5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Concept of Operations

Final

Version 1.0

August 2013

Prepared For:

Cooperative Transportation Systems Pooled Fund Study

By:

Synesis Partners LLC

SYNESIS
PARTNERS

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

REVISION HISTORY

Version	Description
1	submitted to CTS PFS for review, May 29, 2013
2	Incorporates changes in response to comments received on v0.1

1 SCOPE

1.1 Identification

This document is the "Concept of Operations for the "5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application," Final Version 1.0, dated August 2013."

1.2 Document Overview

The structure of this document is generally consistent with the outline of a Concept of Operations document defined in IEEE Standard 1362-1998. Some sections herein have been somewhat enhanced to accommodate more detailed content than are described in the standard, and titles of some sections may have been edited to more specifically capture that enhancement.

Section 2 describes the current situation with respect to processes and systems to be affected by the concept of operations.

Section 3 identifies the need for changes from the current situation.

Section 4 describes the concept for the new system capabilities and their operations.

Section 5 presents operational scenarios.

Section 6 summarizes operational and organizational impacts that may results from the development of the selected applications.

Section 7 provides an analysis of the expected improvements and disadvantages or limitations that may occur following deployment.

Section 8 provides lists of reference documents and acronyms and abbreviations.

1.3 System Overview

Significant effort has been expended in the Federal Highway Administration's (FHWA) Road Weather Management Program and in various federal and state connected vehicle programs to identify opportunities to acquire data from vehicles acting as mobile sensor platforms. Federal, state and local transportation agencies have also been working with automakers and communications technology providers to develop and standardize information exchange between vehicles and the transportation infrastructure, enabling a variety of applications that could improve transportation safety, mobility and environmental performance. This 5.9 GHz Dedicated Short Range Communication (DSRC)

Vehicle-based Road and Weather Condition Application project is a synergistic result of those converging opportunities.

Accurate, timely and route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. The research system developed by this project will collect weather observation data from mobile sensors on transportation agency vehicles; transmit the data by way of DSRC roadside units (RSE) to one or more collection systems; and ultimately make the data available to other information systems such as the New York State DOT INFORM system and the U.S. DOT's Weather Data Environment. In this way, the additional weather information from mobile platforms will eventually enable traffic managers and maintenance personnel to implement operational strategies that optimize the performance of the transportation system by mitigating the effects of weather on the roadways.

Potential use case scenarios for the system are drawn largely from previous road weather and connected vehicle research. Six high-priority connected vehicle road weather applications were identified in the *Concept of Operations for Road Weather Connected Vehicle Applications*. Many of these applications/use cases recognize agency vehicles, including plows and dump trucks, as key sources of connected vehicle road-weather data, particularly since they are logical candidates for the installation of specialized sensors that will generate data sets that will be unavailable from vehicles in the general public fleet. Others of these use cases are focused on delivering data to agency vehicles, especially for winter maintenance decision support and for maintenance management systems. The applications are:

- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet Management Systems
- Variable Speed Limits for Weather-Responsive Traffic Management
- Motorist Advisories and Warnings
- Information for Freight Carriers
- Information and Routing Support for Emergency Responders

2 CURRENT SITUATION

2.1 Background and Objectives

The *Concept of Operations for Road Weather Connected Vehicle Applications* describes in thorough detail the current situation with respect to the convergence of connected vehicle technologies, road weather information, and transportation operations:

> *Weather has a significant impact on the operations of the nation's roadway system year round. Rain reduces pavement friction. Winter weather can leave pavements snow-covered or icy. Fog, smoke, blowing dust, heavy precipitation, and vehicle spray can restrict visibility. Flooding, snow accumulation, and wind-blown debris can cause or obscure lane obstructions. These weather events translate into changes in traffic conditions, roadway safety, travel reliability, operational effectiveness, and productivity.*

> *Traffic conditions may change in a variety of ways. Weather events may prompt travelers to change departure times, cancel trips, choose an alternative route, or select a different mode. Slick pavements, low visibility, and lane obstructions lead to driving at lower speeds or with increased following distances. These changes in driver behavior can impact the operation of signalized roadways, where traffic signals are timed for clear, dry conditions, through reduced traffic throughputs, increased delays, and increased travel times.*

> *Weather affects roadway safety by increasing exposure to hazards and crash risk. Travel reliability for motorists and commercial vehicle operators is affected by a variety of weather conditions. Weather also impacts the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time.*

> *It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance by mitigating the effects of weather on the roadways. The operational approaches used by these personnel dictate their needs for weather and road condition information. Accurate, timely, route-specific weather information, allows traffic and maintenance managers to better operate and maintain roads under adverse conditions.*

> *The U.S. Department of Transportation (USDOT), Federal Highway Administration (FHWA) has defined three types of road weather management*

strategies that may be employed in response to rain, snow, ice, fog, high winds, flooding, tornadoes, hurricanes, and avalanches. These comprise:

- *Advisory strategies that provide information on prevailing and predicted conditions and impacts to motorists;*

- *Control strategies that alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity; and*

- *Treatment strategies that supply resources to roadways to minimize or eliminate weather impacts.*

There are a variety of approaches available to traffic managers to advise travelers of road weather conditions and weather-related travel restrictions (such as road closures due to fog or flooding). Strategies include posting warnings on dynamic message signs (DMS), broadcasting messages via highway advisory radio (HAR), and providing road condition reports through interactive traveler information systems such as web sites and 511 phone systems.

To control traffic flow during adverse weather, traffic managers may regulate lane use (such as lane reversals for evacuations), close hazardous roads and bridges, restrict access on particular roadways to designated vehicle types (e.g., tractor-trailers during high winds), implement variable speed limits, adjust freeway ramp metering rates, or modify traffic signal timings.

Maintenance managers utilize road weather information and decision support tools to assess the nature and magnitude of winter storms, determine the level of staffing required during a weather event, plan road treatment strategies (e.g., plowing, sanding, chemical applications), and activate anti-icing/deicing systems. Beyond winter weather, maintenance managers are also concerned about the impacts of other events such as sand storms and wildfires that may reduce visibility and create hazardous driving conditions.

Access to high quality road weather information helps managers improve safety, enhance traffic flow and travel reliability, and increase agency productivity. Weather mitigation strategies enhance roadway safety by reducing crash frequency and severity, restricting access to hazardous roads, and encouraging safer driver behavior. Road weather management strategies enhance traffic flow and mobility by allowing the public to make more informed travel decisions, promoting more uniform traffic flow, reducing traffic congestion and delay, and minimizing the time to clear roads of snow and ice. Productivity is increased through better interagency communication and data sharing, and by reduced labor, material and equipment costs for snow and ice control operations.

Underneath these broad operational objectives is a common need for actionable weather information based on high-quality weather data relevant to the transportation facilities to be managed. As described in more detail below, transportation operations managers have long depended on traditional weather data from the National Weather Service, commercial weather service providers, and more recently from their own road weather information systems (RWIS). These sources are limiting, however, in that they describe weather conditions in the atmosphere rather than on the ground—as with traditional weather reports and forecasts—or are insufficiently distributed to characterize conditions across the entire road network—as when obtained from fixed roadside environmental sensor stations (ESS). Connected vehicle technologies under development have the potential to address both of these challenges by distributing weather sensors everywhere across the road network at ground level.

2.2   Operational Policies and Constraints

The *Concept of Operations for Road Weather Connected Vehicle Applications* again provides an overview of the operational policies and constraints on acquisition and use of road weather condition information.

> *Operational policies for road weather management activities vary from state-to-state, both in terms of their detail and formality. Although they vary significantly in terms of scope and level of detail, many state transportation agencies have documented policies and procedures that describe strategies for conducting winter and non-winter maintenance activities under various adverse weather conditions. Similar guidelines for the management of traffic operations under adverse weather conditions appear to be less widespread but are gaining ground due to the efforts of the FHWA Weather-Responsive Traffic Management initiative. In many instances, the documented policies and procedures appear to be derived from personnel experience and informal rules of practice. It also appears that documented operational policies are supplemented with undocumented practices.*

> *According to the American Association of State Highway and Transportation Officials (AASHTO), state transportation agencies are increasingly adopting the use of performance-based management approaches. All state departments of transportation track asset condition and safety data. The majority of states provide comprehensive performance data to decision makers to both increase accountability to customers, and achieve the best possible transportation system performance under current levels of investment. The definition of the performance measures and the formality of reporting again appear to vary from state to state,*

but weather-related metrics, particularly relating to snow removal during winter storms, are not uncommon.

Overall, there are no operational policies related to road weather management that are common across the United States. In addition, there do not appear to be any policies that will specifically constrain the development of connected vehicle road weather applications.

2.3   Description of Current Situation

2.3.1   Road Weather Systems

Traffic and maintenance managers use a variety of environmental monitoring systems and other data sources to gather information on weather and related road conditions to make their decisions on how best to mitigate weather impacts. These managers typically use four types of road weather information: atmospheric data (e.g., precipitation type and rate, wind speed and direction), roadway surface data (e.g., surface status and temperature), roadway subsurface data (e.g., subsurface temperature and moisture content), and hydrologic data (e.g., stream levels near roads). These data are generally obtained from various observing system technologies, including fixed sensor stations, transportable sensor stations, mobile sensing devices, and remote sensors.

Additionally, predictions of environmental conditions can be obtained by traffic and maintenance managers from public sources, such as the National Weather Service (NWS) and the Tropical Prediction Center, and from private meteorological service providers. Environmental data may also be obtained from mesoscale environmental monitoring networks, or mesonets, which integrate and disseminate data from many observing systems (including agricultural, flood monitoring and aviation networks).

An environmental sensor station (ESS) is the field component of an overall Road-Weather Information System (RWIS). An ESS comprises one or more sensors measuring atmospheric, surface, subsurface, and water level conditions, while centralized RWIS hardware and software are used to collect and process observation data from numerous ESS. Environmental observation data from the field are then used to develop route-specific forecasts and provide decision support for various operational actions by the traffic and maintenance managers. There are more than 2,400 ESS owned by state transportation agencies. Most of these stations - over 2,000 - are part of an RWIS used to support winter road maintenance activities. The other stations are deployed for various applications, including traffic management, flood monitoring, and aviation.

> *Atmospheric data from ESS can include air temperature and humidity, visibility distance, wind speed and direction, precipitation type and rate, as well as air quality. Roadway surface data include pavement temperature, pavement freeze point, pavement condition (e.g., wet, icy, flooded), pavement chemical concentration, and subsurface conditions (e.g., soil temperature). Water level data include tide levels (e.g., hurricane storm surge), stream, river, and lake levels near roads, and the conditions in areas known to flood during heavy rains or as a result of runoff.*

> *Mobile sensing involves the integration of sensors and other systems onto vehicle platforms. In combination with vehicle location and data communications technologies, mobile sensor systems can be used to sense both pavement conditions (e.g., temperature, friction) and atmospheric conditions (e.g., air temperature). While less widespread than fixed sensors, several state transportation agencies have deployed maintenance vehicles equipped with mobile environmental sensors. These environmental sensors will complement other data collected on vehicles for maintenance purposes, such as snow plow status and material usage. In addition to these efforts by state agencies, the Connected Vehicle program that could be widely deployed on light and heavy vehicles has the potential to dramatically increase the number of mobile sensor systems across the United States.*

The value of obtaining data from heavy vehicles needs to be noted here. Trucks and public transit vehicles operated as part of public fleets offer two particular advantages over privately-owned light vehicles: their data buses generally offer more data that is more easily accessible than that on light vehicles, and there are fewer privacy restrictions associated with their location data. These factors together facilitate gathering a wider range of data types with better correlation to roadway and vehicular conditions than are generally available from privately-owned light vehicles.

The *Concept of Operations for Road Weather Connected Vehicle Applications* continues.

> *The FHWA Road Weather Management Program (RWMP) is currently demonstrating how weather, road condition, and related vehicle data can be collected, transmitted, processed, and used for decision making through the Integrated Mobile Observations (IMO) project. In this project, the National Center for Atmospheric Research (NCAR) is partnering with the Minnesota and Nevada Departments of Transportation to obtain vehicle data from heavy*

vehicles, including snow plows, and light-duty vehicles as they carry on routine maintenance functions across their states.

Additionally, the NWS has sponsored the development of the Mobile Platform Environmental Data (MoPED) system, a mobile sensing system deployed on buses and commercial trucks. Current MoPED data elements comprise road and air temperature, rain intensity, light level, relative humidity, and atmospheric pressure, plus derived values of dew point and sea level pressure.

Remote sensors are located at a significant distance from their target. Examples are satellites and radar systems that can be used for surveillance of meteorological conditions. Images and observations from remote sensors are used for weather monitoring and forecasting from local to global scales. Remote sensing is used to quantitatively measure atmospheric temperature and wind patterns, monitor advancing fronts and storms, and image water in all three of its states (e.g., vapor in the air, clouds, snow cover).

Beyond the deployment of the various environmental data collection systems, other initiatives have been undertaken to make the information usable to the transportation community and others. In 2004, USDOT established the Clarus Initiative with a broad goal to reduce the impact of adverse weather conditions on surface transportation users. The Clarus Initiative is based on the premise that the integration of a wide variety of weather observing, forecasting, and data management systems, combined with robust and continuous data quality checking, could serve as the basis for timely, accurate, and reliable weather and road condition information.

A core component of the Clarus Initiative is the Clarus System. The Clarus System is an integrated observation and data management system that collects near-real time information from state and local government-owned ESS, together with comprehensive metadata on these systems. The Clarus System conducts a variety of quality checks on the data, and makes the data available to public and private sector end-users, and researchers.

The *Clarus* System is, however, nearing the end of its effective life and its functions are being migrated to next-generation systems. Its operations support functions will be moved to the NOAA Meteorological Assimilation Data Ingest System (MADIS)[1]. Like the *Clarus* System, MADIS collects data from surface surveillance systems, but its sources also include hydrological monitoring networks, balloon-borne instruments, Doppler radars, and aircraft sensors. This

---

[1] madis.noaa.gov

multimodal data collection providing a broader range of meteorological data in one system can offer significant advantages for road weather operations. The research functions of *Clarus* will be transitioned to the U.S. DOT's Real-Time Data Capture and Management (RTDCM) program and a new Weather Data Environment (WxDE) that will capture data from both the existing *Clarus* sources and from new mobile sources in the IMO and other connected vehicle deployments. The WxDE will support both near real-time applications and long-term archiving of road weather data.

The RWMP has also invested significantly in connected vehicle technologies through its development of the Vehicle Data Translator (VDT) at NCAR. The VDT ingests and processes mobile data from sensors on vehicle and combines this with ancillary weather data sources. The earliest versions of the VDT were developed around data from connected vehicles in a development test environment in the Detroit area during the winter and spring of 2009 and 2010. For this data to be useful to the broad community of stakeholders, it must be acquired and then processed into meaningful, actionable information. The VDT inputs two types of data:

- Mobile data are all data originating from a vehicle, whether native to the Controller Access Network (CAN) bus or as an add-on sensor (e.g., pavement temperature sensor mounted to a vehicle).

- Ancillary data represent all other data, such as surface weather stations, model output, satellite data, and radar data.

Vehicle data of interest in the VDT include external air temperature, wiper status, headlight status, antilock braking system and traction control system status, rate of change of steering wheel, vehicle velocity, date, time, location, vehicle heading, and pavement temperature; ancillary data elements used in VDT algorithms include radar, satellite, and surface station data from fixed data sources. Algorithms in development through VDT Version 3.0 include:

- A precipitation algorithm that will provide an assessment of the type and intensity (amount/hour) or accumulation rate of precipitation that is falling to the road surface by road segment.

- A pavement condition algorithm is being developed to derive the pavement condition on a segment of roadway from the vehicle observations.

- A visibility algorithm is being designed to provide additional information by road segment on both a general decrease in visibility, and more specific visibility issues.

2.3.2 Connected Vehicle Programs

Connected vehicle programs as a whole represent an interconnected set of cooperative efforts among many constituencies: the U.S. DOT, state and local agencies, vehicle manufacturers, academic and research organizations, commercial vehicle operators, and communications equipment providers. These programs aim to enable interoperable networked wireless communications among vehicles, the infrastructure, and other wireless devices. Connected vehicle applications have the potential to affect all dimensions of surface transportation system operations.

- Connected vehicle safety applications are intended to increase situational awareness and reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission that will support driver advisories, driver warnings, and vehicle and infrastructure controls.
- Connected vehicle mobility applications will provide a connected, data-rich travel environment. The connected vehicle network will capture real-time data from equipment located on-board vehicles and within the infrastructure.
- Connected vehicle environmental applications will both generate and capture environmentally-relevant real-time transportation data and use this data to create actionable information to facilitate "green" transportation choices.

The development and applications of wireless communications in vehicular environments has been a major focus of development within and in support of connected vehicle applications. In particular, 5.9 GHz DSRC technologies have been specified and developed specifically to support V2V and V2I interactions with low wireless communications latency and high bandwidth. Although it is possible to implement many connected vehicle applications with other wireless technologies—cellular data networks or Wi-Fi, for example—DSRC has been developed from its beginnings to meet the specific needs of connected vehicles.

Within this broader context, connected vehicle technologies hold the promise to transform road-weather management. Road weather connected vehicle applications will dramatically expand the amount of data that can be used to assess, forecast, and address the impacts that weather has on roads, vehicles, and

travelers; fundamentally changing the manner in which weather-sensitive transportation system management and operations are conducted. The availability of road weather data from an extended set of mobile sources will vastly improve the ability to detect and forecast road weather and pavement conditions, and will provide the capability to manage road-weather response on specific roadway links.

The potential for improvements in road weather information availability through deployment of connected vehicle technologies is already being demonstrated in the U.S. DOT RWMP IMO projects mentioned earlier. The Nevada DOT IMO demonstration gathered data from sensors on agency vehicles and sent it to a data aggregation system over the state's 915 MHz wireless data network. Minnesota DOT gathered data from snowplow trucks with an existing automated vehicle location (AVL) system and sent it to a data aggregation system over a commercial cellular network. Data from both of these demonstrations was sent to the VDT and the *Clarus* System and will be migrated to the WxDE for future studies. The RWMP and Michigan DOT have started a project demonstrating collection of data from vehicles using cell phones connected directly to a vehicle's CAN bus through the OBD-II port, again sending the observations to data aggregation systems over the cellular network, to be processed by the VDT and ultimately to be archived in the WxDE.

2.4   Users and Other Involved Personnel

The *Concept of Operations for Road Weather Connected Vehicle Applications* describes the key constituencies for road weather information use within transportation operations.

2.4.1 Use of Road Weather Information in Maintenance Operations

Maintenance managers obtain and make extensive use of road weather information. This information help managers make decisions for a variety of winter and non-winter maintenance activities, including decisions about staffing levels, the selection and timing of maintenance activities, and resource management (such as personnel, equipment, and materials), as well as road treatment strategies during winter storms.

Winter road maintenance activities are especially sensitive to weather conditions. During this period of the year, maintenance tasks can often involve snow and ice treatment strategies, including plowing snow, spreading abrasives to improve vehicle traction, and dispensing anti-icing/deicing chemicals to lower the freezing point of precipitation on the pavement. In regions with heavy snowfall,

maintenance managers may erect snow fences adjacent to roads to reduce blowing and drifting snow. Another mitigation strategy involves the use of slope sensors and avalanche forecasts to minimize landslide and avalanche risks. When a slope becomes unstable due to snow accumulation or soil saturation, roads in the slide path may be closed to allow the controlled release of an avalanche or landslide. Snow, mud and debris are cleared and damaged infrastructure is repaired before the affected route can be reopened to traffic.

Many non-winter maintenance activities are also impacted by weather conditions. Mowing is conducted on a cycle throughout the summer months but will be suspended during heavy rain and thunderstorms. The spraying of herbicides is not conducted during rain storms or high winds. Striping requires a dry roadway, no high winds, a minimum ambient air temperature, and no immediate likelihood of rain. Surface repairs (such as pothole and seam repairs) using hot mix asphalt need dry pavement with a minimum ambient air temperature and no risk of rain in the short-term. Many maintenance activities will also be suspended for lightning storms, tornado forecasts, and periods of low visibility to protect the safety of both maintenance personnel and travelers who may unexpectedly encounter maintenance equipment on or near the roadway.

2.4.2   Use of Road Weather Information in Traffic Operations

The FHWA RWMP is encouraging state and local transportation agencies to be more proactive in the way that they manage traffic operations during weather events. Weather Responsive Traffic Management (WRTM) is the central component of the program's efforts. WRTM involves the implementation of traffic advisory, control, and treatment strategies in direct response to or in anticipation of developing roadway and visibility issues that result from deteriorating or forecast weather conditions.

Over the past 10 years, transportation agencies have implemented various strategies to mitigate the impacts of adverse weather on their operations. These strategies range from simple flashing signs to coordinated traffic control strategies and regional traveler information. More recently, various new approaches, technologies, and strategies have emerged that hold potential for WRTM, including Active Traffic and Demand Management (ATDM) and Integrated Corridor Management (ICM). Operational strategies that are currently used by traffic managers include the following:

- *Motorist advisories, alerts and warnings intended to increase the awareness of the traveler to current and impending weather and pavement conditions. Approaches include active warning systems that*

warn drivers of unsafe travel conditions through a particular section of roadway, often in remote or isolated locations; pre-trip road condition information and forecast systems; and en-route weather alerts and pavement condition information;

- *Speed management strategies designed to manage speed during inclement weather events. This includes both advisory, which usually involves posting an advisory travel speed that is deemed safe by the operating agency for the current travel conditions, and regulatory speed management techniques, which include speed limits that change based on road, traffic, or weather conditions;*

- *Vehicle restriction strategies involve placing restrictions on the types or characteristics of vehicles using a facility during inclement weather events. These strategies might include size, height, weight, or profile restrictions;*

- *Road restriction strategies restrict the use of a facility during inclement weather to help travelers avoid sections of roadway that are dangerous or would cause substantial delay. Approaches include lane use restrictions, such as requiring trucks to use a specific lane during inclement weather conditions; parking restrictions including special parking rules that are implemented during significant snow events that restrict when and where on-street parking is permitted; access control and facility closures; and reversible lane operations, particularly during evacuations;*

- *Traffic signal control strategies involve making modifications or influencing the way traffic signals operate during inclement weather. Approaches in this category include changes to vehicle detector configuration, vehicle clearance intervals, interval and phase duration settings, and implementation of special signal coordination plans designed for inclement weather.*

2.4.3 Use of Road Weather Information by Emergency Managers and Emergency Responders

Emergency managers, who are responsible the safe movement or evacuation of people during natural or man-made disasters rely on comprehensive weather and road condition data. Current and predicted weather and road condition information is obtained through RWIS (often through collaboration with transportation agencies or airport operators), water level monitoring systems, federal government sources such as the Tropical Prediction Center, commercial weather information providers, and the media. Emergency managers use decision

support systems that present weather data integrated with population data, topographic data, road and bridge locations, and traffic flow data.

Emergency managers gather weather observations and forecasts to identify hazards, their associated threatened areas, and select a response or mitigation strategy. In response to flooding, tornadoes, hurricanes, wild fires or hazardous material incidents, emergency managers can evacuate vulnerable residents, close threatened roadways and bridges, operate outflow devices to lower water levels, and disseminate information to the public. Many emergency management practices require coordination with traffic managers. Emergency managers may use several control strategies to manage traffic on designated evacuation routes. These strategies include opening shoulder lanes to traffic, contraflow operations to reverse traffic flow in selected freeway lanes, and modified traffic signal timing on arterial routes.

Emergency responders, including fire trucks, ambulances, and paramedics, must routinely operate on roadways affected by adverse weather events. With no option to defer their trips, emergency responders must reach their destinations irrespective of conditions or road closures. Emergency responders rely on routing systems or must make dispatching decisions to hand-off an emergency call to another responder often in the absence of accurate, up-to-date road-weather information.

2.4.4 Use of Road Weather Information by Motorists and Commercial Vehicle Operators

Traffic managers disseminate road weather information to road users of all types to influence their travel decisions. Different types of road users have varying information needs. In the event of a road closure, recreational travelers may need alternative route information, while commuters familiar with their route may not. Passenger vehicle drivers are interested in road surface conditions. Commercial vehicle operators, who are especially sensitive to time delays and routing, may also need information about road restrictions due to high winds, height and weight limits, or subsurface freeze/thaw conditions. Overall, road weather information allows travelers to make decisions about travel mode, departure and travel time, route selection, vehicle type and equipment, and driving behavior.

Road weather information may be disseminated via roadway infrastructure, telephone systems, web sites, and other broadcast media. Roadway systems that are typically controlled by traffic managers utilize highway advisory radio, dynamic message signs, and flashing beacons atop static signs to alert motorists to hazards. Interactive telephone systems and applications on smart phones allow

> *motorists to access road weather information both pre-trip and en-route. Many state transportation agencies provide general road condition data through toll-free or 511 telephone numbers, web sites, and, increasingly, through social media.*

It is also significant in this context that messages can be tailored to particular types of vehicles. For example, high profile vehicles could subscribe to wind advisories and be routed around segments and bridges subject to those advisories.

3   JUSTIFICATION FOR AND NATURE OF CHANGES

This section of the Concept of Operations describes the challenges in the current situation and the opportunities for improvement.

3.1   Justification for Changes

The *Concept of Operations for Road Weather Connected Vehicle Applications* provides a thorough description of the impacts of weather and the case for proactive measures to mitigate its impacts on roadways.

> *The influence and impacts of weather conditions on the operation of the transportation system have been well analyzed[2]. Adverse weather conditions have been shown to have significant impacts on the safety, mobility, and productivity of transportation system users and roadway operators.*
>
> *On average, there are over 6,301,000 vehicle crashes in the United States each year[3]. Twenty-four percent of these crashes, or approximately 1,511,000, are identified as weather-related. Weather-related crashes are defined as those crashes that occur in adverse weather (such as, rain, sleet, snow, high winds, or fog) or on slick pavement (i.e., wet, snowy/slushy, or icy).*
>
> *Weather has similarly dramatic effects on transportation system mobility. Significant roadway capacity reductions can be caused by flooding or by lane obstruction due to snow accumulation and wind-blown debris. Road closures and access restrictions due to hazardous conditions (such as large trucks in high winds) also decrease roadway capacity. Weather events can also reduce mobility and reduce the effectiveness of traffic signal timing plans on arterials. On freeways, light rain or snow can reduce average speed by three to thirteen percent, while heavy rain can decrease average speed by three to sixteen percent, and in heavy snow, average freeway speeds can decline by five to forty percent. Low visibility can cause speed reductions of ten to twelve percent. Freeway capacity reductions can also be significant: from four to eleven percent in light rain; ten to thirty percent in heavy rain; twelve to twenty-seven percent in heavy snow; and by twelve percent in low visibility.*
>
> *Overall, it has been estimated that twenty-three percent of the non-recurrent delay on highways across the nation is due to the impacts associated with snow,*

---

[2] http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm. Retrieved March 31, 2012
[3] Fourteen-year averages from 1995 to 2008 analyzed by Noblis, based on NHTSA data

ice, and fog. This amounts to an estimated 544 million vehicle-hours of delay per year.

Adverse weather increases the operating and maintenance costs of road maintenance agencies, traffic management agencies, emergency management agencies, law enforcement agencies, and commercial vehicle operators. Winter road maintenance activities account for roughly twenty percent of state transportation agency maintenance budgets. Each year, state and local agencies spend more than $2.3 billion on snow and ice control operations.

Each year trucking companies lose an estimated 32.6 billion vehicle-hours due to weather-related congestion in the nation's top 281 metropolitan areas. The estimated cost of weather-related delay to trucking companies is $3.1 billion annually in the nation's 50 largest cities.

The availability of accurate, up-to-date road weather observations that are tailored to the needs of roadway operators, together with the decision support tools that place the observation data in a transportation system operations and management context, can play a significant role in helping better prepare roadway operators and users of the transportation system for adverse weather conditions. In turn, this approach has the potential to improve safety, mobility, and productivity. The FHWA Road Weather Management Program has already undertaken significant work to acquire, quality check, and make available road weather observations from fixed, mobile, and remote sensing systems.

3.2   Description of Opportunities and Desired Changes

The convergence of rapid advances in CV technology with similar advances in processing of mobile weather data has created a unique opportunity to develop and demonstrate collection of weather observations from probe data in standardized DSRC transmissions. This project will bring developments in connected vehicle and road weather research together into an end-to-end prototype of deployable connected vehicle technology for road weather applications. It will:

- Collect data according to latest data standards from embedded vehicle sensors through the vehicle's CAN bus;
- Use interoperable DSRC equipment to send data from the vehicle to roadside units;
- Deploy the newest generation (3.0) of roadside units in locations along the Long Island Expressway where the previous generation equipment was deployed and supported by power and backhaul services;

- Forward data from RSEs to a data aggregation service;
- Provide data from the aggregation service to
  - The VDT, for synthesis of road weather condition data from vehicle-based observations, and
  - The WxDE, where it becomes available for connected vehicle researchers and real-time applications.

3.3   Preliminary System Requirements

A Concept of Operations typically identifies priorities among the changes being proposed as a means of clarifying and providing some bounds to the potential for system development. For this project, that intent is being met by specification of a set of preliminary system requirements.

Table 1 - Preliminary System Requirements

ID	Requirement
100	The system shall acquire weather-related data from vehicles.
110	The system shall be able to acquire weather-related data from a heavy vehicle J1939 data bus.
120	The system shall be able to acquire weather-related data from a vehicle J1979 data bus.
130	The system shall be able to acquire weather-related data from a RS-232 serial data bus.
200	The system shall assemble weather-related data acquired from vehicles into messages.
210	The system shall encode weather-related data elements defined in the SAE J2735 DF_VehicleStatus data frame into a message conforming to the MSG_BasicSafetyMessage specification.
220	The system shall encode weather-related data elements not defined in the SAE J2735 DF_VehicleStatus data frame into free-form local content within a message conforming to the SAE J2735 MSG_BasicSafetyMessage specification.
300	The system shall transmit messages containing weather data from vehicles to roadside units over 5.9 GHz DSRC.
350	The system shall encode digital signatures according to the ToBeSigned message format defined by IEEE 1609.2.

400	The system shall aggregate probe data from RSEs.
450	The system shall associate probe data with its vehicular sources.
500	The system shall make weather and road condition data available to other systems.
510	The system shall make weather and road condition data available to other systems in the form of subscriptions.
520	The system shall make weather and road condition data available to the WxDE.
530	The system shall make weather and road condition data available to the VDT.
600	The system shall monitor the state of its operations.
610	The system shall monitor the state of its RSE operations.
620	The system shall monitor the state of its aggregator operations.

3.4   Changes Considered But Not Included

The nature of this opportunity and the defined scope of work are sufficiently specific that there are few alternatives to the changes described above to be considered outside the detailed design.

This is especially true with respect to the available DSRC-based messaging schemes. Many of the connected vehicle references, including the *Concept of Operations for Road Weather Connected Vehicle Applications* describe the use of the Basic Safety Message (BSM) Part 2 as a means of structuring data obtained from vehicles for DSRC transmission. Although this is an alternative under the SAE J2735 standard, it presents limitations to ensuring effective probe data collection.

The BSM represents a single snapshot in time to be broadcast at a regular interval. There is no provision within the BSM itself for recording or rebroadcast of data that was not received by an RSE. As such, only the BSM data captured and broadcast within range of another DSRC receiver would generally be passed on to a data aggregator. Probe data transmitted in a BSM would effectively cover only the range of the receiving RSE.

Because of the BSM limitations on geographical and temporal range, it would be preferable to use the J2735 Probe Vehicle Data Message (PVDM) as the basis for

weather and road condition data exchange. The PVDM accumulates snapshots into a message that can be stored and sent when an RSE is in range. The management of the PVDM allows some flexibility in how frequently and how many snapshots are written into any particular message. Multiple PVDMs can be accumulated for transmission when in range of a receiving RSE. These characteristics of the PVDM make it preferable to the BSM Part 2 for probe data gathering.

Unfortunately, the current generation of available RSEs does not fully support nor has been tested for implementation of the PVDM. The only alternative supported by RSEs available at this time is to use the BSM Part 2 to transmit the data from the OBE on the vehicle to the RSE and provide the data from the RSE to an aggregator. A work-around solution, described in Section 4.1, will be needed to extend the probe data availability beyond the context of the RSE.

4 CONCEPTS FOR THE PROPOSED APPLICATION

The DSRC-based Mobile Road and Weather Condition application (MRdWxS-D) is described in this section in terms of its system architecture, expressed in two views; its potential operational policies and constraints; modes of operation; user classes; and support environment.

4.1 System Architecture

The system's proposed architecture can be described from various viewpoints, depending on the range of perspectives needed to appropriately detail its design and operation. For the MRdWxS-D, a functional view and a deployment view are offered here.

4.1.1 Functional View

A functional view of the system describes the system and its components in terms of what its major components do—its functions—and in the flow of data among those components.
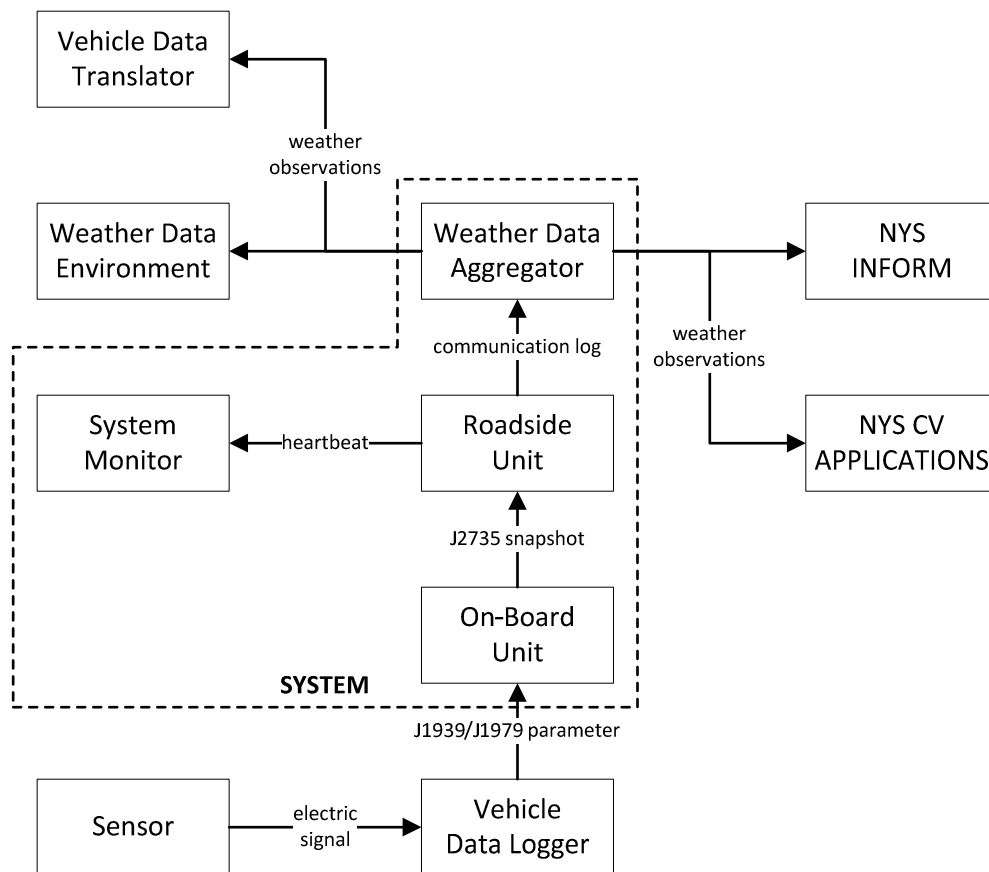

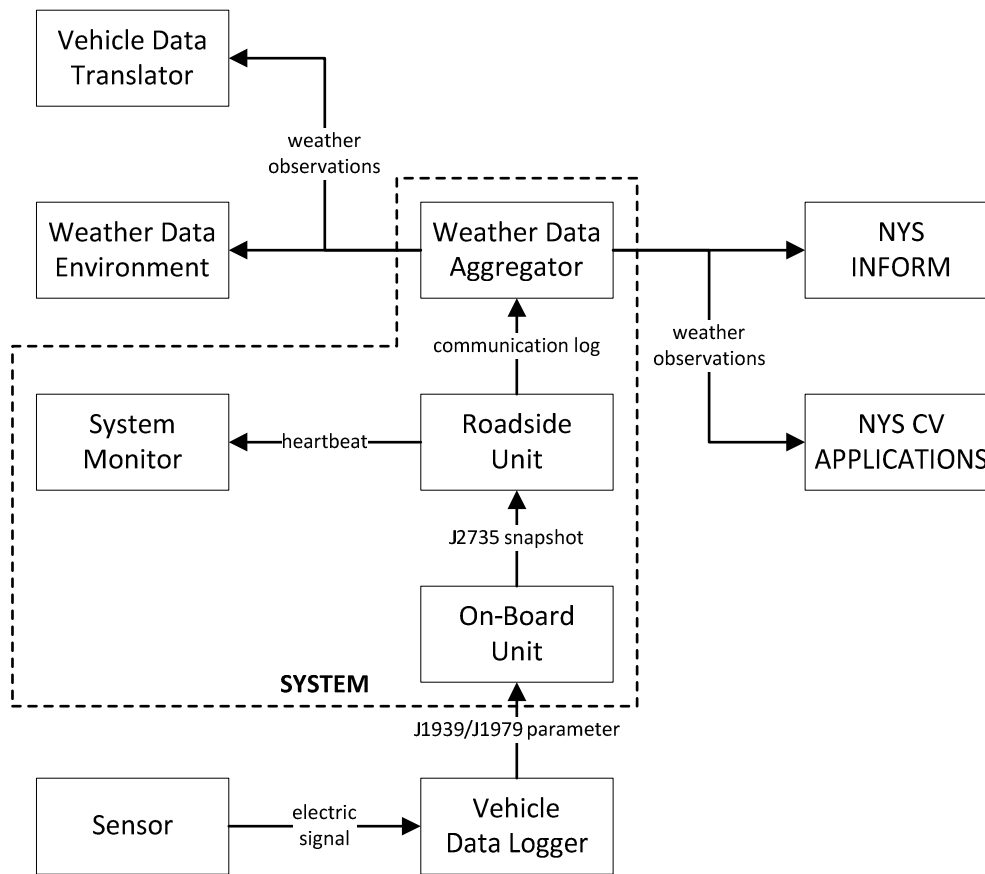
Figure 1 - Functional Data Flows

Figure 1 presents a functional view of the system. Components inside the system boundary are those to be developed in this project; those outside the boundary represent existing systems and users that will (or could) interact with the new MRdWxS-D. The major components of the system in this view are the OBE, the RSE, the system monitor, and the weather data aggregator. Interfacing systems outside the system are the vehicle's sensors, through its data logger, the WxDE, the VDT, and NY State systems that may use the data.

The OBE obtains data from the vehicle data logger through a set of data message standards, each one of which is specific to a particular type of vehicle. As described in the *Messaging Requirements* document, the SAE J1939 standard specifies the data that may be available from heavy vehicles such as snowplow trucks. The SAE J1979 standard describes data that may be available from "light" vehicles including passenger cars and the HELP vehicles that will be used in this project. Each of these standards applies only to those vehicle types for which it is intended, and there is no particular overlap or consistency between the data specifications or standards.

Furthermore, these standards describe the data that *may* be available from those vehicle types. The actual data available from the vehicle will depend on which sensors are installed on the vehicle and connected to its data bus and on the manufacturer's implementation of the standard. Determination of what data have been made available through this interface will come through either manufacturer-specific documentation or through polling and discovery on that interface.

The OBE itself captures the data from the interface, caches it locally, repackages the data for transmission, and transmits the data. Functionally, the OBE watches the stream of data on the data logger interface (the vehicle data bus) for parameters of interest and captures them for further processing. Caching the data enables the system to create snapshots of data from the higher-frequency flow of data provided by the vehicle data logger. The repackaged snapshots are then ready for off-board DSRC transmission.

The snapshot message broadcast from the OBE to the RSE conforms to the MSG_BasicSafetyMessage in the SAE J2735 standard as described by the *Messaging Requirements* document.

The RSE records all network traffic, both input and output, for each physical interface in a separate messaging log file. For this deployment there will be a NYSDOT backhaul network interface and the wireless DSRC interface. There will therefore be four log files: DSRC input, DSRC output, backhaul input, and backhaul output.

The messaging logs are created using the built-in Linux application, tcpdump, which stores raw network packet data in a pcap format file. A pcap file is very straight forward. It contains a main header that identifies the byte order of the captured data, the version of file format being used, the timestamp accuracy, and the maximum length of data stored for each packet. Following the main header is one record for each packet captured which lists the timestamp measured in microseconds, the number of bytes in the original packet, the number of bytes of the packets captured in the file, followed by the actual binary packet data.

The RSE transmits its saved log files to a configured network destination at both a fixed interval (for example, five minutes) as well as when a configured size threshold is reached (for example, ten megabytes). This strategy allows the RSE to conserve local storage space; a busy RSE off-loads log files frequently, while a less busy RSE off-loads much smaller log files at more regular intervals. Care was taken to exclude the log file off-load process from being captured in the backhaul output log file. Otherwise, that file would uncontrollably expand.

5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Concept of Operations

Each RSE is configured to send a heartbeat message—RSE identifier and timestamp—to a network destination at regular intervals, usually one to five minutes. A System Monitor is configured with a list of RSE identifiers and administrator email addresses. When more than two consecutive expected heartbeat messages are missed, the system monitor sends a notification email to the identified administrators for them to investigate and resolve any problems.

The Weather Data Aggregator occupies the network destination address where RSE send their network communication log files. The Weather Data Aggregator receives the log files and reads the J2735 snapshot data from the pcap-formatted data. The J2735 snapshot data are then formatted again to a comma separated value (CSV) file format and published. The received RSE log files will also be stored at the Weather Data Aggregator long-term.

Like the RSEs, the Aggregator is configured to send a heartbeat message to a network destination at regular intervals, usually one to five minutes. The System Monitor is configured with the Aggregator's identity and an administrator email address. When more than two consecutive expected heartbeat messages are missed, the system monitor sends a notification email to the identified administrator for investigation and resolution of any problems. The weather observations' CSV format conforms to the WxDE format. Each record in the file contains values for unique vehicle identifier, timestamp, latitude, longitude, altitude, followed by the weather related values each in their own column.

The WxDE (as described in Section 2.3.1) will subscribe to weather observations from the aggregator. Collection of the subscribed data into the WxDE will require the configuration of an MRdWxS-D collector component. In a similar fashion, the VDT (also described in Section 2.3.1) will subscribe to weather data from the aggregator and need its own collection component configuration.

INFORM can retrieve weather observations from either the WxDE or Weather Data Aggregator, as it is a minimal exercise to create a specific output format for that system, if necessary. NYSDOT systems acquiring observation data from the aggregator can likewise retrieve weather observations from the same endpoints.

4.1.2 Deployment View

The deployment view depicts the equipment likely needed to implement the system as well as the network interconnections and supporting infrastructure hardware. The diagram elements should be familiar from the functional data flow diagram, but they are arranged into organizational boundaries to provide an understanding of what is where and who has operational responsibilities.

To gather weather-related vehicle data, it is first necessary to connect appropriate equipment to the probe vehicles. This takes the form of a data logger—a device capable of receiving and interpreting vehicle diagnostic information in its native format. A data logger specific to an available diagnostic bus is installed in the designated project vehicles: one type for J1979 data and another type for J1939 data. J1939 data loggers also receive and interpret data generated from aftermarket equipment connected to the same data bus.

Each probe vehicle also requires a DSRC OBE to transfer the data from the data logger wirelessly to nearby DSRC RSEs. Normal OBE operation continuously formats and stores J2735 messages derived from the data logger data until the OBE detects that it is in range of a RSE. Then the OBE sends the weather-related snapshot data to the RSE in last-in-first-out order.

RSEs are deployed in NYSDOT equipment cabinet points of presence with necessary antennae mounted on nearby mast arms. RSEs receive their power from the cabinet power bus, either through direct wiring or power-over-Ethernet. Their DSRC interface is connected to the mounted antenna and the IPv6 backhaul network interface is connected to a network switch in the cabinet.

It is at this point that the field equipment interacts with the NYSDOT network. The deployment diagram shows a likely configuration for network equipment in that environment, but is not intended to exhaustively detail the complex NYSDOT network, but only the limited view necessary to describe what is needed for this deployment.

RSEs automatically configure their IPv6 network address from the router announcement provided by a router connected to the same network VLAN. Domain name server addresses are provided through the DHCPv6 mechanism. While newer routers may support RFC 5006 and can provide DNS addresses through the announcement, it is not a given that existing NYSDOT routers or newly acquired RSE will support this option. This configuration is recommended so that RSE, which are expensive to configure locally, are more easily managed in the network environment.
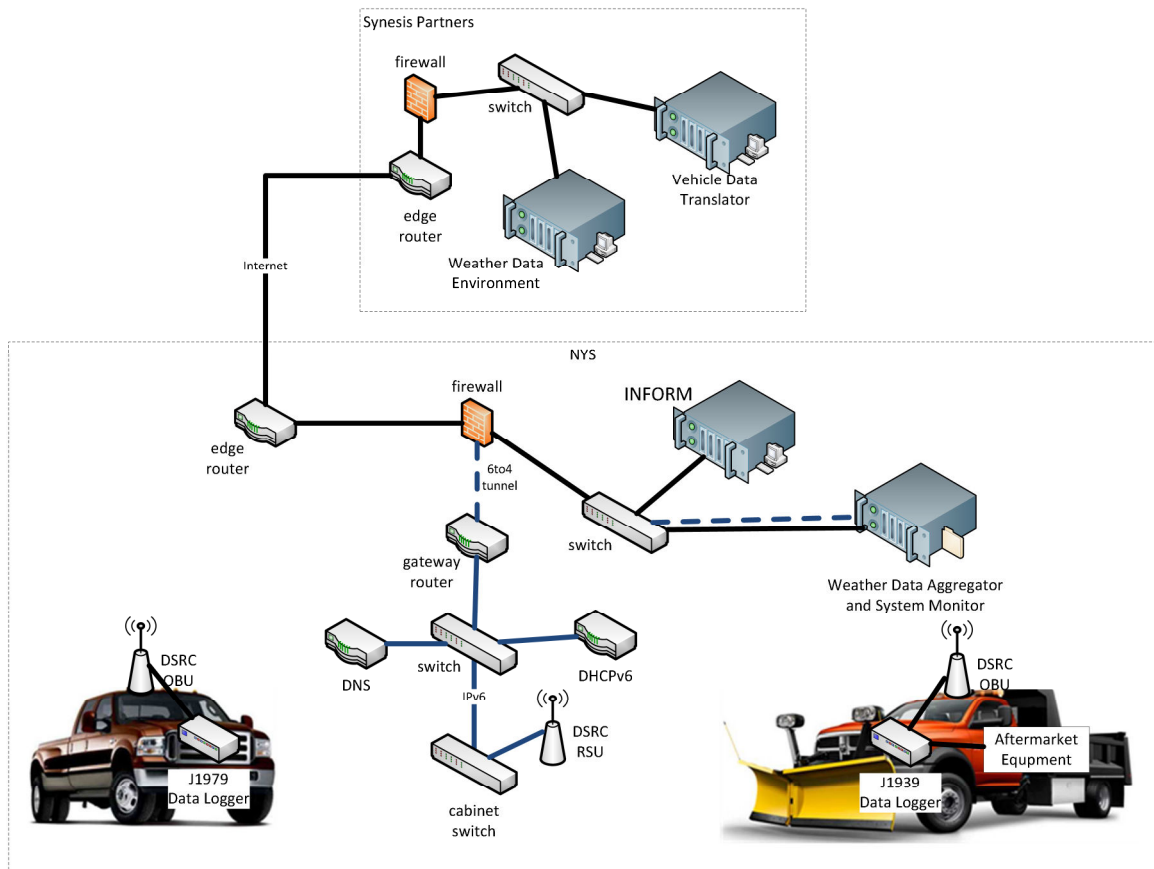
Figure 2 - Proposed Element Deployment for the Mobile Road Weather Application

RSE are configured to send heartbeat status and network log messages to specific network host names at regular intervals. When this occurs, the host name is resolved to an IPv6 address and the information is sent. The gateway router managing the RSE IPv6 network is configured with 6to4 tunnels so that the heartbeat and network log messages can be sent across IPv4 networks to the correct server destination.

The system monitor receives RSE heartbeat messages, and when messages are not received as expected, the system monitor will generate and send an administrative message to system administrators to investigate and resolve perceived RSE issues.

The weather data aggregator receives RSE network logs. The service then reads the J2735 Basic Safety Message Part 2 weather-related observations and formats them for distribution to other systems. This can take the form of comma-separated value files or other formats as described in the previous function data flow section to support receipt by the INFORM, Weather Data Environment, and other interested systems.

The Weather Data Environment, Vehicle Data Translator, and INFORM systems read the information from the weather data aggregator. To do this, the weather data aggregator needs to be network accessible from the network locations where those systems are hosted. This can be accomplished through existing IPv4 equipment and connections as IPv6 communication is handled by the configured 6-to-4 tunnel.

The proposed deployment diagram shows the weather data aggregator and system monitor services hosted within the NYSDOT network. Alternatively, these services can be hosted with Synesis Partners. The advantage of Synesis Partners hosting the weather data aggregator and system monitoring services is that it eliminates the need to find available equipment or acquire and maintain extra NYSDOT equipment and also eliminates configuring an SMTP service to deliver administrative monitoring messages for the system monitor, which may have agency network policy constraints. In the case of Synesis Partners hosting, the 6to4 tunnel would be configured for that external destination.

4.2   Operational Policies and Constraints

This section identifies known current and potential future constraints and risks in the development and operation of the MRdWxS-D.

Data Availability from Mobile Sensor Platforms

The availability of data from vehicles is subject to the sensors on the vehicle (both original equipment and aftermarket modifications) and the manufacturer's implementation of the applicable standards for accessing the data from the CAN bus. As such, data that may be specified for acquisition or transmittal in downstream processes may not be available from the root sources.

Deployment Coverage

Unlike fixed ESS and their associated RWIS, the data coverage from mobile sensor platforms is variable in both geographic and temporal ranges. The availability of data will be highly dependent on the routes driven by the vehicles from which data are being collected, the intervals over which the vehicles are operated, and even by the frequency by which the vehicles encounter RSEs to receive their data transmissions. This concern could be mitigated with additional vehicles—for example, more trucks and transit vehicles—and routes.

Reliability of OBE/RSE Data Exchange

Reliable exchange of data between the vehicle OBE and the infrastructure RSE is limited in range to approximately 300 meters and may be less under some siting

and environmental conditions. For moving vehicles, this will constrain the time interval during which data exchange can occur. Since probe data accumulates on the vehicle OBE until it can be transmitted, it is possible for data to be backlogged for transmission on the OBE if RSEs to receive the data are not encountered frequently enough or for long enough intervals. The latency of data delivery to the aggregator will be somewhat variable until sufficient RSEs are deployed to facilitate regular data exchange. These potential limitations can be evaluated based on the data collected in this study.

WxDE/VDT Data Collection

Like the *Clarus* System before them, the WxDE and VDT use collector components specific to particular data sources to gather data for processing and presentation. These systems also operate independently of the MRdWxS-D. As such, the availability of processed MRdWxS-D data from the WxDE and VDT depends on the implementation and availability of collector components in those systems as well as continued operation of the MRdWxS-D itself. The presence of the MRdWxS-D collector component is assured in this project by the implementation team's access to the WxDE and VDT, but the operational dependency is still subject to the reliability of data connections and intermittent service interruptions.

4.3   Modes of Operation

The modes of operation for the MRdWxS-D are:

Normal – The system is operating as expected. Data are being collected on the vehicle, compiled on the OBE, transmitted to the RSE, received and prepared for subscribers by the aggregator, and successfully collected by the WxDE/VDT.

Degraded – One or more of the system functions are not working properly or may not be available. Some types of malfunction may be known to the System Monitor, but the system will require operator intervention to restore to the Normal mode.

Maintenance – System maintenance may remove some components from Normal operation for finite intervals. Other components that are active during that time will continue to operate normally, but suspend their interaction with the component(s) in Maintenance mode. Components will be designed to resume operations gracefully and recover and reattempt appropriate data exchanges.

4.4   User Classes and Other Involved Personnel

HELP Vehicle Operators – Vehicle operators will be passive participants in the operation of the system. While operating their vehicles, OBES will collect connected vehicle road weather information and will communicate this information to RSEs along the route.

Snow Plow Truck and Maintenance Vehicle Operators – Drivers will be passive participants in the collection and communication of connected vehicle road weather data. If road weather applications like the Enhanced Maintenance Decision Support System (E-MDSS) were deployed, however, these vehicle operators would be recipients of the information generated by the E-MDSS. Operators of these vehicles would interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events.

Maintenance Personnel – This group of users would interact with application like the E-MDSS. They would receive recommendations on winter weather treatment strategies from the E-MDSS based on roadway segment-specific information from the VDT. They would use the decision support tools available through the E-MDSS and direct the actions of the snow plow and other maintenance vehicle operators based on the system outputs.

4.5   Support Environment

The support environments for the MRdWxS-D are straightforward. The weather data aggregator, system monitor, and associated SMTP services can be executed on a single server or even on an existing server that hosts other services. The primary constraint is storage space. At least one TB should be available. The aggregator and system monitor can be hosted within the NYSDOT network or at Synesis Partners' hosting facility.

The project calls for two RSEs to be deployed. Once deployed, very little support should be required. The system monitoring service will alert administrators of RSE problems that require investigation and direct physical intervention should be non-existent to rare.

The bulk of the support occurs with the NYSDOT network components during the initial RSE deployment. This is the time when necessary firewall, router, and switch configurations should be made. Setup generally entails the selection of the switch and RSE IPv6 addresses and configuration of a 6to4 tunnel on the router, and allowing the traffic through intervening firewalls. Once this is completed

and tested no further changes or support should be necessary unless precipitated by administrative need.

5 OPERATIONAL SCENARIO

This section describes the operational scenario for normal operation of the MRdWxS-D. Applications of data gathered by the system could include any of those described in the *Concept of Operations for Road Weather Connected Vehicle Applications*. The applications themselves are not within the scope of the MRdWxS-D.

5.1 Description

This scenario describes the gathering of weather-related data from vehicles equipped with connected vehicles 5.9 GHz wireless devices operating on a roadway with compatible connected vehicle wireless communications and the provision of that data to appropriate data aggregation and publishing services. The general process is that weather-related data is gathered from vehicles by their OBEs, sent by DSRC to RSEs in range, logged on the RSE and sent to a weather data aggregation service, and provided by the aggregator to other subscribing systems. Users have access to the data through the subscribed systems, which may be providing additional value-added application-specific processing. Figure 3 illustrates these interactions and identifies typical actors in each of these roles.
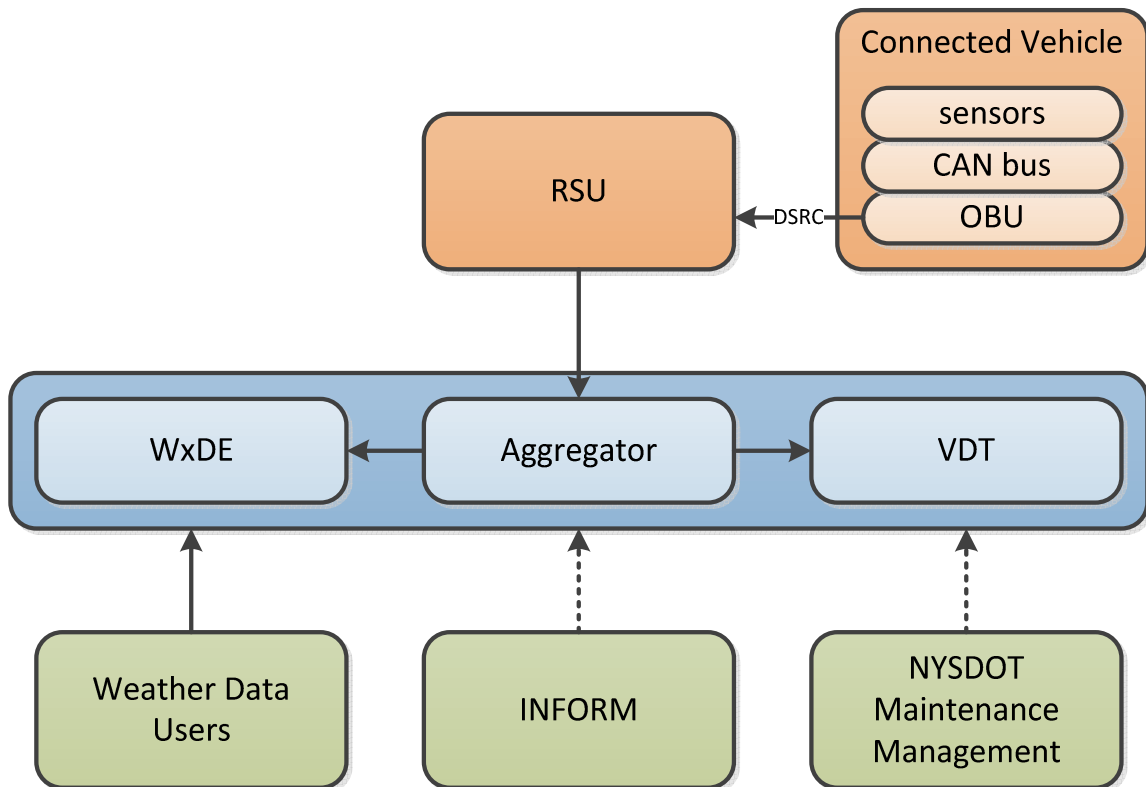
Figure 3 - Road and Weather Condition Interactions

5.2   Steps

1. Vehicles equipped for connected vehicle data gathering operate on the roadways.
2. Sensors on the vehicle measure and report data to the vehicle's data bus (typically a CAN bus).
3. The vehicle's OBE obtains weather-related data from the data bus.
4. OBE formats data into a basic safety message.
5. OBE stores BSM for transmittal.
6. Vehicle comes in range of RSE; OBE receives service announcement from RSE.
7. OBE broadcasts saved BSM to RSE.
8. RSE logs incoming message(s).
9. RSE pushes logs to the data aggregator over the backhaul network.
10. Aggregator formats data for downstream systems.
11. WxDE collects data from aggregator.
12. [Optional] INFORM reads data from aggregator.
13. VDT reads data from aggregator.
14. VDT synthesizes weather data from vehicle data provided by aggregator.

15. Users obtain data from WxDE.
16. [Optional] INFORM obtains data from WxDE.

6   SUMMARY OF IMPACTS

This section provides a summary of key impacts arising from a successful DSRC-based weather and road condition prototype application development and deployment.

6.1   Research Perspective

The MRdWxS-D will significantly advance the state of road weather and connected vehicle research.

- The ability to collect weather-related probe data from vehicles over DSRC will have been conclusively demonstrated.

- The use of SAE J2735 basic safety message part 2 for weather-related data will have been demonstrated over a sustained period of operations.

- The provision of data collected from vehicles over DSRC to the WxDE and VDT for connected vehicle applications research will have been demonstrated.

- Weather-related data from vehicles operating in New York will be collected for operational feedback and longer-term research.

- Developers of connected vehicle road weather applications will have an archive of operations data against which to validate their approaches.

6.2   Operations Perspective

The MRdWxS-D will provide new capabilities in both road weather and connected vehicle operations.

- The CTS PFS and NYSDOT will have developed a prototype connected vehicle capability to enhance DOT operations and kickstart other weather-related applications.

- Agencies wanting to collect weather-related connected vehicle probe data will have access to a demonstrated system and deployment experience.

- NYSDOT will have upgraded part of its connected vehicle field infrastructure for use in other studies, application development efforts and operations.

7 ANALYSIS OF THE PROPOSED SYSTEM

This section provides an analysis of the potential benefits, limitations, advantages, and disadvantages of DSRC-based weather and road condition collection.

7.1 Summary of Potential Benefits and Advantages

The MRdWxS-D will demonstrate key new capabilities to the advantage of all CV applications and deployers.

- It will confirm the results and experience with DSRC equipment and interoperability at similar installations (e.g., the Ann Arbor Safety Pilot).

- It will demonstrate operation of IPv6-based DSRC transactions within a heterogeneous IP network.

- It will collect a significant body of weather-related data using standard basic safety messages.

- It will demonstrate and provide usable statistics on data collection over DSRC for use in follow-on performance assessments and requirements generation.

7.2 Disadvantages and Limitations

Even at a conceptual stage, there are expected to be some challenges in the deployment, operations and extensibility of DSRC-based road and weather condition (probe data) applications.

- The types and discoverability of data available over a vehicle's CAN bus create some uncertainty as to what weather-related data will actually be available.

- Recent DSRC deployments have encountered challenges in deployment and operation of heterogeneous IPv6/IPv4 networks. The range of potential issues is wide enough to create some risk for the project.

- The short range of DSRC creates challenges in the management of data latency. Basic safety messages are generated continuously in vehicle operations, but can only be downloaded over DSRC when a vehicle is in range of an RSE. If RSE contact is too infrequent, data messages can become so backlogged on the RSE that they cannot be cleared faster than they are generated. This also creates a need to study and clarify the best

download queuing algorithms for minimizing the net latency of the probe data being downloaded.

- While a significant body of research has already been undertaken in other IMO projects, there is still a need for additional research on synthesis of road and weather condition data from vehicular probe data. This is clearly a worthwhile research objective, but is also a project limitation in that the performance assessment of the data collection will be limited by not initially having enough information on data collection strategies, particularly in the balance of data types and collection intervals.

- Successful deployment of the system described in this ConOps will provide for demonstration and research purposes, but will be limited in geographical and temporal coverage. This will limit operational use to a similar geography and time domain.

8 REFERENCES

8.1 Referenced Documents

The following references were used in the development of this document.

U.S. Department of Transportation, Federal Highway Administration, "Concept of Operations for Road Weather Connected Vehicle Applications," prepared by Booz Allen Hamilton, Report No. FHWA-JPO-13-047, February 2013.

Mitretek Systems, "Weather Impacts on Arterial Traffic Flow," December 24, 2002.

U.S. Department of Transportation, Federal Highway Administration, "*Clarus*. A Clear Solution for Road Weather Information," Fact Sheet, 2011.

U.S. Department of Transportation, Federal Highway Administration, "Developments in Weather Responsive Traffic Management Strategies," Prepared by Battelle, Report No. FHWA-JPO-11-086, June 2011.

U.S. Department of Transportation, Federal Highway Administration, "Road Weather Information System Environmental Sensor Station Siting Guidelines, Version 2.0," Prepared by SAIC, Report No. FHWA-HOP-05-026, November 2008.

U.S. Department of Transportation, Research and Innovative Technologies Administration, "How Connected Vehicles Work," Fact Sheet, 2011.

U.S. Department of Transportation, Research and Innovative Technologies Administration, "Concept of Operations for the Use of Connected Vehicle Data in Road Weather Applications," Prepared by University Corporation for Atmospheric Research, Draft Report, December 2011.

U.S. Department of Transportation, Research and Innovative Technologies Administration, "The Vehicle Data Translator V3.0 System Description," Prepared by University Corporation for Atmospheric Research, Report No. FHWA-JPO-11-127, May 2011.

8.2 Acronyms and Definitions

Acronyms used in the document are defined in Appendix A.

APPENDIX A – ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AVL	Automatic Vehicle Location
BSM	Basic Safety Message
CAN bus	Controller Access Network bus
CTS PFS	Cooperative Transportation Systems Pooled Fund Study
CV	Connected Vehicle
DHCP	Dynamic Host Configuration Protocol
DMA	Dynamic Mobility Applications
DNS	Domain Name System
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
E-MDSS	Enhanced Maintenance Decision Support System
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
IEEE	Institute of Electrical and Electronics Engineers
IMO	Integrated Mobile Observations
INFORM	NYSDOT's INformation FOR Motorists system
IP	Internet Protocol
MADIS	Meteorological Assimilation Data Ingest System
MDSS	Maintenance Decision Support System
MoPED	Mobile Platform Environmental Data
NCAR	National Center for Atmospheric Research
NOAA	National Oceanographic and Atmospheric Administration
NWS	National Weather Service
NYSDOT	New York State Department of Transportation
pcap	From packet capture; a Unix network system logging

	application interface
PFS	Pooled Fund Study
RFC	Remote Function Call
RWIS	Road Weather Information System
RWMP	Road Weather Management Program
SAE	Society of Automotive Engineers
SMTP	Simple Mail Transfer Protocol
tcpdump	A Unix network traffic packet analyzer application built over the pcap interface
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDT	Vehicle Data Translator
VLAN	Virtual Local Area Network
WxDE	Weather Data Environment