integrating connected vehicle data with infrastructure data will result in a difference in the recommended speeds in the corridor when compared to infrastructure data only.
9. With adequate market penetration, connected vehicle-based speed data by itself can provide estimates of the location of the back of the queue and the length of the queue that are comparable to that provided by infrastructure-based speed sensors only.

Measured Driver Behavior

10. On average, drivers slow down further in advance of congestion when provided Q-WARN notification of distance to beginning of queue.
11. On average, driver speeding (greater than 10 MPH over the ATM/VSL or SPD-HARM recommended speed) is reduced when Q-WARN indicates a queue.
12. On average, drivers speed is within 10 MPH of the SPD-HARM and ATM recommended speeds.
13. On average, there are fewer panic stops as indicated by longitudinal deceleration.

Driver Feedback

14. On average, drivers report that they find Q-WARN and SPD-HARM messages useful, valuable and appropriate for traffic conditions.
15. On average, drivers report that they believe Q-WARN and SPD-HARM messages will improve safety by notifying them of slowed and congested traffic ahead.
16. On average, drivers report that they reduce speed when they are notified by Q-WARN and SPD-HARM messages of congestion ahead.

Test Route Summary

Test vehicles will be driven in a loop on I-5, beginning approximately seven miles south of downtown. They will proceed north on I-5 through downtown and on to approximately 7 miles north of downtown where they will exit and return southbound, returning to their original starting point. This loop will travel through two highway segments with known congestion points, I-5 North going into downtown and I-5 South going into downtown.

Table 2 below summarizes key characteristics of the four segments of the road. Q-WARN messages will be displayed throughout the entire route when warranted.
SPD-HARM messages will be displayed, with the exception of Northbound (NB) I-5 where ATM/VSL messages are displayed by the infrastructure.

Table 2. Characteristics and Messaging along the Test Route.

Road Segment	Mile Post	Congestion	Speed Detectors	ATM/VSL Signage	Q-WARN Messages	SPD-HARM Messages
NB I-5 from South into Downtown	MP 157.23 to 164.46	Fixed	Approx. 0.5 mile spacing	Signs spaced approx. 0.5 miles	Yes	No
NB I-5 from Downtown North	MP 165 to 174	Variable	Approx. 1 mile spacing	None	Yes	Yes
SB I-5 from North into Downtown	MP 165 to 174	Fixed	Approx. 1 mile spacing	None	Yes	Yes
SB I-5 from Downtown South	MP 157.23 to 164.46	Variable	Approx. 1 mile spacing	None	Yes	Yes

Source: Battelle

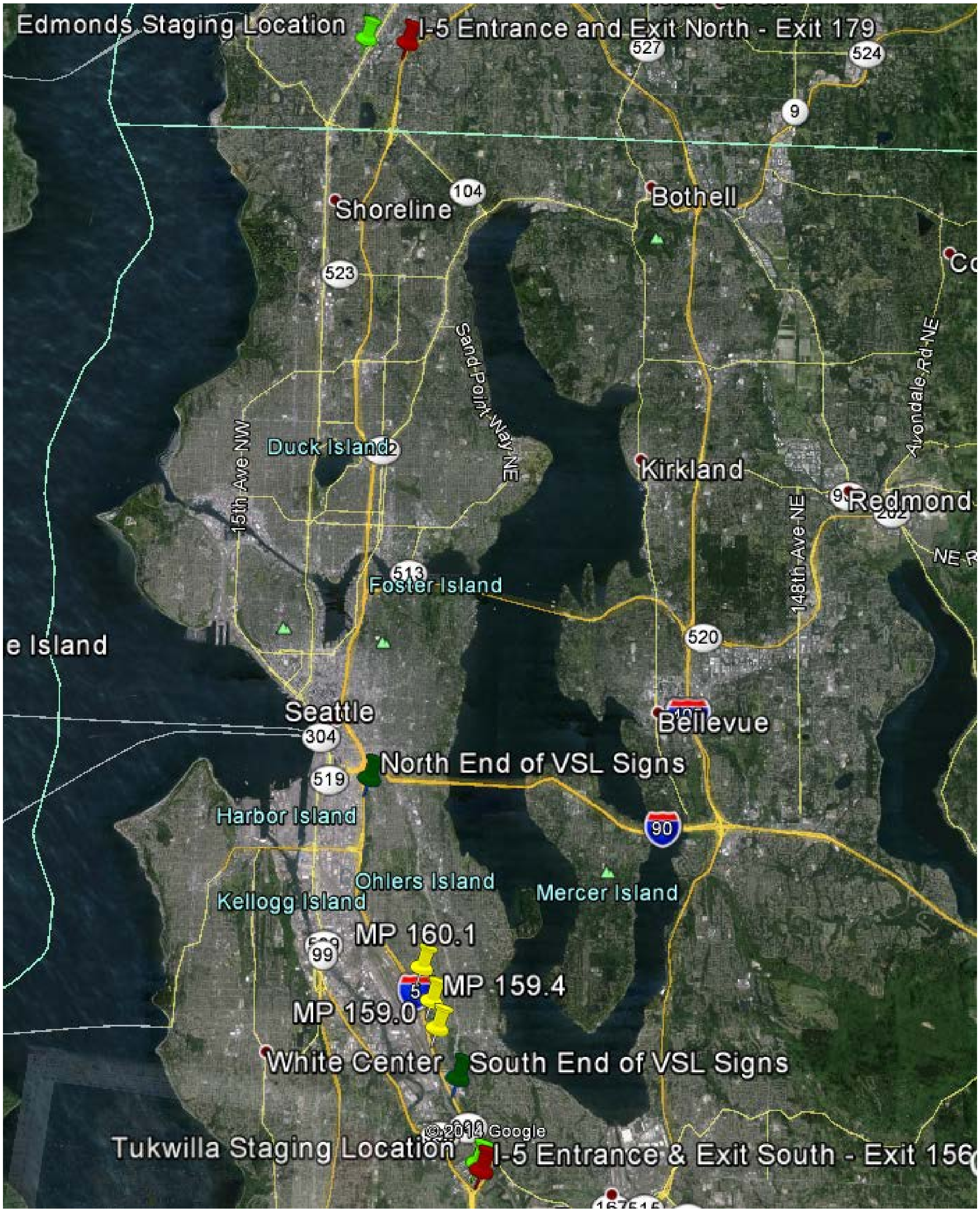
Figure 13 shows a Google Earth view of the I-5 Test Route. Red pins show the location of the North and South I-5 entrance and exits for the route (Exit 156 and 179). Light Green Pins show the location of the Edmunds and Tukwilla vehicle staging areas which are large parking lots near the entrances. Yellow Pins show the locations of three RSUs at Mileposts 159, 159.4 and 160.1. Dark Green Pins show South and North Ends of the I-5 Northbound ATM/VSL corridor.

Infrastructure- and Connected Vehicle-based Speed Detection

The test route includes a section of highway about seven miles in length along I5 from MP 157.23 to 164.46 that has inductive loop speed detectors in each lane and about 0.5 mile apart, which are expected to provide speed and occupancy data every 20 seconds. Detectors elsewhere in the corridor are spaced approximately one (1) mile apart. The OBUs are expected to provide the BSM data every second. For the purposes of using the connected vehicle data from equipped vehicles more accurately, each link (segment between consecutive detector stations) will be broken down into smaller links of approximately 0.1 mile. This can be accomplished by having the boundaries of the sub-links at a MP marker every 0.1 mile. For example the first sub-link within the first link can be from 157.3 to 157.4 and so on. The last sub-link within the corridor will be from 164.3 to 164.4.

DSRC Communications along Route

In the small scale demonstration, the team plans to equip test vehicles with OBUs that will have the capability to transmit the BSM either using DSRC radio or cellular radio when a DSRC RSU is not present. Three DSRC RSUs will be installed along the test section. The RSEs will be used to demonstrate the capability of the in-vehicle system to automatically switch between sending and receiving messages via DSRC and sending and receiving messages via cellular communications and to demonstrate that both methods provide the latency needed to support SPD-HARM and Q-WARN functionality.



Source: Google Earth

Figure 13. Google Earth View of I-5 Test Route showing Entrance and Exit and RSU locations.

Vehicle Deployment

As a small-scale demonstration, the Battelle Team anticipates deploying 15 to 24 vehicles with connected vehicle technology in two platoons, with one-third of the vehicles in the first and two-thirds of the vehicles in the second. Each platoon will concentrate the number of vehicles within a link and sublink to give us relatively compact CV data flowing through the congested area for both comparison with loop detector data and enhancement. Platoons will be spaced so that the Q-WARN and SPD-HARM messages received by the second platoon will be based upon connected vehicle data from the first platoon, integrated with infrastructure data.

Cars in each platoon will be released linearly. Drivers will be instructed to drive as they normally would, naturalistically, passing each other and changing lanes as desired. They will not be expected to remain in sequential order or in the same lane.

Alternative vehicle deployment strategies are being analyzed and considered to maximize the value of the data obtained. These alternatives will be reviewed and discussed with U.S. DOT prior to the demonstration.

Demonstration Schedule

Onboarding of participants and system installation in vehicles will occur the week of January 5 (the first week of January). Vehicles will be deployed on the Test Route the week of January 12, the second week of January. Vehicles will be deployed on the Test Route on each of the five week days during morning rush hour beginning at 6:30 am. A single set of drivers will be recruited that can support all five days. On the first, Monday, deployment Q-WARN and SPD-HARM messages will not be displayed, in order to capture baseline behavior without driver messaging. Q-WARN and SPD-HARM messages will be displayed during the Tuesday through Friday Test Route deployments. The connected vehicle system will be removed the last day while participants fill out the driver questionnaire. Drivers will be paid a stipend for their time.

Driver Survey

Following the test, the drivers will be asked to respond to a brief survey to obtain their feedback and comments on the value and usability of the system.

Data to be Collected

Data will be collected from multiple sources and captured in the INFLO database. All data will be captured as a function of milepost location along the route northbound or southbound and a function of time. Key data include infrastructure data, vehicle data and INFLO messages summarized below.

Infrastructure Data

Speed and occupancy data will be collected from the WSDOT loop detectors system every 20 seconds. ATM recommended speeds displayed on the VSL will be captured in the database at 20 second intervals. Recommended speed data will be captured after the demonstration as these data are not available in real time.

Vehicle Data

The following vehicle data will be captured every second (1 Hz):

- GPS Latitude and Longitude, at approximately road level accuracy
- Speed

- Heading
- Longitudinal acceleration*
- Lateral acceleration*
- Ambient Air temperature.

Longitudinal and lateral accelerations are not standard data elements available through the vehicles OBC-II port, but Battelle's VITAL system can capture this data on many vehicles. Battelle will strive to recruit drivers with vehicles from the population from which Battelle can capture this data. Data elements indicating the application of brakes is not readily available. The Battelle Team will use longitudinal deceleration where possible to indicate likely braking.

INFLO Messages

During the conduct of this demonstration, the Battelle Team will be running the TME-based Q-WARN and SPD-HARM algorithms. The algorithms will be generating Q-WARN and SPD-HARM messages based upon:

- WSDOT infrastructure data only
- Connected vehicle data only
- Integrated WSDOT infrastructure and connected vehicle data.

The messages delivered to drivers will be generated from integrated WSDOT Infrastructure and connected vehicle data. The infrastructure only and vehicle only messages will be captured in the database for subsequent comparison and analysis.

Where congestion is detected the Q-WARN algorithm will generate two messages:

- Q-Ahead with distance to beginning of queue (congestion) for vehicles approaching a queue and
- In-Queue with distance and time to the end of queue for vehicles in a queue.

SPD-HARM messages will recommend speeds for drivers before areas of congestion to maintain flow and reduce risk of collisions due to speed differentials.

Process for Verifying Data Quality and Minimum Thresholds

The INFLO data aggregators will conduct the necessary data checks to verify that the infrastructure detector data (volume, occupancy, and speed) received from WSDOT are valid before using the real-time traffic data in the INFLO algorithms (SPD-HARM and Q-WARN). We adopted some of the infrastructure detector data checks used by WSDOT into our INFLO algorithms. Similarly, validity checks will be conducted on the connected vehicle data received from vehicles to determine that the data is valid for use in making decisions for the roadway segment being monitored. For example, the location of the vehicle will be compared to the boundaries of the roadway segment being monitored to determine if the vehicle information can be used or not.

The Infrastructure data thresholds that were adopted from the WSDOT algorithm include:

- Occupancy = 8%
- Volume = 10 vehicles per minute
- Max Speed = 65 mph
- Min Speed = 35 mph.

Some of the infrastructure data checks that were adopted from the WSDOT algorithm to insure data quality include:

- If occupancy and volume are less than thresholds, use the Max Speed
- If occupancy or volume are less than thresholds, use calculated speed
- If neither occupancy or volume are less than thresholds, use trap speed/Wavetronix
- If speed = 0.0, use Max Speed
- Any Local Speed above Max Speed is set to Max Speed.

The research team will evaluate the messages that are received from the connected vehicles during the early stages of the deployment to set thresholds for connected vehicles data quality. These thresholds will include:

- Minimum number of vehicles in a sub-link for use of the connected vehicle data to calculate the speed of a sub-link and
- Percentage of queued vehicles in a sub-link to declare a sub-link as queued.

Data Analysis

The data to be collected during the demonstration can be used for a variety of analyses. Following is a description of the data comparisons and analyses that will be performed to help assess the hypotheses introduced earlier.

System Functionality and Performance

1. INFLO DSRC only and cellular only communications capture 98% of broadcast BSMs.
   - Compare INFLO database log of time BSMs received with BSM time stamp
     - Received via DSRC
     - Received via cellular
2. INFLO communications capture BSM data when switching between DSRC and cellular communications with less than 4% loss of data.
   - Count/measure gaps in time/BSMs when vehicles enter/exit RSU range
3. INFLO system delivers Q-WARN and SPD-HARM messages to the drivers at least 1 mile in advance of congestion.
   - Plot first delivery of Q-Ahead distance for each detection of congestion from algorithms and or database
   - Plot first receipt of Q-Ahead distance for each detection of congestion from vehicles

4. INFLO system delivers messages to drivers within 5 seconds of detection of congestion (using both DSRC and cellular).
   - Compare INFLO database log of time Q-WARN/SPD-HARM messages received from the algorithms to log of time Q-WARN/SPD-HARM messages received by vehicle (messages need to be numbered).
     - Received via DSRC
     - Received via cellular

Algorithm Performance

5. Integrating connected vehicle data with infrastructure data will result in improved time of detection/notification that queues are present in the deployment corridor when compared to infrastructure data only.
   - Compare Database Log of Time Q-WARN/SPD-HARM messages received from the algorithms
     - WSDOT Infrastructure Data Only
     - Connected vehicle Data Only
     - Integrated WSDOT Infrastructure and connected vehicle Data
6. Integrating connected vehicle data with infrastructure data will result in improved resolution in the location of the back of queue after each iteration when compared to infrastructure data only.
   - Plot resolution of the location of the back of the queue
     - WSDOT infrastructure data only
     - Connected vehicle data only
     - Integrated WSDOT infrastructure and connected vehicle data
7. Integrating connected vehicle data with infrastructure data will result in improved precision in estimating vehicle speeds in the queue when compared to infrastructure data only.
   - Compare speeds in queue estimates
     - WSDOT infrastructure data only
     - Connected vehicle data only
     - Integrated WSDOT infrastructure and connected vehicle data
8. Integrating connected vehicle data with infrastructure data will result in a difference in the recommended speeds in the corridor when compared to infrastructure data only.
   - Compare SPD-HARM Recommended Speeds for
     - WSDOT infrastructure data only
     - Connected vehicle data only
     - Integrated WSDOT infrastructure and connected vehicle data
9. With adequate market penetration, connected vehicle-based speed data by itself can provide estimates of the location of the back of the queue and the length of the queue that are comparable to that provided by infrastructure-based speed sensors only.
   - Compare location of the back of the queue and the length of the queue
     - WSDOT infrastructure data only
     - Connected vehicle data only

Measured Driver Behavior

10. On average, drivers slow down further in advance of congestion when provided Q-WARN notification of distance to beginning of Queue.

- Plot connected vehicle driver speed as a function of distance to beginning of queue

11. On average, driver speeding (greater than 10 MPH over the ATM/VSL or SPD-HARM recommended speed) is reduced when Q-WARN indicates a queue ahead.

- Plot connected vehicle driver speed as a function of distance to beginning of queue

12. On average, drivers speed is within 10 MPH of the SPD-HARM and ATM recommended speeds.

- Plot driver speed versus SPD-HARM recommended speed
- Plot driver speed versus ATM/VSL recommended speed

13. On average, there are fewer panic stops as indicated by longitudinal deceleration

- Plot maximum deceleration events as a function of distance to end of queue (up to 0.5 mile from queue).
- Plot maximum deceleration events as a function of distance from beginning of queue from 0.5 mile ahead of queue throughout length of queue.

Driver Feedback

The following hypotheses will be explored through post-demonstration driver surveys.

14. On average, drivers report that they find Q-WARN and SPD-HARM messages useful, valuable and appropriate for traffic conditions.

15. On average, drivers report that they believe Q-WARN and SPD-HARM messages will improve safety by notifying them of slowed and congested traffic ahead.

16. On average, drivers report that they reduce speed when they are notified by Q-WARN and SPD-HARM messages of congestion ahead.

Data Transfer

One of the main objectives of the INFLO and other DMA demonstrations is to gather data in a real-world setting for both the immediate impact assessment and future operations and user behavior research. Data logging is a core aspect of our INFLO system architecture. The data elements described here will be transmitted with appropriate metadata to U.S. DOT's contractors and the Research Data Exchange. Prior to submission, any data that could possibly compromise PII or similar will be scrubbed.

Chapter 5 Prototype Demonstration Report

Following completion of the data collection period, the Battelle Team will compile and submit a report summarizing the work performed and the results of the INFLO Prototype Seattle Small-Scale Demonstration. In addition to describing the site plan and experimental plan summarized here the report will discuss what could be learned relative to the objectives of the demonstration including the functionality and performance of the INFLO Prototype System, as well as the insights gained in supporting two key hypotheses. The report will discuss the results of:

- Demonstration of the basic functionality of the INFLO Prototype System in an operational highway traffic environment, including its ability to:
    - Capture location and telematics data from connected vehicles and vehicle speed data from infrastructure
    - Analyze the data to detect congestion and determine the beginning and end of congestion queues
    - Formulate recommendations
    - Communicate those recommendations to drivers.
- Demonstration of connected vehicle data capture using both cellular communications and DSRC communications.
- Demonstration that the INFLO Prototype System has the latency, processing speed and bandwidth to support this functionality in an operational traffic environment.
- Assessment of the integration of connected vehicle-based speed data with infrastructure-based speed sensor data to improve resolution of estimates of the location of the back of the queue and the length of the queue.
- Assessment of using connected vehicle-based speed data by itself to provide estimates of the location of the back of the queue and the length of the queue that are comparable to that provided by infrastructure-based speed sensors only.
- Assessment of driver behavior using speed, acceleration, and deceleration data as a quantitative measure of driver behavior.
    - Summary of driver impressions and feedback concerning the system, its performance and its benefits.

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