System Design Document for the INFLO Prototype

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16. Abstract

This report documents the high level System Design Document (SDD) for the prototype development and demonstration of the Intelligent Network Flow Optimization (INFLO) application bundle, with a focus on the Speed Harmonization (SPD-HARM) and Queue Warning (Q-WARN) applications. These two applications together comprise a tightly integrated bundle that is a key research activity within the Dynamic Mobility Applications (DMA) portion of the Connected Vehicle Program.

This SDD is a representation of a system/software design that is to be used for recording design information, addressing various design concerns, and communicating that information to the INFLO stakeholders.
This document provides a representation of the INFLO software system created to facilitate analysis, planning, implementation, and decision making. It is a blueprint or model of the INFLO software, communications, and to some extent, the hardware systems. The SDD is used as the primary medium for communicating design information.

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Chapter 1 Introduction

This report documents the high level System Design Document (SDD) for the prototype development and demonstration of the Intelligent Network Flow Optimization (INFLO) application bundle, with a focus on the Speed Harmonization (SPD-HARM), Queue Warning (Q-WARN) applications. These two applications together comprise a tightly integrated bundle that is a key research activity within the Dynamic Mobility Applications (DMA) portion of the Connected Vehicle Program.

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The SDD shows how the software system will be structured to satisfy the requirements identified in the INFLO requirements specification. It is a translation of requirements into a description of the structure and behavior of the system, the software components, the interfaces, and the data necessary for implementing the software solution.

The overall approach to this SDD is based on the guidance described in IEEE Std 1016-2009, the *IEEE Standard for Information Technology – Systems Design – Software Design Description*.

[1] Example format and explanatory text sourced from the Software Design Description Template.

Chapter 2 System Architectural Design

The INFLO system architecture is described in the *INFLO Architecture Description Document* (ADD). High level details are repeated here for readability. For more detailed architecture information please consult the ADD.

System Description

Applications

There are two primary capabilities of the INFLO system; Dynamic Speed Harmonization (SPD-HARM) and Queue Warning (Q-WARN). Detailed descriptions of both can be found in the INFLO *Concept Development and Needs Identification* and the *Report on Detailed Requirements for the INFLO Prototype* documents. Below are brief descriptions of each application.

Speed Harmonization

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

The INFLO SPD-HARM application concept aims to realize these benefits by utilizing connected vehicle-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.

Queue Warning

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

System Architecture

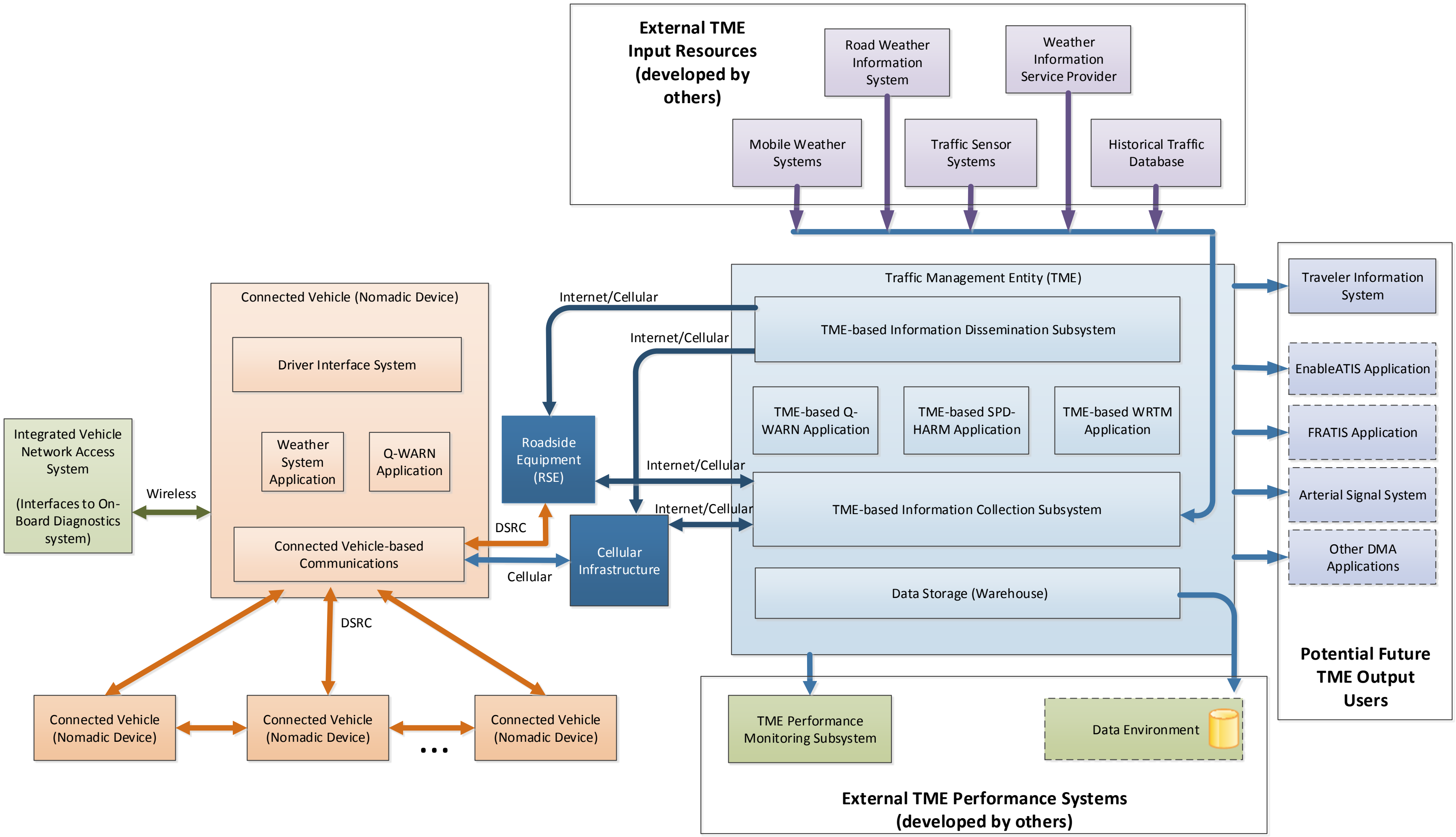
Figure 2-1 shows an INFLO system-level diagram with arrows indicating the various information flows between the entities. A detailed description of each of these elements can be found in the *INFLO Architecture Description Document*.

Design Constraints

There are a few design constraints that have dictated some of the design decisions made for the INFLO prototype. In general constraints are considered to be any condition or limitation that should be considered as part of the design effort. In this section we summarize those constraints and provide brief rationale.

General Constraints

- The only known battery-operated DSRC radio, the Arada System's Locomate ME OBU radio contains only a single 5.9GHz radio
- Similarly, this same Locomate radio supports only a limited number of active Bluetooth connections
- Due to the limited amount of schedule and budget the number of features that can feasibly be implemented will be limited. To overcome this constraint a comprehensive schedule of implementation and deadlines will be created to ensure that all necessary features will have sufficient time allocated to their development.
- Retrieving usable data from vehicles to the level for the BSM Part II is vehicle dependent. A good portion of the data required for the BSM Part II is proprietary data and is dependent on the year and make of the car. Data will be demonstrated thru use of an OBDII connection, however, without using an OEM supplied integrated vehicle all of the data items may not be available.



Source: Battelle / TTI

Figure 2-1. INFLO Prototype System Diagram

Chapter 3 Design Concerns

This section enumerates and expands upon the primary INFLO design concerns. Design concerns are specific areas of stakeholder interest that need to be accounted for during the design efforts. Design concerns do not always directly impact tangible design decisions or system features but sometimes result in systemic properties of a system. For example, the need to protect Personally Identifiable Information (PII) must be taken into account in the design of many of the INFLO components.

User Interfaces

Many of the INFLO components work independently of a human user but each computational component must have, at the very least, a user interface for maintenance, monitoring, and debugging purposes. Components that have more sophisticated user interaction must have proportionally more complex user interfaces. The following list enumerates the components and the user interface support.

- Connected Vehicle (Nomadic Device) Driver Interface System – This component is will have a graphical user interface that displays the Q-WARN and SPD-HARM information when in normal operational mode. However, as this is a prototype, it also has the ability to support debug and diagnostics in the vehicle when being used for testing purposes by a development team member. It will be the primary user interface for vehicle operators while in the field.

- Road Side Equipment – This component will provide a simple telnet interface, through a network connection, as specified by the current U.S. DOT RSE specifications[2]. This will permit the test conductor to install and execute software components on the RSE, revise configuration parameters and monitor status.

- Nomadic Device DSRC Radio Module – This component will expose a simple user interface, via telnet, to allow for installation and operation of software component on the device, setup configuration parameters, monitor status, perform self-test, etc. This interface is intended for the software developer and deployment team and not the end user.

- Cloud Service – The cloud service(s) will 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.

[2] Fehr, Walton, U.S. Department of Transportation, “5.9GHz DSRC Roadside Equipment” Device Specification, Version 3.0, March 1, 2013.

- Traffic Management Entity – The TME will provide an interface to configure settings associated with the functioning of the SPD-HARM and Q-WARN algorithms, and monitor status and performance of these. This interface is intended for the development / test team.

Networking and Communications

The design of the INFLO networking architecture must strive to minimize the end-to-end latency of a single BSM message on its journey from a Nomadic Device to the TME. The bulk of the volume of communications data in the system will in all likelihood be emanating from the Nomadic Device BSM traffic broadcast over DSRC/WAVE to the RSE. If the networking communications do not operate efficiently, a small bit of delay introduced at various hops along the way will accumulate into a significant amount by the time the BSM has reached its final destination at the TME. This amount of delay is compounded as more and more vehicles enter the system. An effective design should define a strategy for profiling latency, for instance by recording timestamps at each hop and later using comparative analysis techniques to identify bottlenecks in the system as network volume is increased.

The design should leverage parallel processing using multiple threads, and establish consumer/ producer queues to minimize the time spent waiting for physical data transfers to complete. A multi-threaded pipeline allows both receiving and sending tasks to be performed at the same time. The consumer/producer queues provide a means for tasks to be deferred temporarily until processor resources become available, essentially creating a flexible workflow that will adapt to the computing environment.

The INFLO networking architecture must scale well, such that as more vehicles are added to the system, more hardware resources may be utilized to process the network load. Contingencies should be established for the situation when the network is overly saturated with BSMs, where the INFLO pipeline may be unable to keep up with the flow of inbound data. Due to hardware and bandwidth limitations, at some point of network saturation the INFLO system may be unable to send all BSM traffic to the TME in a timely manner. Key performance parameters (such as maximum end-to-end latency) must be identified in order to recognize when the system is in a saturated state and can automatically begin executing contingencies, such as dropping BSMs according to a pre-determined strategy in order to prioritize timeliness over volume. This strategy is discussed in later sections of this document.

External Interfaces

The data collected from the nomadic devices, and the corresponding actions conveyed to the user of the INFLO applications, have value for other Intelligent Transportation System (ITS) and DMA applications that either exist or are envisioned to exist in the future. However, as these emerging applications are similarly in the prototyping stage, work being performed by different parties, it is not currently possible to fully harmonize all data needs between and amongst these entities. As such, the INFLO prototype system makes no specific attempts to interface directly with any of these external applications. However, the INFLO bundle will be designed with an open architecture and utilize standardized message formats and interfaces to the extent possible in order to allow for this necessary integration. As part of the overall Connected Vehicle architecture, use of standards such as the SAE J2735:2009 Message Set for DSRC Communications will prescribe a common set of data elements and messages found in the transportation environment. Similarly, use of communications standards currently in place the ITS community, such as the NTCIP family of standards, as well as standards used in the broader global internet, standards such as TCP/IP (v6) and RESTful web services, will be used to remain consistent with the open architecture vision and not preclude integration with other external systems.

Security

Security is fundamental to the success of the Connected Vehicle program, and tremendous efforts on the part of U.S. DOT, the vehicle OEMs and other industry partners have been performed and continue to be undertaken to ensure that all aspects of the Connected Vehicle environment are secure. As such, no new security techniques will be developed under this work, but instead, will be fulfilled by current approaches.

Specific to connected vehicles, the efforts have primarily focused on the DSRC-based over-the-air (OTA) security between vehicles and between infrastructure and vehicles, approaches which include signing and encrypting OTA data using public key / private key digital certificates and secure communication layers. This work continue to evolve, put for purpose of the INFLO prototype, this OTA security will be implemented, as exists today as part of the U.S. DOT Safety Pilot Model Deployment using a security credential management system (SCMS) and a secure DSRC-stack. Details of this approach are available in the *Security Credential Management System Design* – April 12, 2012, available from U.S. DOT, as well as the IEEE 1609 family of standards. For purposes of this prototype demonstration, the test team will serve as the certificate authority and will self-certify the devices used.

The above addresses only the DSRC aspect of over the air security; however this same application of digital certificates can be used for the cellular-based communications to be implemented along with industry best-practices for secure communications, such as the use of secure socket layers (SSL).

All backhaul connections from either the roadside device, the virtual TME and the cellular provider will also implement similar industry best-practices for security, again through the use of SSL and similar.

Finally, the cloud-based data repository and computing platform will also use industry-based best-practices. Our choice in selecting the Microsoft Azure environment to host the prototype considered security, and while it has only recently obtained a government-level certification, it provides the necessary mechanisms to demonstrate the application of security at this level within the INFLO prototype.

Protection of Personally Identifiable Information

The protection of Personally Identifiable Information (PII) and Sensitive Personally Identifiable Information (SPII) is critical to the success of the INFLO prototype demonstrations and well as all other U.S. DOT connected vehicle programs. Any breach of privacy would be a setback to this program in any area that is already sensitive. As identified in the TOPR, all data sent to the U.S. DOT Research Data Exchange (RDE) must be free of PII. However, the need to protect PII must go further than that, ensuring that PII/SPII is protected throughout the duration of the project and not just data sent to the RDE. The good news is that the INFLO prototype demonstration is expected to capture little to no PII data. However, to ensure no breach of this information occurs, the following measures will be put in place.

Protection will start with the local collection and storage of data. Battelle intends to use the Microsoft Azure cloud services to host the systems that will collect and temporarily house any potential PII data. The Azure services received the Federal Information Security Management Act of 2002 (FISMA) Authorization to Operate (ATO) in December 2010. (Mark Estberg, Senior Director of Risk and Compliance, Microsoft Global Foundation Services, 2010). FISMA regulations help ensure the protection of data though the use of NIST Special Publication 800-53 Revision 3 "Recommended Security Controls for Federal Information Systems and Organizations." By using Azure, and following the recommended guidelines published by Microsoft and NIST, we can ensure that PII is protected.

Any devices used by participants will be paid for and supplied and by Battelle, and as such, no financial data will be collected for any participant nor will any devices be specifically associated with or identifiable to a participant. Also, as there is no need to associate participants with devices for purposes of the application demonstration, no data even associated with the participants will need to be store on the cloud or provided to the RDE.

Lastly, all collected cloud-based data will be de-identified and scrubbed for PII removal prior to transmittal to the RDE. Again, as shown in Figure 7-15, minimal data associated with a particular device is captured, however techniques such as eliminating the initial and final two (2) minutes of a trip (based on movement of vehicle), or similarly, awaiting for a random distance to have been traversed before commencing the data transmissions, will protect a person's place of work or residence will still be employed. Similarly, any specific, traceable devices IDs or similar will be removed.

Weather Sensing

Sensing of weather state at the vehicle (or around the nomadic device when not in a vehicle) is accomplished in two ways. The first is by collecting weather related and weather relevant data from the vehicles ODB-II port when available. The second is by collecting ambient conditions around the nomadic device through the use of built-in sensor capability of the specified mobile phone. Sensing in vehicle environmental conditions like temperature and barometric pressure is of little value but when the device goes "nomadic" and is operating outside of the vehicle this kind of data may prove to be valuable not only for INFLO but for future U.S. DOT programs. This is the reason to develop a prototype nomadic device that can move from car to transit to pedestrian which includes the ability to collect weather data.

Packaging

Packaging in this context refers to the hardware components that will be utilized to implement the INFLO prototype. In particular, the nomadic device is the primary hardware output of this effort, and as currently envisioned, will be comprised of a combination of existing, commercial-off-the-shelf (COTS), components, that when integrated, will provide the functionality required of said device.

The two primary components that comprise the nomadic device are the smartphone and the battery-powered DSRC radio. Our intent is to remove the DSRC radio from its current, cube-shaped packaging, as shown in Figure 7-7, and to house the single printed circuit board, along with a separate battery and the necessary GPS and RF radios, into a 'backshell' case that will then attach to the back of the smartphone in a manner similar to how many extended battery cases connect. Communications between the DSRC radio and the phone will be via Bluetooth, as is indicated elsewhere in this design document. Connections to provide power to both the phone and the radio will also be included in the backshell design.

The In-Vehicle Network Access System, also known as the VITAL OBD-II dongle, is shown in Figure 7-1. It consists of the OBD-II connector to interface with the vehicle, and a Bluetooth capability to communicate with other devices.

Power

Similar to the prior section related to packaging, this section discusses the power requirements of the nomadic device and the corresponding in-vehicle network access system.

The nomadic device will be battery powered such that it can be removed from the vehicle power source and truly demonstrated as being nomadic. This feature ensures the DSRC radio will continue to transmit Basic Safety Messages at the 10Hz frequency throughout this duration, along with an ability to perform the simple weather-related measurements. The main batteries (there are two – one for the smartphone and one for the DSRC radio) are rechargeable and are expected to last at least two hours without being recharged. It should be noted that truly low-powered, mobile DSRC chipsets are only now being developed and our not available for this prototype.

The device will also support operating/charging when installed in the vehicle through the use of a simple accessory port (formerly cigarette lighter) cable which will supply power at 12VDC to the device. The time to fully recharge in this manner has not yet been determined, but is expected to be similar to times typical of current generation smartphones.

Finally, the nomadic device will support charging from standard household outlets (110-120 VAC) using an AC-to-DC transformer. Again, the recharge time has not yet been determined but is expected to be similar to current generation smartphone charge times.

The In-Vehicle Network Access System will draw power from the vehicle directly through the OBD-II port. The module was designed specifically for semi-permanent installation in the vehicle, and as such, has a lower-power mode that will detect when the ignition is off and switch to this mode in order to preserve vehicle battery power when the device / vehicle is not in use.

Chapter 4 Components Description

This section identifies the components that will make up the INFLO prototype system as seen both logically and physically.

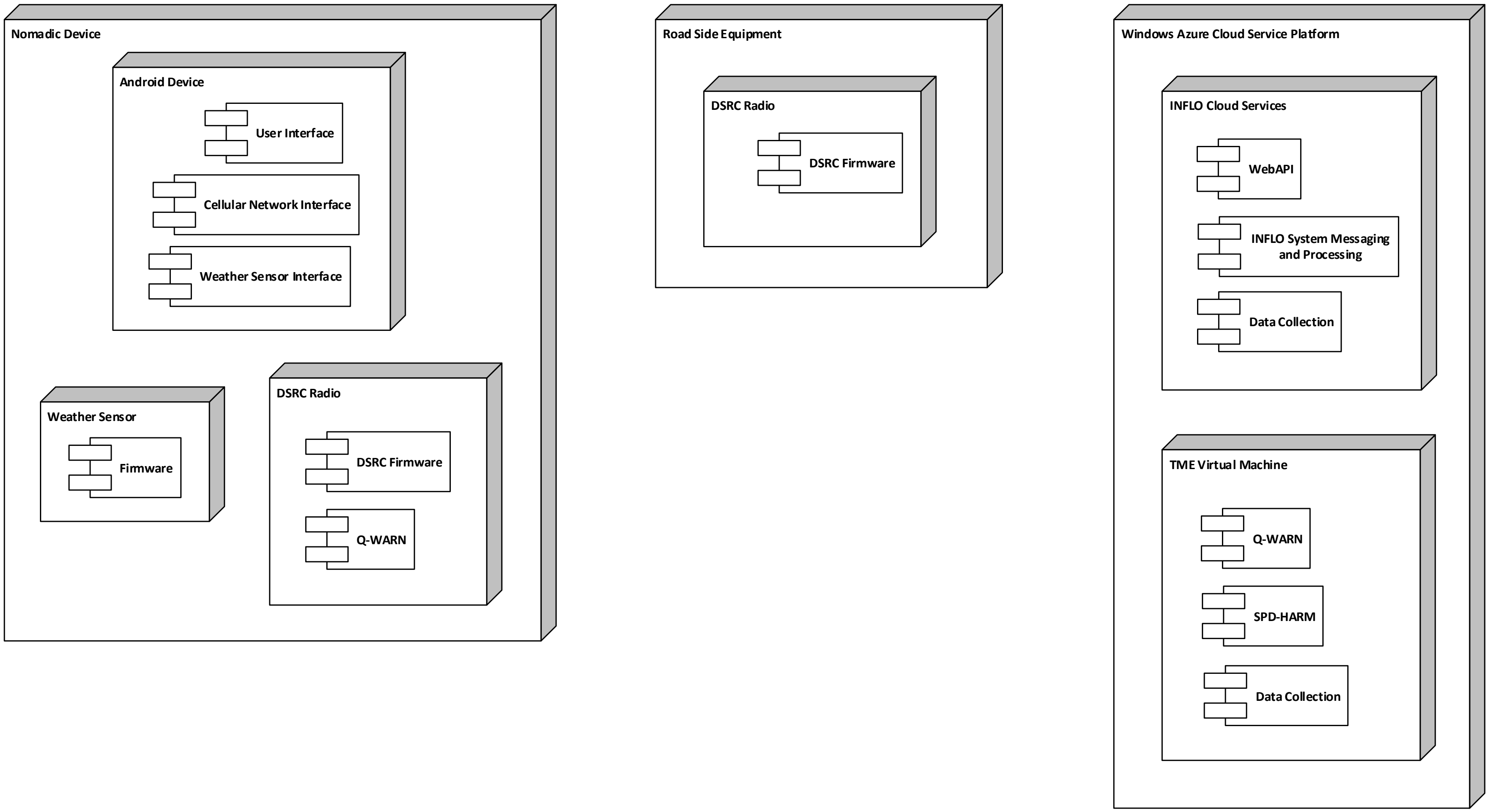
Decomposition Description

The objective of this section is to divide the system into separate components that can be considered, implemented, changed, and tested with minimal effect on other entities. The INFLO system can be broken into a first level decomposition as follows:

- The Nomadic Device
- The Roadside Equipment
- The INFLO Cloud Services
- The Traffic Management Entity running within the Windows Azure cloud computing infrastructure

External components, e.g. the Road Weather Information System or Traveler Information System which are not being developed as part of the INFLO prototype are not included in this decomposition.

Figure 4-1 shows a high level Deployment Diagram that models the physical deployment of the above components. In other words it depicts a static view of the run-time configuration of processing nodes and the components that run on those nodes.



Source: Battelle

Figure 4-1. High Level Deployment Diagram

Component Selection

This section parallels the previous section put further specifies the specific make/buy components and the rationale for their use.

Component	Selection Specifics	Rationale
Android Device	Samsung Galaxy S4	• Support for Bluetooth Low Energy • Integrated temperature sensor if needed • Large high resolution display
DSRC Radio	Arada System's LocoMate™ ME OBU	• Only available device that is portable and battery powered • Approved for use in other U.S. DOT programs (Safety Pilot)
Roadside Equipment	Arada System's LocoMate™ RSE	• Commonality with Nomadic Device DSRC Radio (supports using the same firmware)
Cloud Services	Microsoft Windows Azure	• Commonality with other U.S. DOT programs • Ease of use • Low cost • Mature tool chain

Chapter 5 Internal Interfaces

Internal interfaces consist of the following intra-INFLO system component interfaces:

- Nomadic Device to Nomadic Device
- Nomadic Device to Roadside Equipment (RSE)
- RSE to Cloud API
- Could Service to TME
- Cloud Service to Database
- TME to Database
- Nomadic Device to Cloud API

Each of these are described in detail below.

Nomadic Device to Nomadic Device

The Nomadic Device will operate in the same manner as any other vehicle equipped with DSRC radios. It will transmit both BSM Part 1 and Part 2. It will receive and process and BSM, RSA, TIM and MAP message that conform to the SAE J2735:2009 specification. In addition to the traditional V2V communications the nomadic device will transmit self-generated Q-WARN messages, in the form of RSA, TIM and MAP messages, to other equipped vehicles in proximity. The nomadic device will also forward any Q-WARN or SPD-HARM messages, received from an RSE in the form of RSA, TIM and MAP messages, to any other OBE in range.

Message	
Basic Safety Message (BSM) Part One	• Transmitted message will conform to SAE J2735 specification. • Will receive and process.
Basic Safety Message (BSM) Part Two	• Transmitted message will conform to SAE J2735 specification. Will fill the following information when available: 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, Differential wheel, speed. • Will add additional event for Queued State. • Will receive and process.
Road Side Alert (RSA)	• Transmitted message will conform to SAE J2735 specification. • Transmitted from the nomadic device based on Q-WARN application. • Forwarded from TME through the nomadic device.
Traveler Information Message (TIM)	• Transmitted message will conform to SAE J2735 specification. • Transmitted from the nomadic device based on Q-WARN application. • Forwarded from TME through the nomadic device.
Map Data (MAP)	• Transmitted message will conform to SAE J2735 specification. • Transmitted from the nomadic device based on Q-WARN application. • Forwarded from TME through the nomadic device.

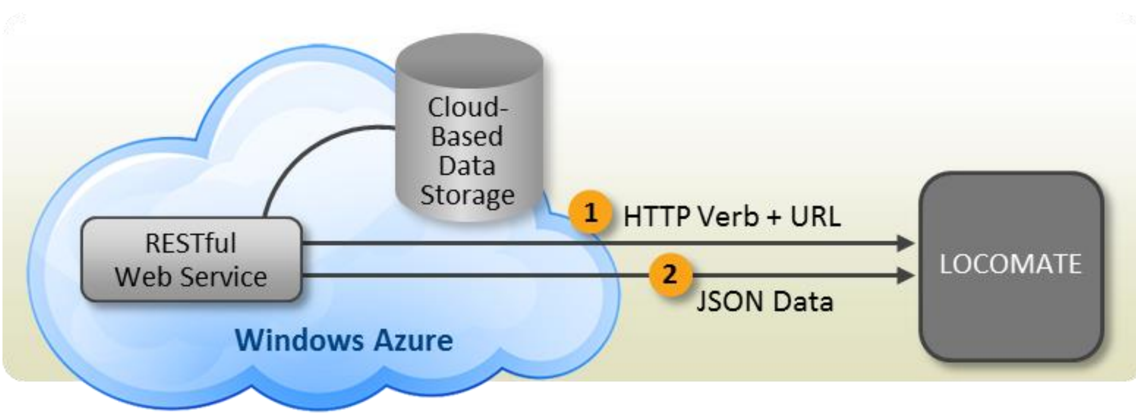
Nomadic Device to RSE

The Nomadic Device will receive and process and BSM, RSA, and TIM messages, that conform to the SAE J2735 specification, from the RSE. The nomadic device will forward any Q-WARN or SPD-HARM messages from an RSE in the form of RSA and TIM messages to any other OBE in range. The following table identifies the message types and any usage considerations.

Message	
BSM Part One	• Transmitted message will conform to SAE J2735 specification
BSM Part Two	• Transmitted message will conform to SAE J2735 specification. Will fill the following information when available: 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, Differential wheel speed (NOTE: *required) • Will add additional event for Queued State
Road Side Alert (RSA)	• Transmitted message will conform to SAE J2735 specification. • Transmitted from the nomadic device based on Q-WARN application.
Traveler Information Message (TIM)	• Transmitted message will conform to SAE J2735 specification. • Transmitted from the nomadic device based on Q-WARN application.

RSE to Cloud API

The Cloud Service will host a secure Cloud Web Server over HTTPS protocol (Hypertext Transfer Protocol Secure). This secure Cloud Web Server will implement a simple Representational State Transfer (REST) architecture to service requests from the RSEs (see Figure 5-1).



Source: Battelle

Figure 5-1. Cloud Based RESTful Service

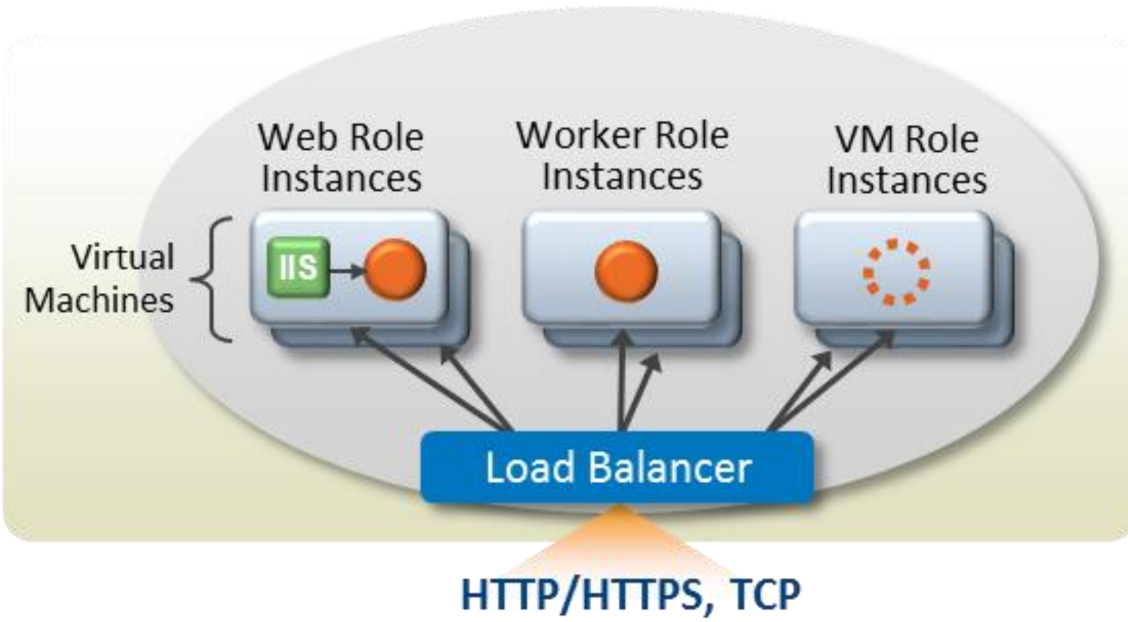
An RSE web client will request a persistent HTTPS connection (Keep-Alive) with the Cloud Web Server to reduce the overhead otherwise required to repeatedly open temporary HTTPS client connections. As indicated in the table below, a 'wrapper' object will be used to encapsulate the J2735 message payload in an industry standard JSON message, for purposes of exchanging with the cloud-services. This allow for both RSE to cloud and Nomadic Device (via cellular) to cloud to have consistent message formats and a single interface on the cloud.

Request	Resource	Parameters	Response
GET	I2V/MAP	Lat/Lon	Wrapper MAP object (JSON)
GET	I2V/TIM	Lat/Lon	Wrapper TIM object (JSON)
GET	I2V/RSA	Lat/Lon	Wrapper RSA object (JSON)

Request	Resource	Parameters	Content
POST	BSMBundle		Wrapper BSMBundle object (JSON)

Cloud Service to TME

The Cloud Service will host multiple Virtual Machines (VMs) that provide basic web server and back-end database worker functionality for the TME, as shown in Figure 5-2 (on the left side). In Microsoft Windows Azure, these VM instances are known as Web Roles and Worker Roles. The function of these roles is to service request from Internet clients over HTTPS. In the context of INFLO, these web roles will fulfill requests for I2V resources and update the database upon receiving BSM POSTs. All VMs have access to shared database storage (not shown in figure).



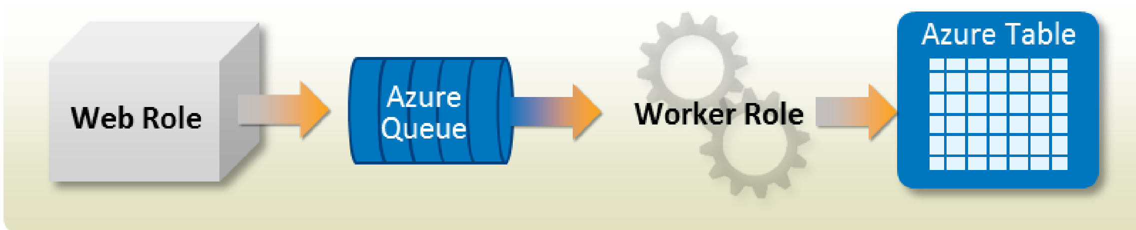
Source: Battelle

Figure 5-2. Azure Cloud Service VM Roles

In addition to these web-related roles, the Cloud Service will also host an isolated internal Virtual Machine for running the main TME application, which is responsible for analyzing traffic data in real time and generating appropriate intelligent traffic alerts. This main TME application is expected to require significant computing resources to process the TME algorithms, and for this reason the TME application will be hosted on its own dedicated Virtual Machine. Communications between the TME and the cloud services components will be facilitated over a secure, virtual private network (VPN) using web service interfaces similar to how the RSE and nomadic device communicate with the cloud services.

Cloud Service to Database

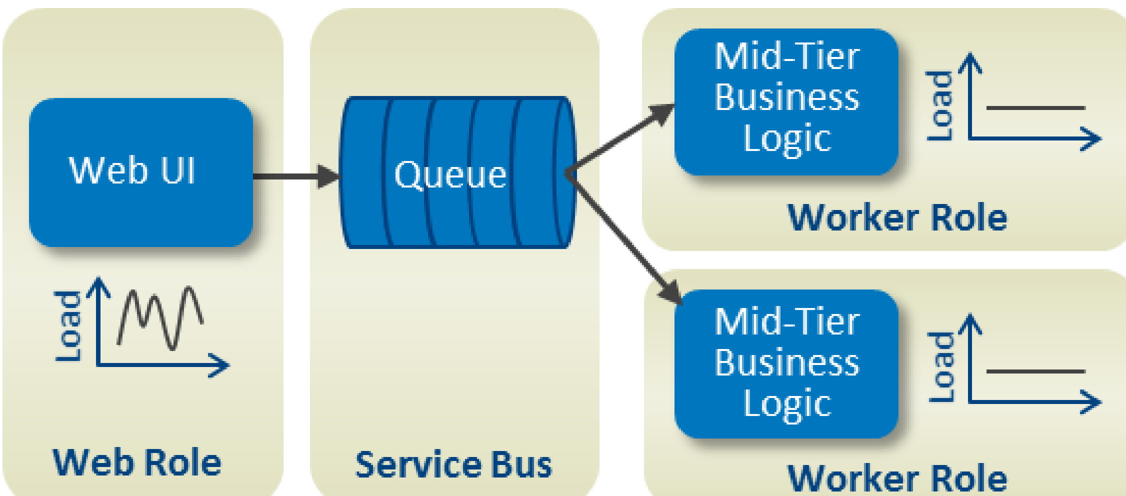
The Cloud Service will provide all back-end functionality required to efficiently process inbound BSM bundles, using the pre-built functionality packaged with Azure Web Roles, Worker Roles, and Service Bus Queues. The high-level process flow for updating the Azure database is shown in Figure 5-3.



Source: Battelle

Figure 5-3. Updating the Azure Database

Loading can be balanced and further parallelized by adding more Web Roles and Worker Roles to process the main Service Bus Queue, as shown in Figure 5-4.



Source: Battelle

Figure 5-4. Azure Load Balancing With Additional Roles

TME to Database

The TME applications require the acquisition of data from external sources including:

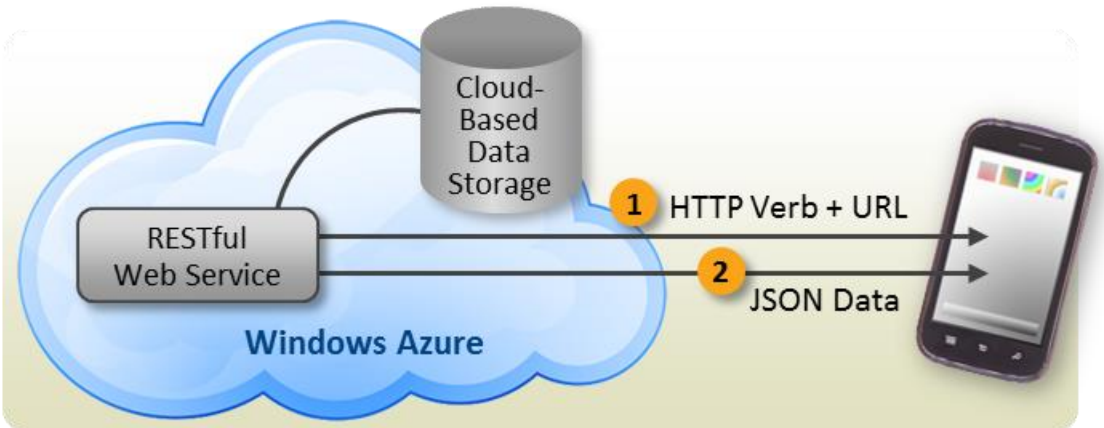
- Traffic Sensor Systems (TSS) will provide the required traffic data from infrastructure based sensors like radars or loops. The data provided shall be by lane and include at a minimum the average speed, volume, and occupancy in a specific lane during the time interval requested.
- Environmental Sensor Stations (ESS) may provide weather data from both permanent and portable sensors.
- Mobile ESS will provide weather data from mobile maintenance vehicles that are equipped with weather sensors.
- Weather Information Service Providers will provide weather alerts that will be used to determine the roadways that could be affected by severe weather conditions as well as contribute to the logic facilitating y the weather data polling frequency from infrastructure ESS and mobile ESS systems.
- Connected Vehicle Cloud will provide connected vehicle traffic and weather data that was collected from connected vehicles.

A separate data aggregation module will be developed to interface with each one of the external data providers to listen/poll the required data at a frequency defined by the application, perform any necessary data validation requirements to insure that the data collected is within the thresholds defined by the application, process the acquired inputs to generate the data required by the INFLO application (for instance, determining the roadway link where a connected vehicle is located based on its mile marker location or if a roadway link is congested or queued), and finally write the raw data received from the external sources and the processed data into the INFLO database. The INFLO data aggregation modules will use the query language provided by the database and Ethernet TCP/IP protocols to write the collected data into the various tables in the database.

The recommended link target speeds generated by the INFLO applications, the collected weather data, and the queue and weather alerts disseminated to connected vehicles and infrastructure dynamic message signs, will also be logged into the INFLO database to be used by the performance monitoring system.

Nomadic Device to Cloud API

This interface is similar to the RSE to Cloud API interface previously discussed but is included for consistency in documenting each interface in the design. The Cloud Service will host a secure web server over HTTPS protocol (Hypertext Transfer Protocol Secure). This secure web server will implement a simple Representational State Transfer (REST) architecture to service requests directly from the Nomadic Device via a cellular connection originated from the smartphone component of the nomadic device.



Source: Battelle

Figure 5-5. Cloud RESTful Web Server

A Nomadic Device web client will request a persistent HTTPS connection (Keep-Alive) with the Cloud Web Server to reduce the overhead otherwise required to repeatedly open temporary HTTPS client connections (see Figure 5-5). As indicated in the table below, a 'wrapper' object will be used to encapsulate the J2735 message payload in an industry standard JSON messages, for purposes of exchanging with the cloud-services. This allow for both RSE to cloud and Nomadic Device (via cellular) to cloud to have consistent message formats and a single interface on the cloud.

Request	Resource	Parameters	Response
GET	I2V/MAP	Lat/Lon	Wrapper MAP object (JSON)
GET	I2V/TIM	Lat/Lon	Wrapper TIM object (JSON)
GET	I2V/RSA	Lat/Lon	Wrapper RSA object (JSON)

Request	Resource	Parameters	Content
POST	BSMBundle		Wrapper BSMBundle object (JSON)

Chapter 6 External Interfaces

In this section, designers, programmers, and testers can find information about design entities that are not part of the core INFLO system.

Vehicle Interface

The Vehicle Interface will be a Bluetooth module that plugs into the OBD-II port on a vehicle. The Nomadic Device DSRC radio will connect to this module to receive data from the vehicles CAN bus.

Variable Message Signage

The TME will have the capability to disseminate the recommended roadway link target speeds and queue/weather alerts and warnings to drivers through infrastructure based dynamic message signs and variable speed limit signs. In order to facilitate this, the infrastructure signs should be NTCIP 1203 compliant. The 1203 NTCIP standard can be used with serial, TCP/IP, or UDP communications protocols to display messages on the signs.

Mobile Environmental Sensor Station (Mobile ESS)

The INFLO prototype will contain a data aggregation application to interface with a representative example of a Mobile ESS devices to acquire weather observations made for a roadway link. The frequency of accessing the Mobile ESS system will be either defined by application or based on weather alerts received from Weather Information Service Providers. The acquired information will be checked to verify that the data collected is valid and if it applies to the roadway network being monitored. The data will be saved into the INFLO database where it can be used by the WRTM module to generate weather alerts/warnings, and to determine the recommended target safe speed for each roadway link being monitored.

Environmental Sensor Station (ESS)

The INFLO prototype will contain a data aggregation application that will interface with a representative example of an ESS infrastructure device to acquire weather observables associated with a roadway link. Typically this is accessed through an agency's road weather information system (RWIS). The frequency of accessing the data will be either determined by the user or based on weather alerts received from Weather Information Service Providers. The acquired information will be checked to verify that the data collected is valid and if it applies to the roadway network being monitored. The data will be saved into the INFLO database where it can be used by the WRTM module to generate weather alerts/warnings, and to determine the recommended target safe speed based on roadway conditions for each roadway link being monitored.

Traffic Sensor Systems (TSS)

A dedicated data aggregation module will interface with a representative example of a TSS system that is collecting data from infrastructure traffic sensors installed in each lane of the roadway being monitored. The frequency of polling the TSS is application defined. The TSS will use NTCIP standard 1209 together with either Ethernet TCP/IP or UDP protocols to interface with the TSS. The data received from TSS for each lane detector should include volume, average speed, and occupancy for each lane for the requested time interval. The lane data is aggregated to calculate the average speed, volume, and average occupancy across all lanes for each detector station configured in the TSS. The detector station data will be used to further determine a roadway link local speed and if the link is queued or congested based on user defined threshold.

Weather Information Service Providers

A dedicated data aggregation module will interface with the Weather Information Service Providers like the National Weather Service (NWS) to demonstrate a representative example of this function and receive weather alerts. The weather alerts will be used to determine the affected roadway links and to modify the frequency of polling the infrastructure based ESS and mobile ESS devices during the weather alert specified time interval.

TME Performance Monitoring System

The Performance Monitoring System is a subsystem of the TME that monitors the effectiveness of speed harmonization and queue warning heuristics, recommendations, and policies on the transportation network using safety and mobility measures, and could be used an input to the respective algorithms. The TME PMS is not within the scope of the INFLO Prototype, however it is being shown in the diagram for consistency with the broader INFLO concept.

Data Environment

The Data Environment supports the TME Performance measure system by providing a location for storing the outputs of the INFLO system in order to allow for the TME Performance Monitoring System to function. Similar to the TME PMS, the Data Environment will not be prototyped for this phase of the project, but is being shown in the diagram for consistency with the broader INFLO concept of operations.

Historical Traffic Database

The Historical Traffic Database provides access to legacy data related to roadway link speeds, traffic volumes, conditions and other factors and within the broader INFLO concept of operation, supports the concept of queue prediction logic. The scope of the INFLO prototype does not include the prediction model.

Chapter 7 Component Design

As previously discussed, the INFLO Prototype is comprised of several major component that are integrated into a single system that enable the deployment of the SPD-HARM and Q-WARN applications. These components are as follows:

- In Vehicle Network Access System
- Nomadic Device User Interface Module (aka smartphone)
- Nomadic Device DSRC Radio Module
- Road Side Equipment
- Cloud Service
- INFLO Database
- Virtual Traffic Management Entity (TME)

The components are described in detail throughout the remainder of this chapter.

In Vehicle Network Access System

The In Vehicle Network Access System (IVNAAS) will implement an OBD-II interface that will be handled by the VITAL module. The VITAL module is 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 7-1). This module will allow the DSRC radio to receive vehicle dynamics to populate the Basic Safety Message Part II. The availability of data is vehicle dependent.

Source: Battelle

Figure 7-1. VITAL OBD-II Module

Nomadic Device User Interface Module

The Nomadic Device User Interface Module will be a mobile device (cell phone) running the Android operating system. The goals/features of this component are:

1. Provide an interface to the cellular network (i.e., the TME via the Internet)
2. Management of the connection back to the Azure Web Service hosting the TME
3. Integrate and exposing the ambient weather sensor data
4. Graphical user interface to communicate the following to the user:
    - INFLO system state
    - Nomadic device system state
    - SPD-HARM messages (recommended speed for example)
    - Q-WARN messages (queue location, time to end of queue, etc.)

5. Interfacing with the DSRC radio module in the nomadic device via a Bluetooth connections to send weather data to the DSRC radio module and receive TME bound messages.

Platform

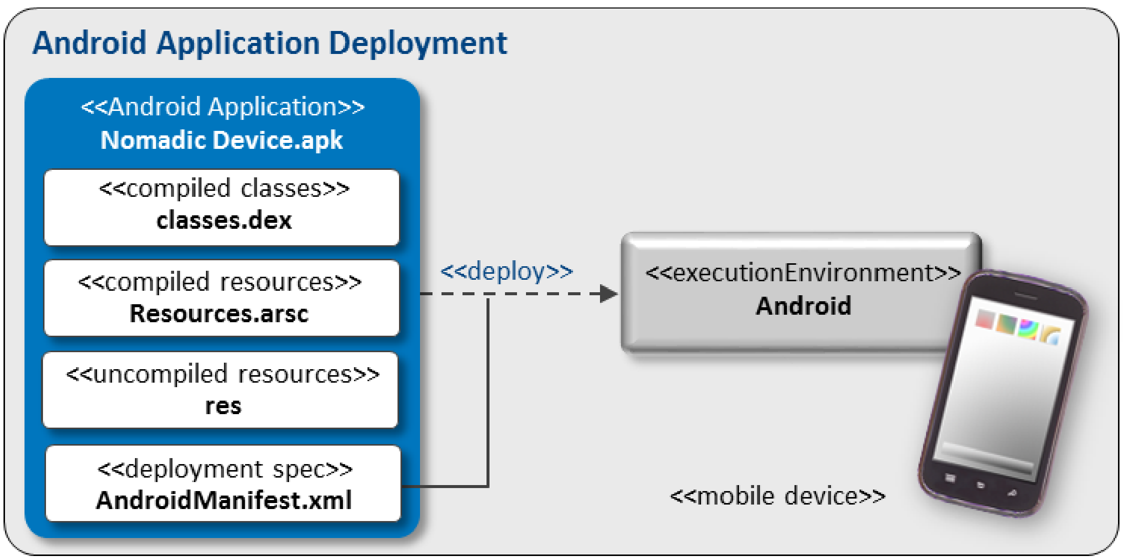
The target platform is the Samsung Galaxy S4 which is a 5" Android based cell phone however the software developed for the Nomadic Device User Interface Module will run on any type of Android device as long as that device supports Android 4.3 (API Level 18).

Development Stack

The Nomadic Device User Interface Module will be built using Google's Android SDK and targeted at Android devices running at least Android 4.3 Jelly Bean (API level 18).

Deployment Diagram

Figure 7-2 shows the basic deployment diagram for the Nomadic Device User Interface Module. This is a standard deployment model used by most basic Android applications[3].



Source: Battelle

Figure 7-2. Nomadic Device User Interface Application Deployment Diagram

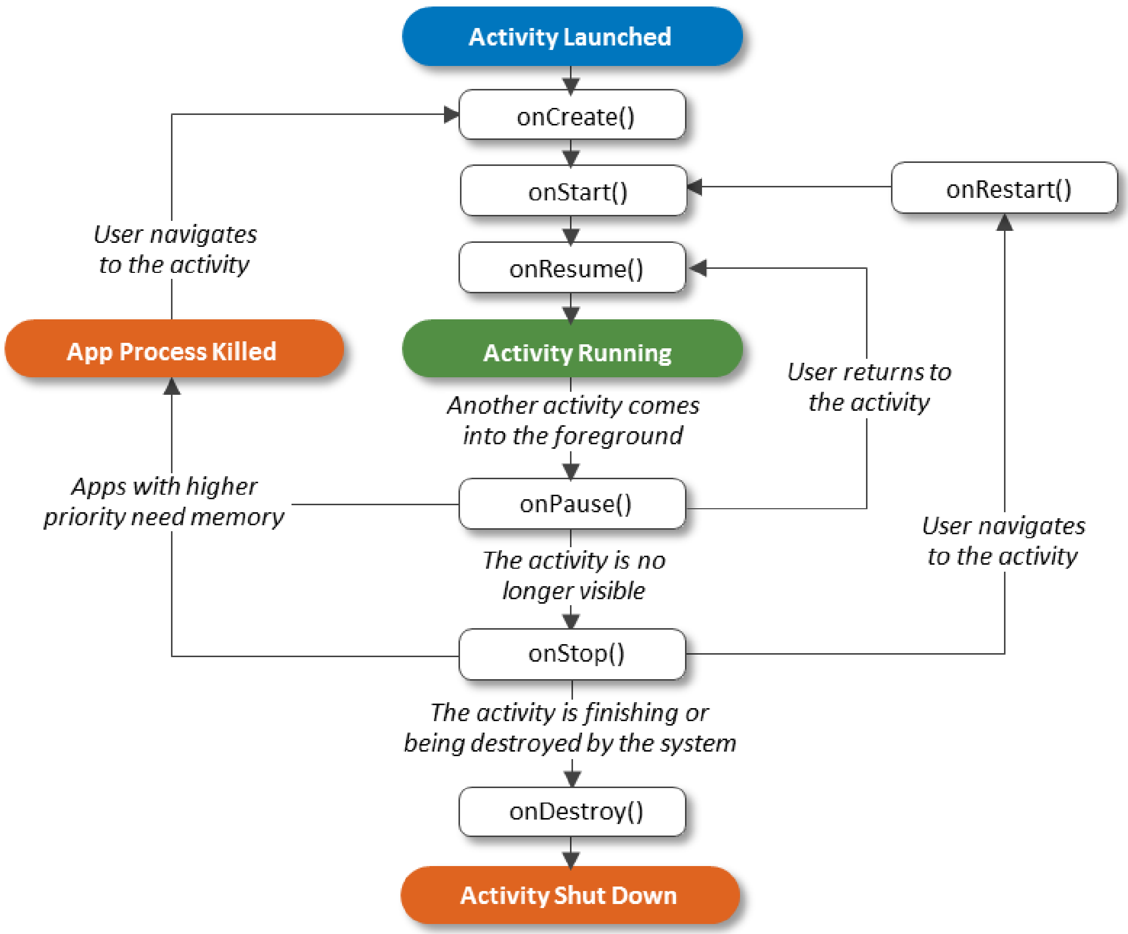
Application

Most Android applications are composed of Activities. The activities normally live in a lifecycle controlled by the Android OS. The intent is that the INFLO application on the nomadic device is the only executing application on the device but the system must support the user switching to other activities (applications) or responding the operating system events. Figure 7-3 shows the Nomadic Device User Interface Module lifecycle[4]. This diagram shows the important state paths of an Activity. The square rectangles represent callback methods which will be implemented to perform operations

[3] UML Diagrams website

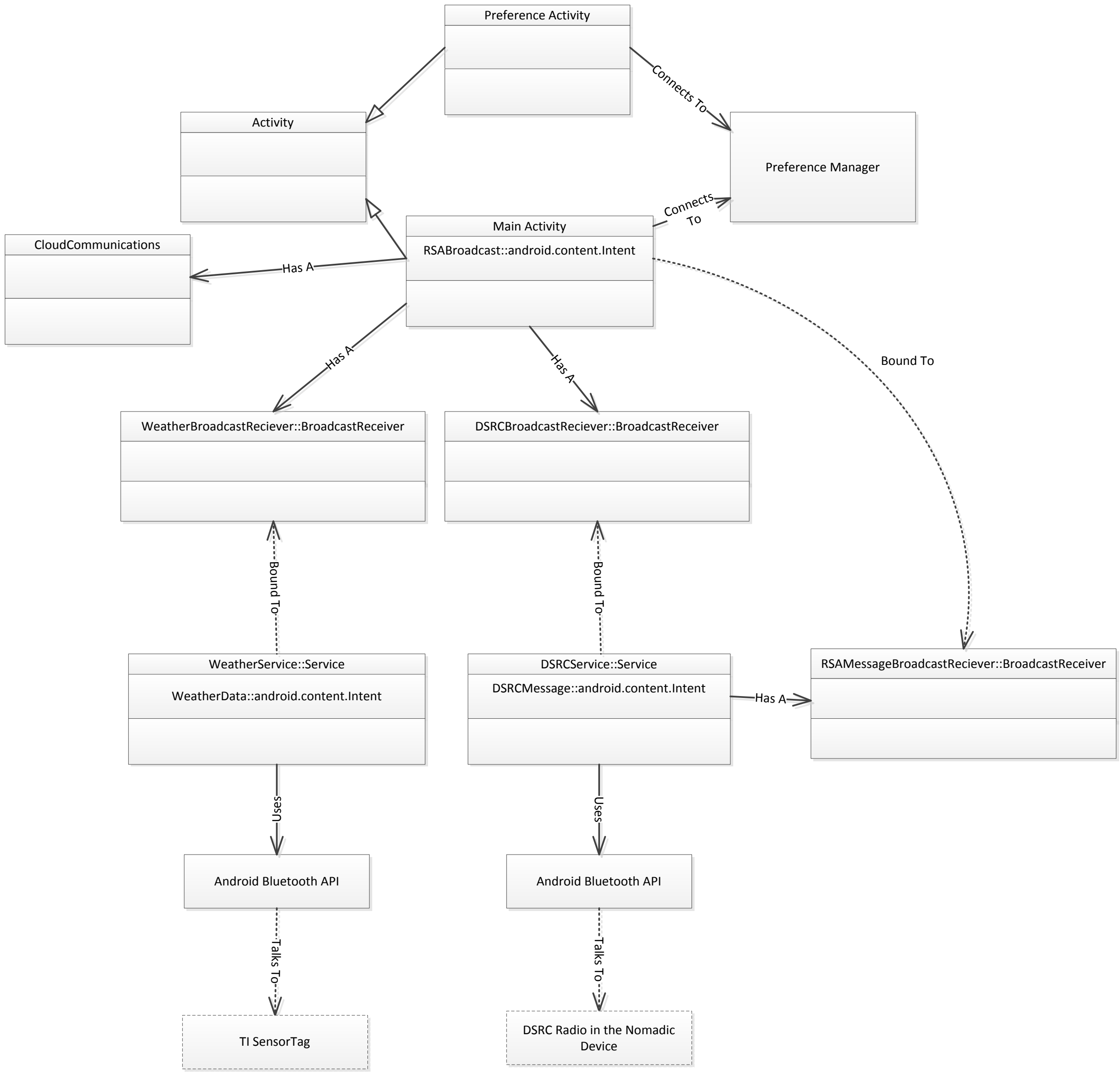
[4] Android Developers website

when the Activity moves between states. The colored ovals are major states the Activity can be in. Figure 7-4 shows a simplified object model for the Nomadic Device User Interface Application.



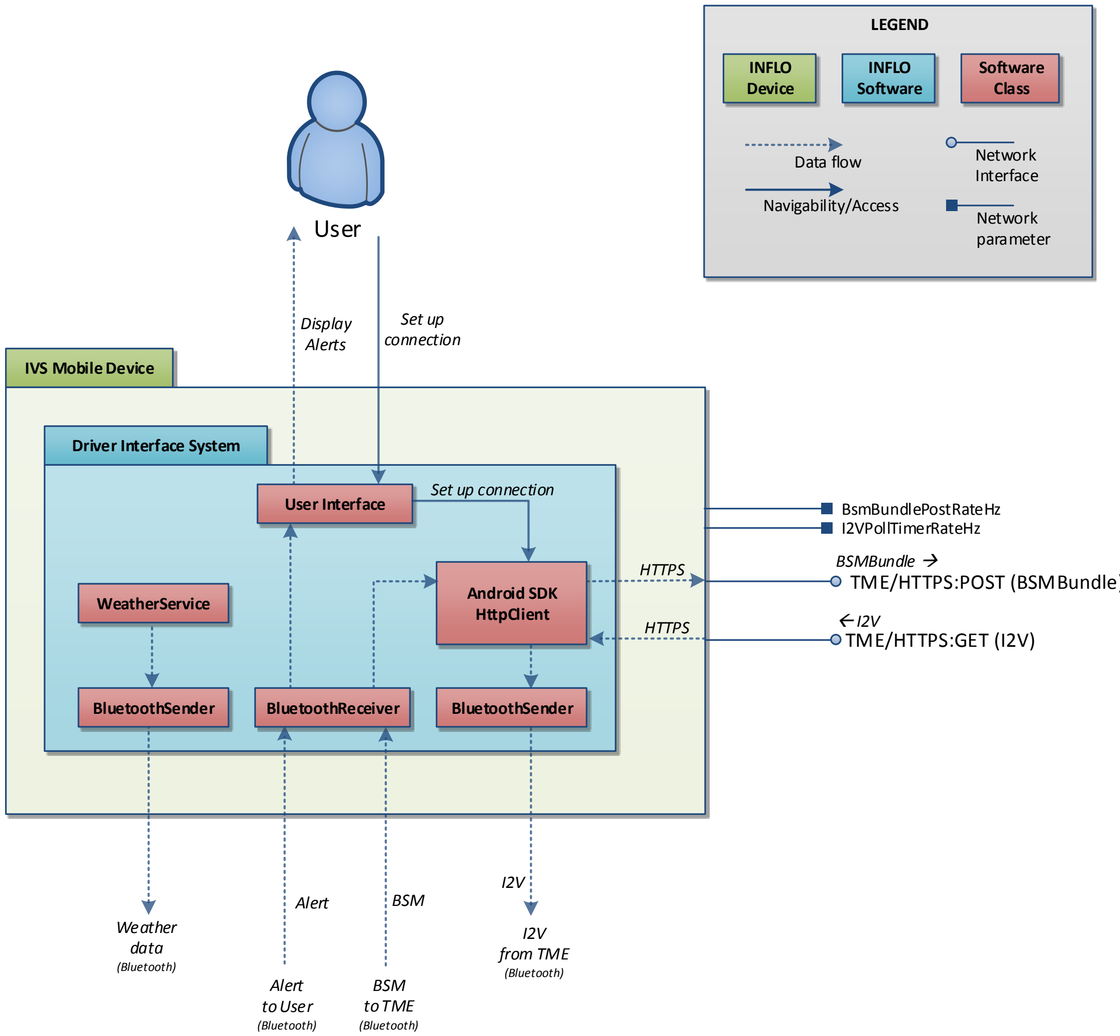
Source: Battelle

Figure 7-3. Nomadic Device User Interface Application Lifecycle



Source: Battelle

Figure 7-4. Nomadic Device User Interface Application Object Model



Source: Battelle

Figure 7-5. Mobile Device Data Flow

Bluetooth Interfaces

To support communications between the smartphone device and the nomadic device's integrated DSRC radio, the application will leverage the Android support for the Bluetooth network stack, which allows a device to wirelessly exchange data with other Bluetooth devices (see Figure 7-5). The application framework provides access to the Bluetooth functionality through the Android Bluetooth APIs (for both Bluetooth Low Energy and standard Bluetooth). These APIs let applications wirelessly connect to other Bluetooth devices, enabling point-to-point and multipoint wireless features.

Support for interfacing with the weather sensor and the integrated DSRC radio will be handled by two Android services. The Android Service object supports developers by providing a way to manage long running or persistent operations while not blocking the main user interface activities. In other words, it is a facility for the application to tell the system about something it wants to be doing in the background (even when the user is not directly interacting with the application).

- The DSRCService will implement and support bi-directional communications between the Android device and the DSRC radio. The DSRC radio in the nomadic device will be responsible for much of the INFLO processing that is not handled by the TME. When not in range of road side equipment, data bound for the DSRC radio in the nomadic device will come through the cellular link provided by the Android device and pass, essentially unchanged, to the DSRC radio. Similarly, data bound for the TME will flow through the DSRCService to the Android devices cellular connection to the TME.

Intents and Broadcast Receivers

An Intent in Android is an abstract description of an operation to be performed. It can be sent to any interested component who implements a BroadcastReceiver. Details of how this works can be found in the Android API documentation. The MainActivity in this design will expose a BroadcastReceiver for both the WeatherService and the DSRCService. It will, via the CloudCommunications object, send incoming RSA information to the DSRC radio component via the same Intents to BroadcastReceiver mechanism on the DSRCService component.

CloudCommunications

The CloudCommunications component acts as a cellular network bridge and is responsible for synchronous communications with the INFLO Windows Azure WebAPI interfaces. There will be a configurable timer that essentially polls the WebAPI. Each call will post status packets (BSM's for example) to the WebAPI and at the same time query for location specific data (RSA's for example). When BSM's are not available/valid this interface will continue to the poll the TME for location specific updates. Note that this interface is only active when the nomadic device is not in range of RSE.

User Interface

Figure 7-6 shows a draft user interface for the INFLO application running on the nomadic device. There will be no focus on human factors or industrial design for this prototype.

Source: Battelle

Figure 7-6. INFLO Nomadic Device User Interface Examples

In the mockups the screens are made as simple as possible with the goal of displaying:

- Recommended speed (SPD-HARM)
- Distance to an approaching queue (Q-WARN)
- Some level of color based warning for distance to queue and/or current speed relative to recommended speed

The Android application's user interface will contain settings and debug/diagnostic screens as well but those are not shown here.

Nomadic Device DSRC Radio Module

The nomadic device DSRC radio will be a small portable unit that can run on battery power. The unit will be the main processing for the nomadic device. The unit will receive messaging from the DSRC radio and the cellular network (via the paired smartphone device). It will process all messages and supply any needed information for driver alerts/warnings.

The unit will interface to the User Interface Module via Bluetooth. The radio will receive both V2V and I2V communications. The radio will transmit Basic Safety Messages (Part I and Part II) to other DSRC radios that are in range. The DSRC radio will also host 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 Nomadic Device will transmit both Basic Safety Messages Part One and Basic Safety Messages Part Two. The part two data will be populated by data from the vehicle, data from the onboard GPS and data collected by weather sensors. The BSM will be transmitted at 10 Hz with the Part Two transmitted at 1HZ. The Nomadic Device will also transmit any Q-WARN indicators calculated in the onboard Q-WARN Application (as part of the BSM Part Two). The radio will also forward any Q-WARN message received from the TME.

The Nomadic device will receive 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 Q-WARN application. The Nomadic device will also receive and process at a minimum the following messages from the infrastructure whether it is from a local DSRC radio or the cellular connection: MAP, Road Side Alert (RSA) and Traveler Information Message (TIM). The preceding messages will subsequently be rebroadcast for reception by other nomadic devices within radio range.

Source: Battelle

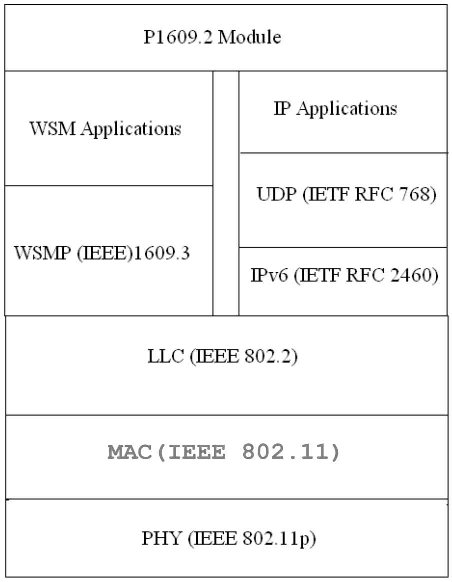
Figure 7-7. Nomadic Device DSRC Radio Module

Platform

The nomadic DSRC radio will use an Arada System's LocoMate™ ME OBU battery powered unit, shown in Figure 7-7. The LocoMate™ ME OBU comes in a tiny form factor for in-vehicle deployment with a full DSRC WAVE software solution and applications for integration with smart phones to ease the human-user-interface. The solution is integrated with GPS (better than 1 meter accuracy), Bluetooth and high-power 802.11p radios. It is fully compliant with Omni-Air's certification and used in worldwide deployments including the US Department of Transportations' Safety Pilot in Ann Arbor, Michigan.

Development Stack

The Nomadic Device DSRC application will be written in C using interfaces supplied by the manufacturer. The development for the application that resides on the DSRC will use Arada's WAVE API version 1.86. The application will be built to execute on a Linux operating system using the LocoMate™ tool chain version 1.42. This API includes Security, GPS positioning and SAE J2735 messaging. Figure 7-8 shows the WAVE stack as included on the Arada DSRC devices.



Source: Arada Systems

Figure 7-8. Arada API Interfacing with the WAVE Stack

Application

The application will be based on Arada's example code for the On-Board Equipment deployment. This example implements the messaging, logging and security for the WAVE messages. Additional functionality will be added to this application to incorporate the following. The design of the application can be seen Figure 7-9.

- Q-WARN on board application
- Vehicle Data integration into the BSM Part II message
- Weather Data integration into the BSM Part II message
- User Interface messaging
- Cellular Communications via Bluetooth
- Queued State determination and integration into the BSM Part II message
- Alert Forwarding via DSRC

Q-WARN Application

The Q-WARN application is the core in-vehicle application. It functions to process real-time data and make individual queue warning determinations based on that data. This application will take BSM Messages from surrounding vehicles and determine the queue state of the vehicle. If it is determined that a queue exists, the application will populate an event indicator field in the outgoing BSM Part II messages. Details of the Q-WARN application may be found in the separately published Report on Dynamic Speed Harmonization with Queue Warning Algorithm Design[5], produced concurrent with this design document.

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

Vehicle Data Bluetooth Receiver

The vehicle data will be collected from a Bluetooth link to an OBD-II module that will allow the application to determine specific states of the vehicle. The receiver will connect to the module and receive raw CAN messages from the vehicle. The messages will then be decoded to extract the vehicle status. When the device is in nomadic mode (i.e. not installed in the vehicle) the vehicle data for the BSM Part II will not be populated. The data that may be obtained from the vehicle, when the nomadic device is installed, is listed in Table 7-1. NOTE: Not all of these elements are available on all vehicles. It is vehicle make and model dependent.

Table 7-1. Basic Safety Message Part II Data Elements

Data Elements
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
Differential wheel speed

Source: Battelle

This Bluetooth receiver will also receive the weather data from the Nomadic Device User Interface Module. All of this data is passed to the BSM Generator for inclusion into the Basic Safety Message Part II.

I2V Bluetooth Receiver

The Infrastructure to vehicle receiver will handle any incoming message from the TME over the cellular link. The messages that will be received are the Road Side Alert, Traveler Information and Map Data. The messages will be received in ASCII and they will be converted to a binary ASN.1 format. The messages will then be processed by the existing Arada message handlers.

Alert Bluetooth Sender

The Alert Bluetooth Sender will relay messages to the User Interface to be displayed to the user. The alert will come from either the TME or the on-board Q-WARN application. The alert will contain ITIS Codes for the text display that the user interface will use a table lookup to decode.

Message Bluetooth Sender

The Message Bluetooth sender serves to transmit data/messages generated on the DSRC module to the User Interface module in order to facilitate over-the-air communications via the cellular network. The Basic Safety Message Part II will be received internally from the BSM Network Controller and in turn, will be sent to the Nomadic Device User Interface Module for transmission on the cellular network. These Basic Safety Messages will only be sent via the cellular network when the Nomadic Device DSRC is not in range of an RSE. The Message Bluetooth sender will also be used to transmit any alert message to the User Interface module for subsequent display on that module.

Basic Safety Message Generator

The Basic Safety Message Generator will fill all applicable fields in the BSM from data that it receives from multiple inputs. The weather data will be filled in from data received from the Nomadic Device User Interface Module. The vehicle data, when the nomadic device is installed as an OBE, will be used to populate the appropriate fields. The time and GPS position will be retrieved from the integrated GPS receiver.

I2V Network Controller

The Infrastructure to Vehicle Network Controller will handle all messages between the infrastructure and the nomadic device.

I2V Receiver

The Infrastructure to Vehicle Receiver will receive any messages from an RSE over the DSRC radio. All messages will be sent to the I2V Network Controller for handling.

BSM Network Controller

The Basic Safety Message Controller will be responsible for deciding where and when to send the BSM messages. When the Nomadic Device is within range of an RSE it will only send the BSM Part II message through the DSRC radio. When the Nomadic Device is not in range of an RSE it will send the BSM Part II message to the Nomadic Device User Interface Module for transmission on the cellular network. The BSM Part I message will only be sent through the DSRC radio.

BSM Receiver

The Basic Safety Message Receiver will receive any BSM from surrounding DSRC transmissions. These messages will be buffered for use by the Q-WARN Application. The buffer will utilize a first in – first out type of approach and will be configurable to conserve system memory resources.

BSM Drop Strategy

The BSM Drop Strategy will determine which messages should remain and/or be added to the queue when the queue becomes full. There are three strategies that can be employed to determine which messages to keep in the queue. The specific strategy or strategies used will not be determined until device testing occurs and will be finalized at that time.

BSM Drop Dense Strategy

This strategy will drop a message from a closely grouped set of messages. The closeness of the messages indicates a low rate of travel or being stopped. Many messages from the same area do no contribute much to the applications running on the TME.

BSM Drop Bursty Strategy

This strategy will drop messages that are sent very close together. This will allow a nice distribution of data to time.

BSM Drop Oldest Strategy

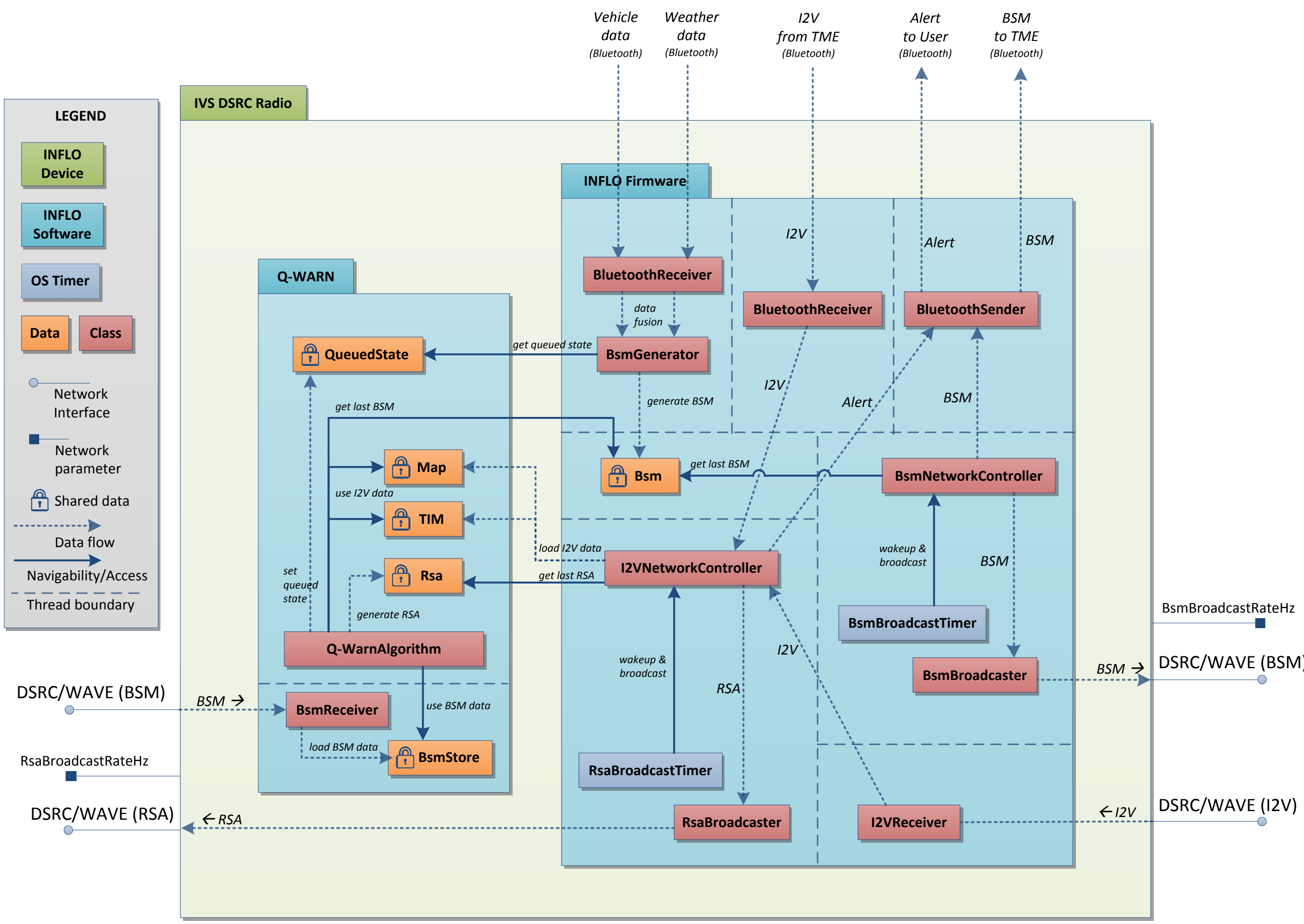
This strategy will drop the oldest message in the queue. This will allow the messages that get sent to the TME to be the latest available.

BSM Broadcaster

The Basic Safety Message Broadcaster will broadcast the current BSM over the DSRC radio to any other DSRC radio within range. The Basic Safety Message Part I will be broadcast at 10 Hz and the Basic Safety Message Part II will be broadcast at 1 Hz.

RSA, MAP and TIM Broadcaster

The Road Side Alert Broadcaster will broadcast a Q-WARN RSA or TIM message to any other DSRC within range. The messages will be populated from the on-board Q-WARN application and will contain data concerning the queue. The broadcaster will transmit a MAP message if any is available for the geographic location.



Source: Battelle

Figure 7-9. In-Vehicle DSRC Design

User Interface

The user interface to the LocoMate™ GO is through a telnet connection using hardwired Ethernet. Once a user has logged into the device a command line interface is used to configure the device using standard Linux commands. A command line interface is provided by Arada that will allow the user to manage the operation of the DSRC radio and its external interfaces.

Road Side Equipment

The Road Side Equipment will be an Arada LocoMate™ RSU which will handle all communications from the TME to vehicles and nomadic devices and communications from the vehicles to the TME. The Road Side Equipment will forward any warnings from the TME to all devices within its range. The RSE will also collect BSM Part II messages and subsequently forward these messages to the TME for use by the infrastructure-based algorithms.

Source: Arada Systems

Figure 7-10. Road Side Equipment Arada LocoMate™ RSU

Platform

The Road Side Equipment will be an Arada LocoMate™ RSU which comes in an industrial outdoor NEMA rated enclosure that allows for seamless outdoor deployments with a full DSRC WAVE software solution (see Figure 7-10). The solution is integrated with GPS, Bluetooth and high-power 802.11p radios. It is fully compliant with Omni-Air's certification and used in worldwide deployments including the US Department of Transportations' Safety Pilot in Ann Arbor, Michigan.

Development Stack

The Nomadic Device DSRC application will be written in C using interfaces supplied by the manufacturer. The development for the application that resides on the DSRC will use Arada's WAVE API version 1.86. The application will be built to execute on a Linux operating system using the LocoMate™ tool chain version 1.42. This API includes Security, GPS positioning and SAE J2735 messaging.

Application

The Road Side Equipment will forward any messages received from the TME to any DSRC radios within range. These messages must conform to the SAE J2735 specification. The RSE will also receive Basic Safety Messages received by any DSRC within range. The application will queue the BSM Part II messages and send them in a block to the TME. The queue will allow the RSE to send a block of messages to the TME at a slower rate than sending them one at a time. The design of the RSE software can be seen in Figure 7-11.

BSM Receiver

The Basic Safety Message Receiver will receive any BSM from surrounding DSRC transmissions. If the Basic Safety Message is a Part II then the receiver will attempt to add the message to the send queue. If the send queue is full then the message will be sent to the BSM Drop Strategy to determine which messages should be in the queue.

BSM Drop Strategy

The BSM Drop Strategy will determine which messages should remain and/or be added to the queue when the queue becomes full. There are three strategies that can be employed to determine which messages to keep in the queue. The specific strategy or strategies used will not be determined until device testing occurs and will be finalized at that time.

- **BSM Drop Dense Strategy**
  This strategy will drop a message from a geographically close set of messages. The closeness of the messages indicates a low rate of travel or being stopped. Many messages from the same area do no contribute much to the applications running on the TME.

- **BSM Drop Bursty Strategy**
  This strategy will drop messages that are sent very close (temporally close) together. This will allow a nice distribution of data to time.

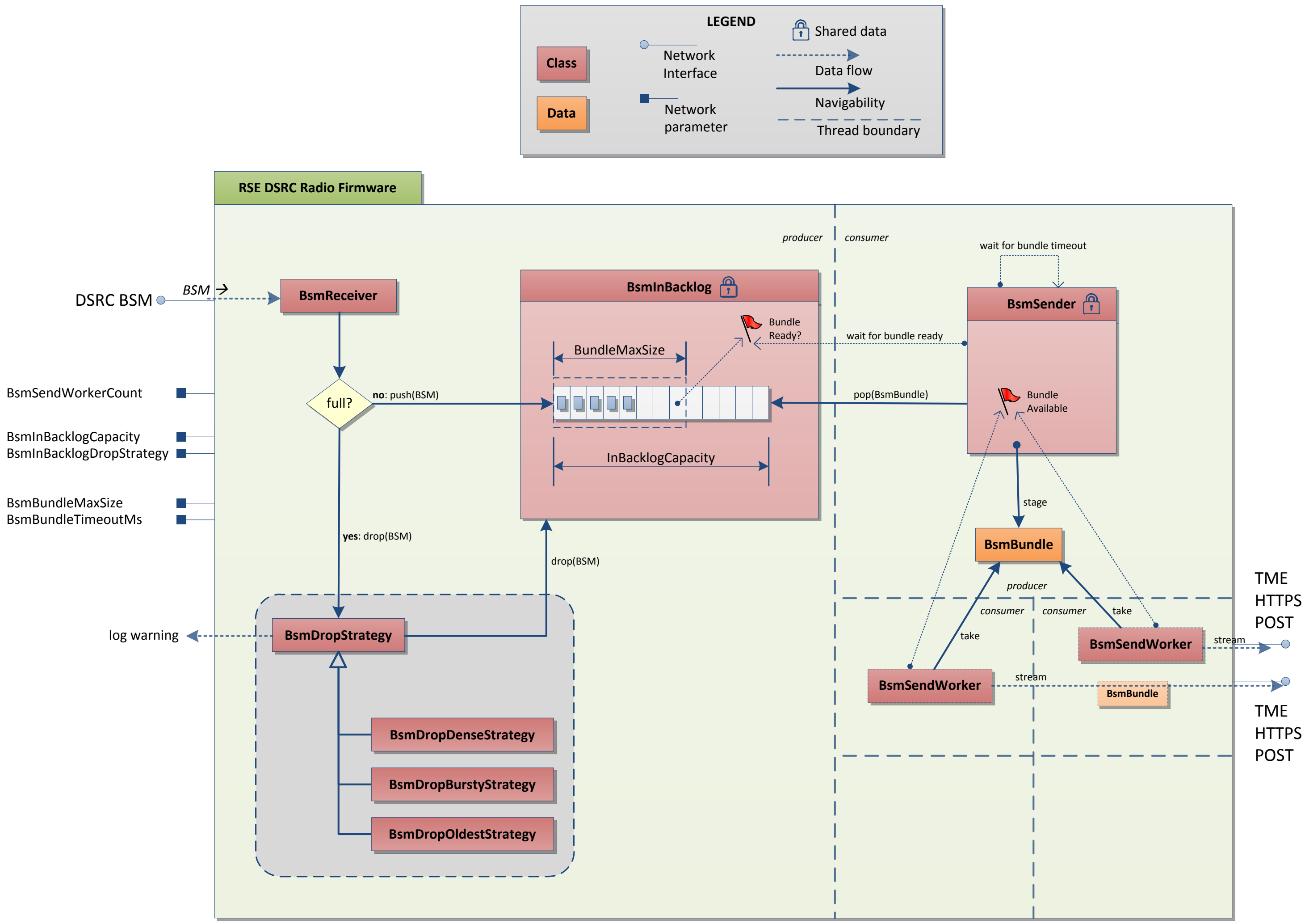
- **BSM Drop Oldest Strategy**
  This strategy will drop the oldest message in the queue. This will allow the messages that get sent to the TME to be the latest available.

BSM Sender

The Basic Safety Message Sender is responsible for sending any queued BSM messages to the TME. It will send the bundled messages to a BSMSendWorker that will send the messages to the TME.

Message Handler

The Message Handler is responsible for receiving any messages from the TME and forwarding them to the DSRC radio to be sent to any other DSRC radios that are in range. The messages must be J2735 compliant.



Source: Battelle

Figure 7-11. Road Side DSRC Radio Design

User Interface

The user interface to the Arada LocoMate™ RSU is through a Bluetooth telnet connection. Once a user has logged into the device a command line interface is used to configure the device using standard Linux commands. A command line interface is provided by Arada that will allow the user to manage the operation of the DSRC radio and its external interfaces.

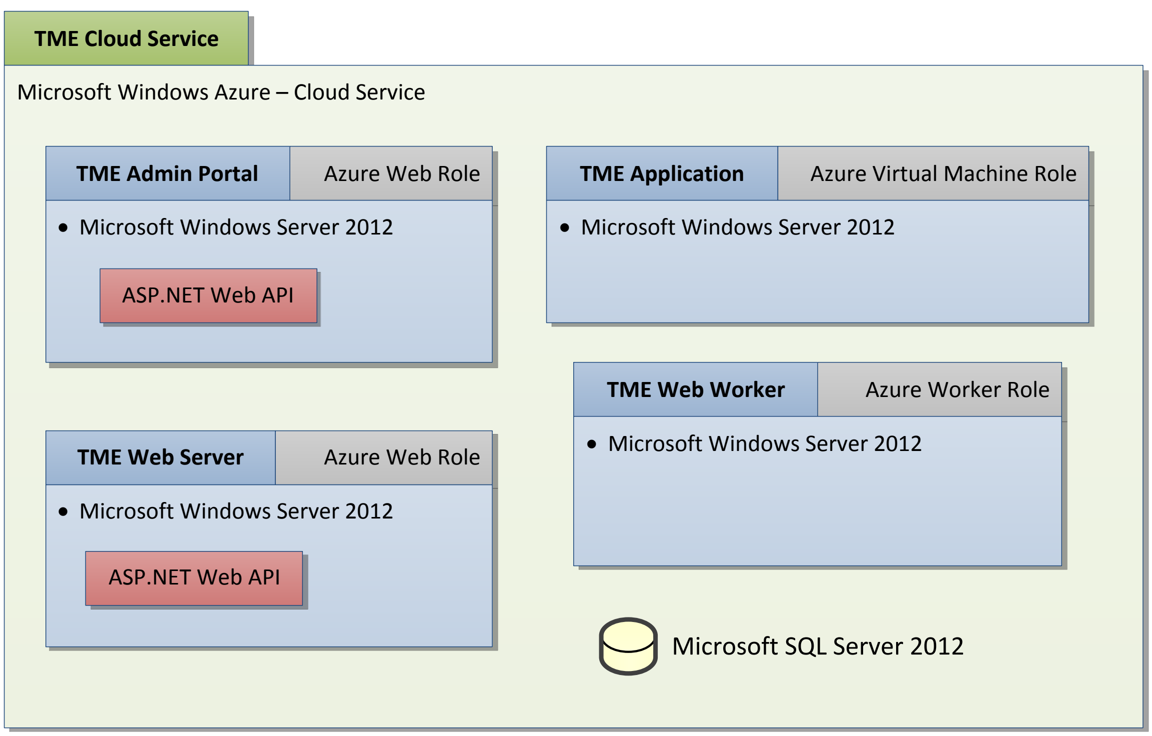
Cloud Service

The Cloud Service will be a Microsoft Azure Cloud Service comprised of the following components:

- SQL Database
- Web Role (TME Web Server)
- Web Role (Admin Portal)
- Worker Role (Database Worker)
- Virtual Machine Role (TME Application)

Platform

The computing platforms for each VM in the Azure Cloud Service will be selected as shown in Figure 7-12.

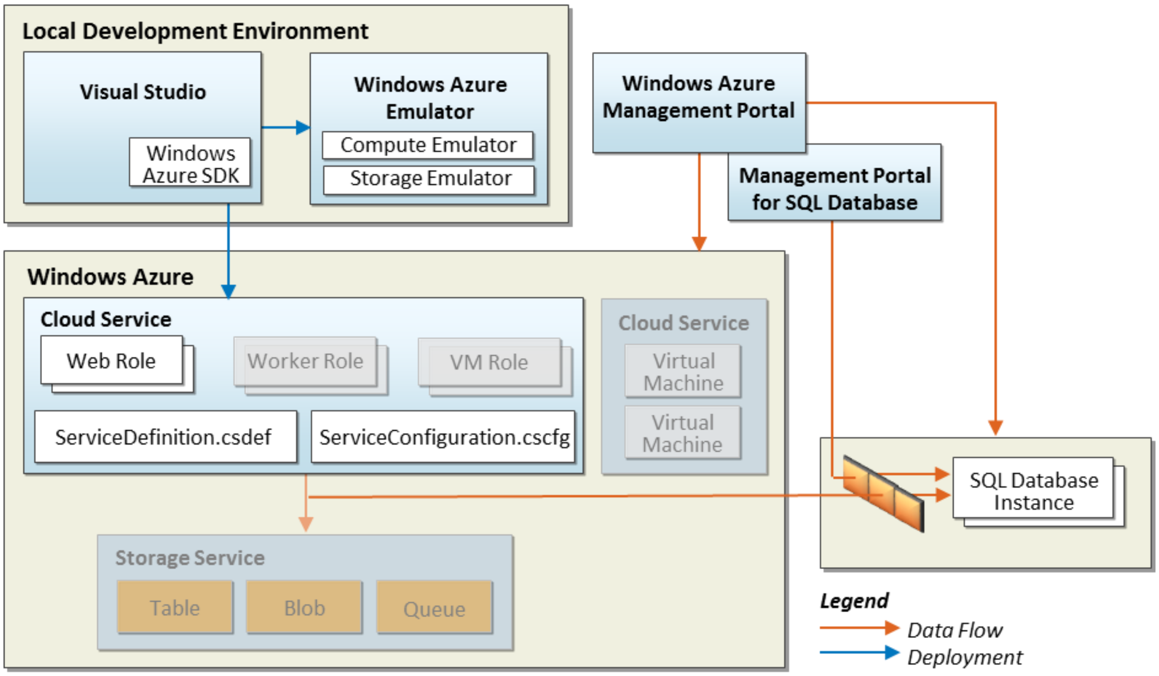


Source: Battelle

Figure 7-12. Cloud Service Computing Platforms

Development Stack

The Azure software developer will use Microsoft Visual Studio 2012 with the Windows Azure SDK installed. The Azure SDK provides an Azure Emulator for local unit testing. The Windows Azure Management Portal provides most configuration capabilities via an interactive web site interface. This stack is shown in Figure 7-13 and is discussed in detail below.

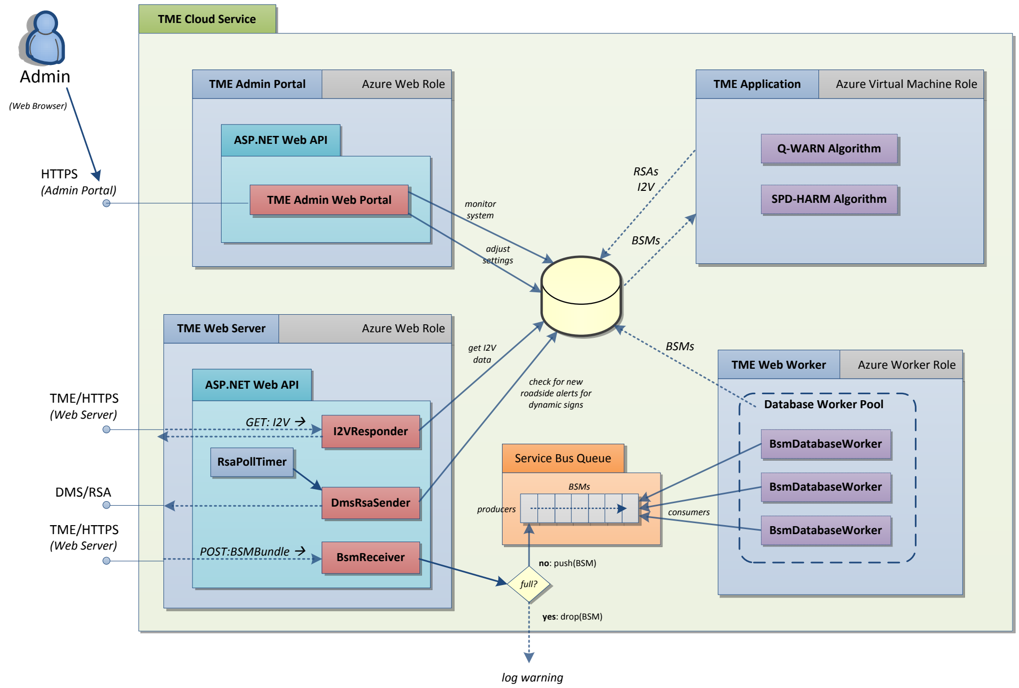


Source: Battelle

Figure 7-13. Windows Azure Development Stack

Processes

The internal design of the Cloud Service is depicted in the Figure 7-14. The SQL Database is at the center of the process flow. A Service Bus Queue will be established to separate the process of receiving BSMs (coming from web clients in the Web Role), from the process of updating the database using a pool of database worker threads in the Worker Role. The TME Application will poll the database as needed to gather BSM data for analyzing the traffic system, and will generate I2V messages if a Q-WARN or SPD-HARM condition is determined. The Web Role for the TME Web Server will respond to requests for I2V messages; upon receiving a GET I2V request, the Web Role will check the database and retrieve the requested I2V message if present given the request parameters (I2V region/location).



Source: Battelle

Figure 7-14. TME Cloud Service Design

User Interface

The user interface to the Microsoft Azure Cloud Service is the Microsoft Windows Azure Management Portal, which is an interactive web site located at the following URL: https://account.windowsazure.com.

The Azure Portal provides Remote Desktop (RDP) access to all virtual machines, primarily for development and diagnostic purposes.

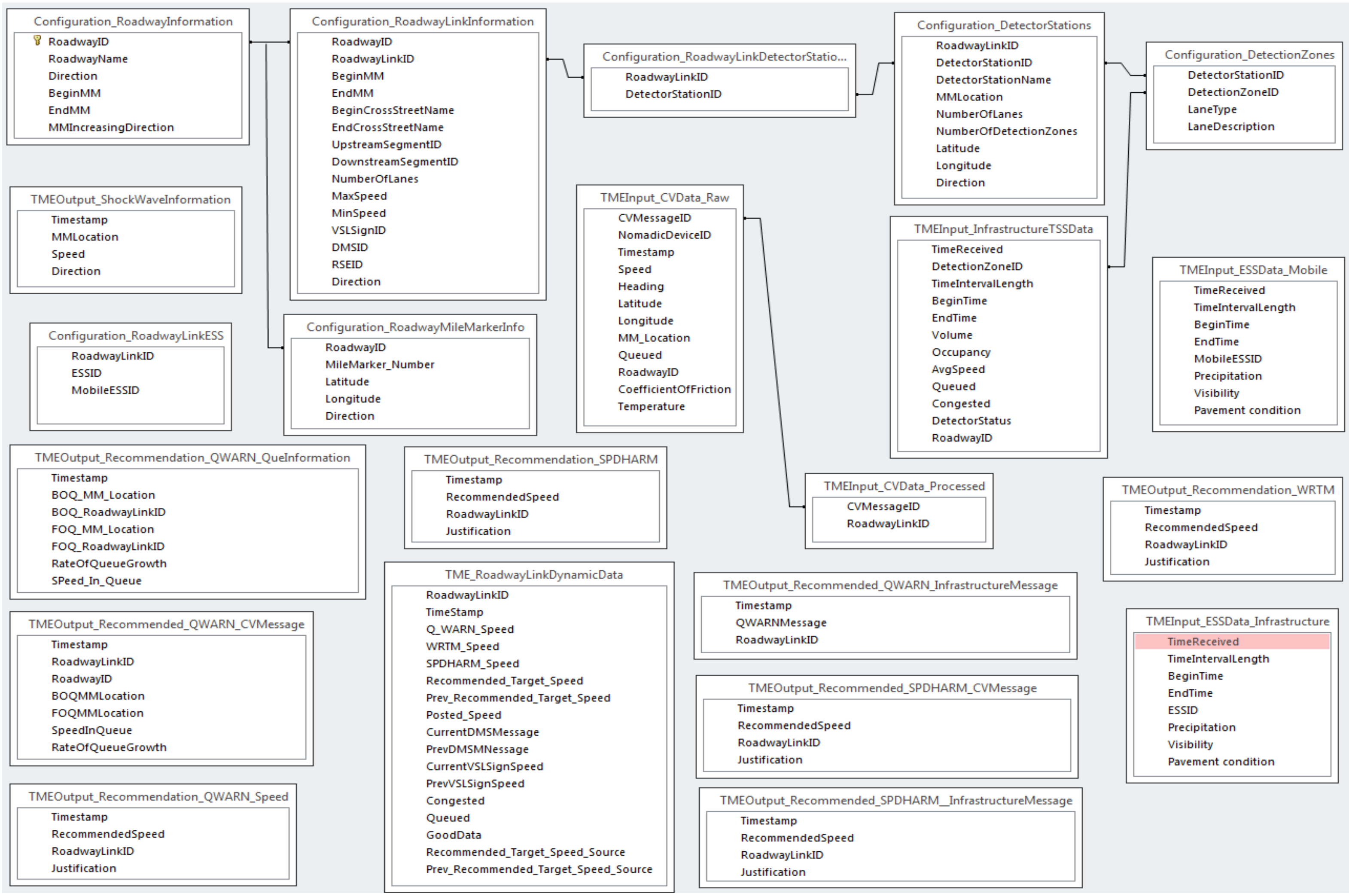
An INFLO Admin Portal will provide real-time diagnostic information about the TME to the INFLO Administrator via a simple web portal interface. The INFLO Admin will need to be able to modify values in a reserved configuration settings table in the database to adjust the TME algorithms. Due to project constraints, it may be adequate to provide the Admin with direct access to the SQL database using SQL Server Management Console by having the Admin connect to an Azure VM via RDP, which would allow the Admin to view and modify specific reserved tables in the database to adjust the TME algorithms.

INFLO Database

Figure 7-15 shows the INFLO Database. This database lives in the Windows Azure INFLO cloud service. It will hold incoming data from the nomadic devices (BSM type of data), road side alerts, settings, etc. It sits between the web service layer and the TME.

INFLO Database Data Dictionary

Following Figure 7-15, Table 7-2 documents the data dictionary for the INFLO Database.



Source: Texas A&M Transportation Institute

Figure 7-15. INFLO Database Tables

Table 7-2. INFLO TME Database Data Dictionary

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Configuration_INFLOApps_Thresholds						
CVDATA_PollingFrequency	Yes	Number-Integer	seconds		TMDD	Frequency of vehicle broadcasting BSM and weather data to TME Cloud
CVDATA_TMECloud_PollingFrequency	Yes	Number-Integer	seconds		TMDD	Frequency of polling connected vehicle data from the TME Cloud
TSSData_PollingFrequency	Yes	Number-Integer	seconds		TMDD	Frequency of polling the infrastructure traffic sensor data
ESSData_PollingFrequency	Yes	Number-Integer	minutes		TMDD	Frequency of polling the infrastructure ESS data
MobileESSData_PollingFrequency	Yes	Number-Integer	minutes		TMDD	Frequency of polling the mobile ESS data
QueueSpreedThreshold	Yes	Number-Integer	miles per hour		TMDD	Speed threshold used to determine if roadway links are queued based on infrastructure traffic sensor data
CongestionSpeedThreshold	Yes	Number-Integer	miles per hour		TMDD	Speed threshold used to determine if a roadway link is congested based on infrastructure traffic sensor data

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Configuration_RoadwayInformation						
RoadwayIdentifier	Yes	Text		Static	TMDD	A unique ID identifying a roadway name with a specific direction. Example, RoadwayID = 1 identifies I-35 North
RoadwayName	Yes	Text		Static	TMDD	Road name
Direction	Yes	Text		Static	TMDD	Direction of travel of roadway
BeginMileMarker	Yes	Number-Double	miles	Static	TMDD	Roadway beginning mile marker (TMDD – roadway-linear-reference) Accuracy of 1/10th of a mile.
EndMileMarker	Yes	Number-Double	miles	Static	TMDD	Roadway ending line marker (TMDD – roadway-linear-reference) Accuracy of 1/10th of a mile.
MMIncreasingDirection	Yes	Text		static	TMDD	Direction of increasing mile marker numbering for the roadway (Example: south/north/east/west)
Configuration_RoadwayLinkInformation						
RoadwayIdentifier	Yes	Text		static	TMDD	Identifier of the roadway the link belongs to
RoadwayLinkIdentifier	Yes	text		static	TMDD	A unique ID identifying a section of roadway
BeginMileMarker	Yes	Number-Double	miles	static	TMDD	Roadway link beginning mile marker

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
EndMileMarker	Yes	Number-Double	miles	static	TMDD	Roadway link ending mile marker
BeginCrossStreetName		Text		static	TMDD	Name of the nearest cross street close to the beginning of the roadway link
EndCrossStreetName		Text		static	TMDD	Name of the nearest cross street close to the end of the roadway link
UpstreamRoadwayLinkIdentifier		Text		static	TMDD	Identifier of the adjacent upstream roadway link
DownstreamRoadwayLinkIdentifier		Text		static	TMDD	Identifier of the adjacent downstream roadway link
NumberOfLanes		Number-Integer			TMDD	Number of lanes in this roadway link
SpeedLimit	Yes	Number-Integer	miles per hour		TMDD	posted speed limit for this section of roadway
VLSSignID		Text		static	TMDD	Identifier of the variable speed limit sign associated with the roadway link
DMSID		Text		static	TMDD	Identifier of the Dynamic Message sign associated with the roadway link
Direction	Yes	Text		static	TMDD	Direction of travel of the roadway link

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Configuration_RoadwayLinkDetectorStation						
RoadwayLinkIdentifier	Yes	Text		static	TMDD	A unique ID identifying a roadway link
DetectorStationIdentifier	Yes	Text		static	TMDD	A unique ID that identifies the location and other information associated with a detector station installed in a roadway link
Configuration_DetectorStation						
DetectorStationIdentifier	Yes	Text		static	TMDD	A unique ID that identifies the location and other information associated with a detector station within an agency's infrastructure devices inventory
DetectorStationName		Text		static	TMDD	Name of closest street or area where the detector station is located
MileMarkerLocation		Number-Double	miles	static	TMDD	Mile marker location of the detector station
NumberOfLanes		Number-Integer			TMDD	Number of lanes monitored by the detector station detection zones
NumberOfDeteectionZones		Number-Integer			TMDD	Number of detection zones installed or defined in the detection device/s that are part of the detector station

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Latitude		Number-Double		static	TMDD	Geographical location of the detector station
Longitude		Number-Double		static	TMDD	Geographical location of the detector station
Direction		Text		static	TMDD	Direction of travel monitored by the detector station detection zones
Configuration_DetectionZone						
DetectorStationIdentifier	Yes	Text		static	TMDD	A unique ID that identifies the location and other information associated with a detector station within an agency's infrastructure devices inventory
DetectionZoneIdentifier	Yes	Text		static	TMDD	A unique ID that identifies a detection zone within a detector station
DetectionZoneType		Text		static	TMDD	Detector technology used type: loop, radar, magnetometers, video, etc.
LaneNumber		Number-Integer		static	TMDD	Number of lane the detection zone is monitoring
LaneType		Text		static	TMDD	Exit/Entrance/Through/Toll/HOT/HOV/Shoulder/etc.
LaneDescription		Text				Includes any additional information about a lane
DataType		Text		static	TMDD	Actual, reconstructed, historical,

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
						predicted, smoothed, averaged, estimated
DetectionZoneStatus		Text			TMDD	On, off, out-of-service, unavailable, unknown, marginal, failed
Configuration_RoadwayLinkESS						
RoadwayLinkIdentifier	Yes	Text		static	TMDD	A unique ID identifying a roadway link
ESSIdentifier	Yes	Text		static	TMDD	A unique identifier that is assigned to an infrastructure ESS or mobile ESS by the operating agency
Configuration_ESS						
ESSIdentifier	Yes	Text		static	TMDD	A unique identifier that is assigned to the ESS by the operating agency
ESSType	Yes	Text		static	TMDD	Atmospheric, wind, temperature, precipitation, visibility, pavement, subsurface, other, unknown
ESSOperationType		Text		static	TMDD	Staffed, automatic, unknown, other
ESSMobilityType	Yes	Text		static	TMDD	Permanent, transportable, mobile, other

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Configuration_RoadwayMileMarkerInfo						
RoadwayIdentifier	Yes	Text		static	TMDD	A unique ID identifying a roadway name with a specific direction. Example, RoadwayID = 1 identifies I-35 North
DirectionOfTravel	Yes	Text		static	TMDD	Direction of roadway travel
MileMarkerNumber	Yes	Number-Double	miles	static	TMDD	Linear reference location information
Latitude	Yes	Number-Double		static	TMDD	Geographical location of the mile marker
Longitude	Yes	Number-Double		static	TMDD	Geographical location of the mile marker
TME_RoadwayLinkDynamicData						
Timestamp	Yes	DateTime			TMDD	Local time zone date and time when the recommendation was generated
RoadwayLinkIdentifier	Yes	Text			TMDD	Identifier of the roadway link the speed applies to
TMELink_Speed		Number-Integer			TMDD	Roadway link local speed recommended by the TMELinkSpeed application
WRTMSpeed		Number-Integer			TMDD	Roadway link local speed recommended by the WRTM application

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
RecommendedTargetSpeed	Yes	Number-Integer			TMDD	The selected recommended target speed
RecommendedTargetSpeedSource	Yes	Text			TMDD	The application (Q_WARN, SPD-HARM, or WRTM) local speed that was selected for the roadway link
DMSSignMessage		Text			TMDD	Current message displayed on the DMS associated with the roadway link
VLSSignSpeed		Text			TMDD	Current speed displayed on the VLS associated with the roadway link
Congested	Yes	Yes/No				Yes if the roadway link local speed is below the Congested speed threshold
Queued	Yes	Yes/No				Yes if the roadway link local speed is below the queued speed threshold
PreviousRecommendedTargetSpeed	Yes	Number-Integer			TMDD	Previous roadway link recommended target speed
PreviousRecommendedTargetSpeedSource	Yes	Text			TMDD	previous roadway link recommended speed source

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
TMEInput_CVData_Raw						
CVMessageIdentifier	Yes	Number-Integer				An automatic unique number assigned to each message received from connected vehicle by the TME
NomadicDeviceIdentifier		Text				The nomadic device unique identifier. This data element is tracked and used only in the prototype testing for evaluation purposes.
Timestamp	Yes	DateTime			TMDD	The local time zone date and time when the message was generated by the nomadic device
Speed	Yes	Number-Integer			TMDD	Speed of the vehicle when the message was generated
Heading	Yes	Number-Double				Heading of the vehicle when the message was generated
Latitude	Yes	Number-Double			TMDD	Geographical location of the vehicle when the message was generated
Longitude	Yes	Number-Double			TMDD	Geographical location of the vehicle when the message was generated
MileMarkerLocation	Yes	Number-Double			TMDD	Mile marker location when the message was generated

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Queued	Yes	Yes/No				The queued state (Yes/No) of the vehicle when the message was generated
RoadwayIdentifier		Text			TMDD	Identifier of the roadway where the vehicle was traveling when the message was generated
CoefficientOfFriction		Number-Double			TMDD	Coefficient of friction of the pavement where the vehicle was traveling when the message was generated
Temperature		Number-Integer			TMDD	Outside the vehicle temperature when the message was generated
TMEInput_CVData_Processed						
CVMessageIdentifier	Yes	Number-Integer				An automatic unique number assigned to each message received from connected vehicle by the TME
RoadwayLinkIdentifier	Yes	Text			TMDD	Roadway link where the vehicle was traveling when it generated the message sent to TME
TMEInput_InfrastructureTSSData						
Timestamp	Yes	DateTime			TMDD	Local time zone date and time when traffic data was received from the Infrastructure TSS
DetectionZoneIdentifier	Yes	Text			TMDD	Detection zone unique id

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
TimeIntervalLength	Yes	Number-Integer	Seconds		TMDD	Length of time interval traffic data was requested for from the TSS
BeginTimestamp		DateTime			TMDD	Beginning date and time of the interval traffic data was requested for from the TSS
EndTimestamp		DateTime			TMDD	Ending Date and time of the interval traffic data was requested for from the TSS
Volume	Yes	Number-Integer	count		TMDD	Detection zone vehicle count during the time interval traffic data was requested for from the TSS
Occupancy	Yes	Number-Double			TMDD	Detection zone occupancy during the time interval traffic data was requested for from the TSS
AvgSpeed	Yes	Number-Integer	miles per hour		TMDD	Detection zone average speed during the time interval traffic data was requested for from the TSS
Queued	Yes	Yes/No				Queued state of detection zone. Yes if avgspeed during requested time interval falls below the queue speed threshold
Congested	Yes	Yes/No				Congested state of detection zone. Yes if avgspeed during requested time interval falls below the congestion speed threshold
DetectionZoneStatus	Yes	Text			TMDD	On, off, out-of-service, unavailable,

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
						unknown, marginal, failed
RoadwayLinkIdentifier	Yes	Text			TMDD	Roadway link the detection zone is associated with
TMEInput_ESSData_Infrastructure						
Timestamp	Yes	DateTime			TMDD	Local time zone date and time when weather data was received from the Infrastructure ESS
ESSIdentifier	Yes	Text			TMDD	Environmental Sensor Station identifier
EssWindData	Yes	Text			NTCIP 1204 Weather Block	The NTCIP 1204 Wind data will be used to generate a wind advisory alert
EssVisibilityData	Yes	Text			NTCIP 1204 Weather Block	The NTCIP 1204 Visibility data will be used to calculate the current visibility
EssSurfaceStatus	Yes	Text			NTCIP 1204 Pavement Sensor	The 1204 Surface data will be used to calculate a pavement coefficient of friction
TMEInput_ESSData_Mobile						
Timestamp	Yes	DateTime			TMDD	Local time zone date and time when weather data was received from the Mobile ESS
ESSIdentifier	Yes	Text			TMDD	Mobile Environmental Sensor Station identifier

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
EssMobileData		Number-Double			NTCIP 1204 Mobile Block	The NTCIP 1204 Mobile data block will be used to calculate a pavement coefficient of friction
TMEOutput_Recommendation_Alerts_WRTM						
Timestamp	Yes	DateTime		Minutes	TMDD	Date and time the weather alert was generated
WeatherAlert	Yes	Text		Minutes	IT IS Codes	Weather alert message to send to connected vehicles and infrastructure signs due to severe weather conditions
Justification		Text		Minutes	IT IS Codes	Justification for the weather alert
RoadwayIdentifier	Yes	Text		Minutes	TMDD	Identifier of the roadway affected by the weather alert
BeginMileMarker	Yes	Number-Double	miles	Minutes	TMDD	Beginning mile marker of the roadway links affected by the weather alert
EndMileMarker	Yes	Number-Double	miles	Minutes	TMDD	Ending mile marker of the roadway links affected by the weather alert
BeginTime	Yes	DateTime		Minutes	TMDD	The start time when the weather alert will apply for the affected roadway links
EndTime	Yes	DateTime		Minutes	TMDD	The end time when the weather alert will expire for the affected links

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
TMEOutput_Recommendation_Speed_TMELinkSpeed						
Timestamp	Yes	DateTime		1 Minute	TMDD	Local time zone date and time when the recommendation was generated
RecommendedTargetSpeed	Yes	Number-Integer		1 Minute	TMDD	Recommended safe speed generated by the Q_WARN application for the roadway links that are queued
Justification		Text		1 Minute	TMDD	Justification for the recommended target speed for the affected roadway links
RoadwayLinkIdentifier	Yes	Text		1 Minute	TMDD	Identifier of the roadway with the reduced speed links
TMEOutput_Recommendation_Speed_WRTM						
Timestamp	Yes	DateTime		1 Minute	TMDD	Local time zone date and time when the recommendation was generated
RecommendedTargetSpeed	Yes	Number-Integer		1 Minute	TMDD	Recommended safe speed generated by the WRTM application for the roadway links affected by severe weather conditions

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
Justification		Text		1 Minute		Justification for the recommended target speed for the affected roadway links
RoadwayLinkIdentifier	Yes	Text		1 Minute	TMDD	Identifier of the roadway with the reduced speed links
TMEOutput_ShockwaveInformation						
Timestamp	Yes	DateTime		1 Minute	TMDD	Local time zone date and time when the shockwave was detected
RoadwayIdentifier	Yes	Text		1 Minute	TMDD	Identifier of the roadway where the shockwave was detected
MileMarkerLocation	Yes	Number-Double	miles	1 Minute	TMDD	Roadway mile marker location where the shockwave was detected
ShockwaveSpeed	Yes	Number-Integer		1 Minute	TMDD	Speed of the detected shockwave
ShockwaveDirection	Yes	Text		1 Minute	TMDD	Direction the shockwave is moving

Table 7-2. INFLO TME Database Data Dictionary (Continued)

Data Element	Required	Type	Unit of Measure	Refresh Rate	Standard/ References	Description
TMEOutput_QWARN_QueueInformation						
Timestamp	Yes	DateTime		1 Minute	TMDD	Local time zone date and time when the queue was detected
BOQ_MileMarker_Location	Yes	Text		1 Minute	TMDD	Back of detected queue mile marker location
BOQ_RoadwayLinkIdentifier	Yes	Number-Integer		1 Minute	TMDD	Identifier of the roadway where the back of detected queue is located
FOQ_MileMarkerLocation	Yes	Text		1 Minute	TMDD	Front of detected queue mile marker location
FOQ_RoadwayLinkIdentifier	Yes	Number-Integer		1 Minute	TMDD	Identifier of the roadway where the front of the detected queue is located
RateOfQueueGrowth		Number-Double		1 Minute		Rate of growth of the queue from one time interval to another. It can positive indicating a growing queue or negative indicating a dissipating queue
SpeedInQueue		Number-Integer		1 Minute	TMDD	The average speed of the vehicles in the queue

Source: Texas A&M Transportation Institute

Virtual Traffic Management Entity

The Virtual TME consists of a Microsoft Windows virtual server that will be used to host the TME based INFLO applications and support software. The Virtual TME will also include a database system like Microsoft SQL server database to log the input data acquired by the various INFLO applications, recommendations generated by the INFLO applications, and the system configuration information. Configuration information includes the roadway network configuration, user entered settings, and threshold used by the INFLO applications in making decisions and generating recommendations. The following sections provide a brief description of the major components of the virtual TME. The interfaces used to collect and aggregate input data required by the INFLO applications from connected vehicles and other infrastructure based sensors are described in section 6 under External Interfaces.

TME Weather Application

The TME Weather Application is responsible for developing recommended roadway target speeds as well as road weather alerts and warnings based on measured weather conditions. The TME Weather Application will interface with INFLO database to obtain road weather information provided by the infrastructure-based ESSs, mobile ESSs, and connected vehicles. Road weather information will be extracted from the INFLO database every 15 minutes. Forecast weather information will be used to activate the TME Weather application

TME Q-Warn Application

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 will interface with the INFLO database to extract both connected vehicle data and infrastructure-based traffic data to determine information about the queue. The application will consist 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 traffic data. The TME Q-Warn application will use the queue state data element in both the connected vehicle and infrastructure-based traffic data to determine the links in the network operating in a queue state. The TME Q-Warn application will then produce 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 will then forward information about the queue to the TME Message Generator, which will then use the information to generate appropriate queue warning alerts for display on infrastructure-based dynamic message signs and for broadcast to connected vehicles. Details of the Q-WARN application may be found in the separately published Report on Dynamic Speed Harmonization with Queue Warning Algorithm Design[6], produced concurrent with this design document.

TME Message Generator

The TME Message Generator application is responsible for producing and formatting speed recommendations and alert message for display on infrastructure-based dynamic message signs and for broadcast to connected vehicles. The TME Message Generators will interface with the TME WRTM, TME Link Speed Arbitrator, and the TME Q-Warn applications to receive road weather alerts,

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

harmonized link speed, and with the queue characteristics information. Using the information from these applications, the TME Message Generator interface with a TMCs DMS control software to format and transmit an appropriate Center-to-Center (C2C) message for displaying alerts and speed recommendation of the TMC's dynamic message signs. The TME Message Generator will also be responsible for developing and formatting an appropriate J2735 alert message for broadcast to connected vehicle. The TME Message Generator will send the appropriate J2735 message to the connected vehicle cloud for broadcast to connected vehicles.

TME Link-Speed Arbitrator

The TME Link-Speed Arbitrator is an application that is responsible for providing "harmonized" link speeds to the TME Message Generator. The TME Link-Speed Arbitrator will receive local link speed recommendations from both the TME_WRTM and the TME Link Speed applications. The TME_WRTM application will produce recommended link speeds appropriate for the prevailing weather conditions in the corridor. The TME Link Speed application produces recommended target speed for detected traffic congestion and queuing situations. The goal/purpose of the TME Link-Speed Arbitrator is to take these speed recommendations and determine which the appropriate speeds for each link on the roadway network. The application will apply user defined priority rules to select the appropriate speeds. Once the recommended link target speeds have been selected, the TME Link-Speed Arbitrator will then group target speeds into troupes and then apply harmonization rules for transitions speeds between recommended troupes. The TME Link-Speed Arbitrator will then pass the harmonized speed recommendation to the TME Message Generator for formatting for displaying on infrastructure-based dynamic message signs and for broadcasting to connected vehicles. Details of the TME Link-Speed Arbitrator (aka SPD-HARM) application may be found in the separately published Report on Dynamic Speed Harmonization with Queue Warning Algorithm Design[7], produced concurrent with this design document.

Networking/Topology Diagrams

Figure 7-16 and Figure 7-17 show the networking both from the nomadic device perspective, as well as from the infrastructure. These diagrams capture the extent of the messages flows between the various components of the INFLO prototype system.

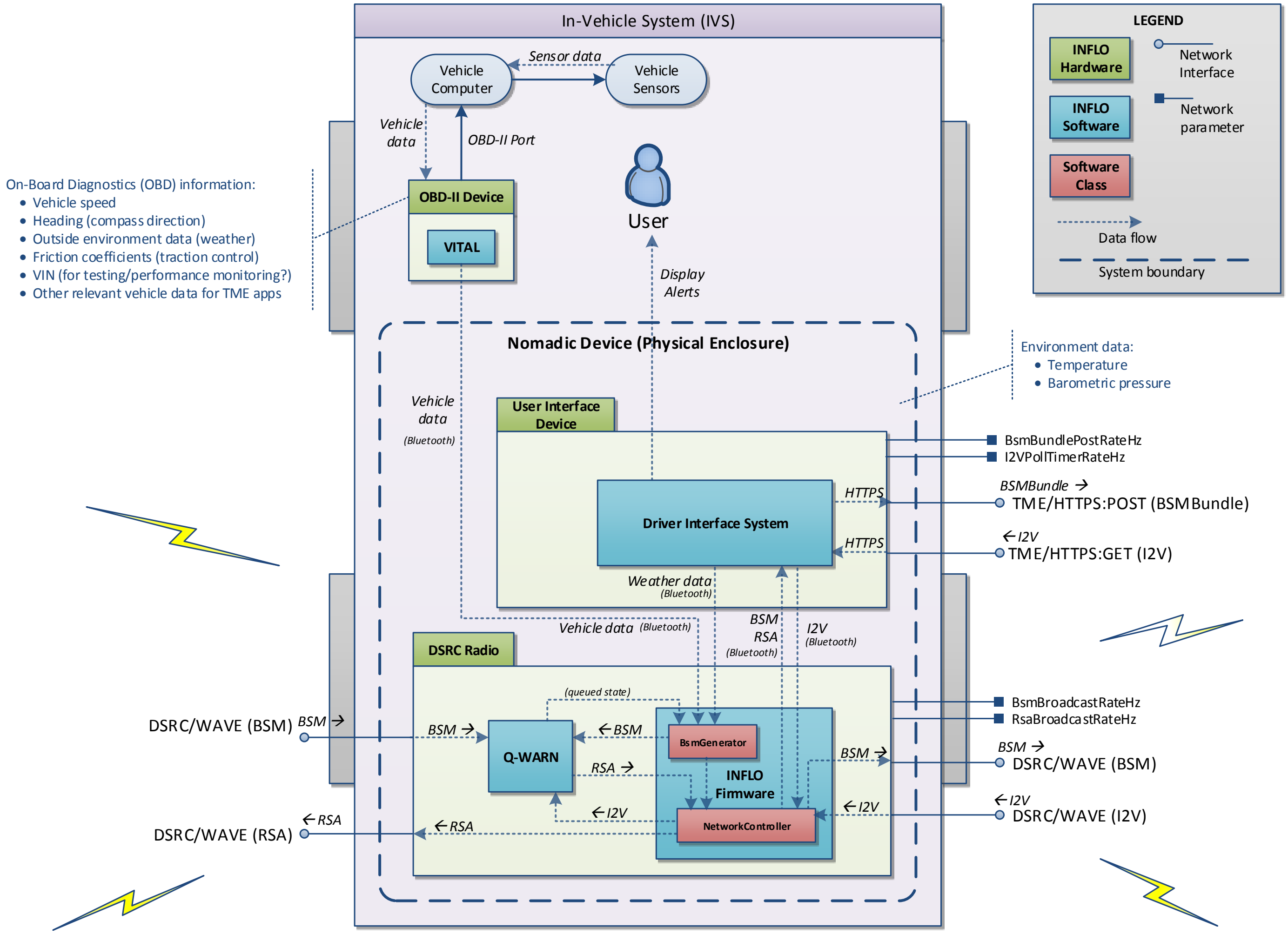
Time Synchronization

Synchronization of time across the multiple platforms required of the connected vehicle architecture will be facilitated using the appropriate service or source associated with each of these platforms. All will be based on Universal Coordinated Time (UTC) with corrections for 'leap' days included. GPS-enabled devices will acquire their time from that available on the device. Both the nomadic device and the roadside equipment will synchronize time using this source. Similarly, the Microsoft Azure cloud services utilize a time reference based on UTC. Finally, the TME will also be synchronized to a similar, internet-based time source.

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

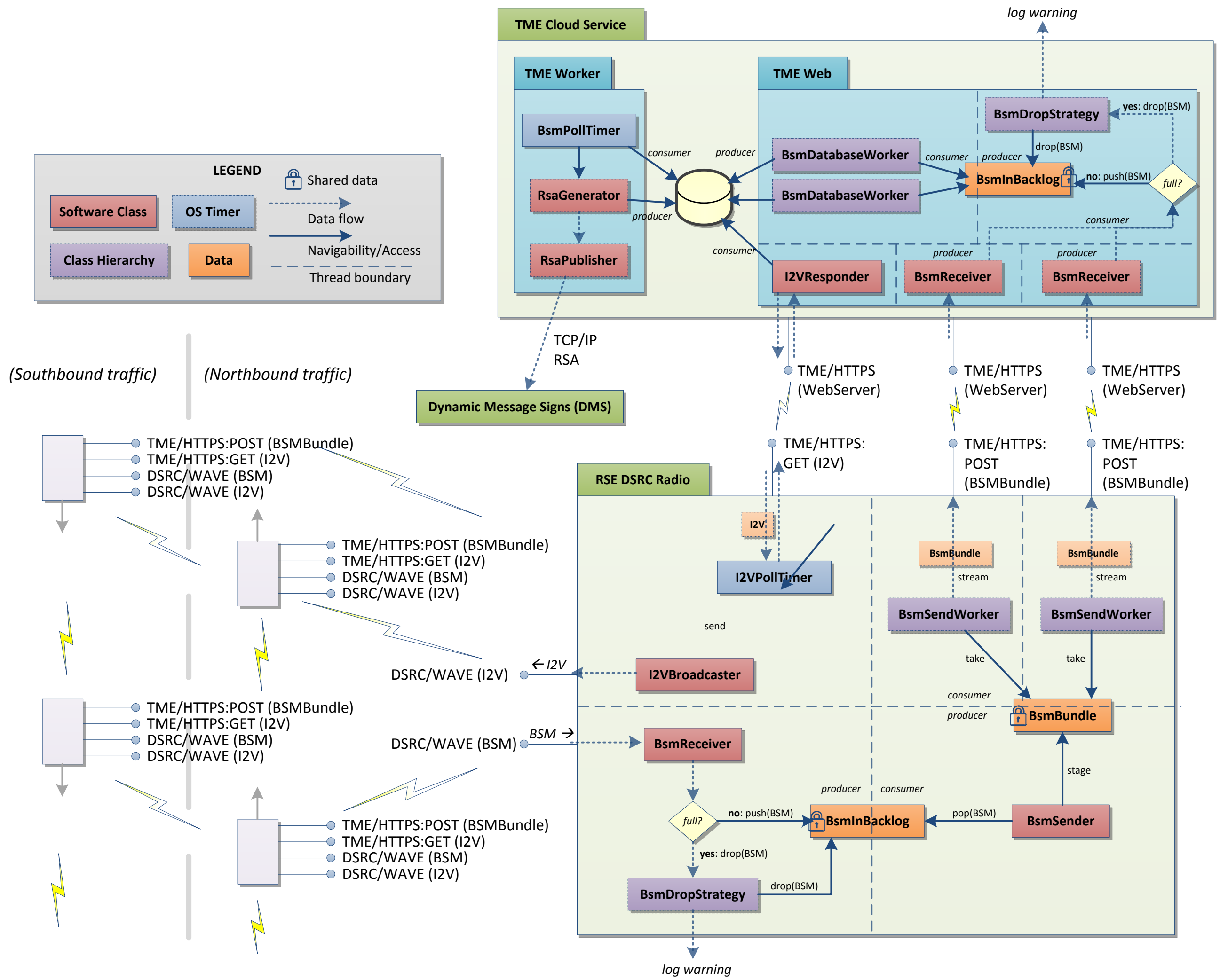
Time stamps for information that is outside of the control of the INFLO prototype, for instance, infrastructure-based link speed data, will be evaluated, and if necessary, an adjustment applied. However, the nature of the applications associated with INFLO, while time dependent, or not time sensitive as the millisecond or even second level.

Unless otherwise indicated in the design, all timestamp information transmitted or buffered by the INFLO applications will be maintained in UTC format.



Source: Battelle

Figure 7-16. Networking from Nomadic Device Perspective



Source: Battelle

Figure 7-17. INFLO Networking

APPENDIX A. Abbreviations

API	Application Programming Interface
ASN	Abstract Syntax Notation
BSM	Basic Safety Message
CAN	Controller Area Network
COTS	Commercial Off The Shelf
DMA	Dynamic Mobility Applications
DSRC	Dedicated Short Range Communications
ESS	Environmental Sensor Station
GATT	Generic Attribute Profile
GPS	Global Positioning System
HTTPS	Hypertext Transfer Protocol Secure
INFLO	Intelligent Network Flow Optimization
IR	Infrared
JSON	JavaScript Object Notation
MAP	Map Data Message
NEMA	National Electronic Manufacturers Association
NWS	National Weather Service
NTCIP	National Transportation Communications for ITS Protocol
OBD	On-board Diagnostics
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
PII	Personally Identifiably Information
Q-WARN	Queue Warning
RDP	Remote Desktop Protocol
REST	Representational State Transfer
RSA	Road Side Alert
RSE/RSU	Roadside Equipment/Road Side Unit
SAE	Society of Automotive Engineers
SDD	System Design Document
SDK	Software Development Kit
SPD-HARM	Speed Harmonization
SQL	Structured Query Language

TCP	Transmission Control Protocol
TIM	Traveler Information Message
TMC/TME	Transportation Management Center/Entity
TSS	TRAFFIC SENSOR SYSTEMS
UDP	User Datagram Protocol
URL	Uniform resource locator
U.S. DOT	United States Department of Transportation
VM	Virtual Machine
WAVE	Wireless Access in Vehicular Environments
WRTM	Weather Road Traffic Management

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