Module 13: Connected Vehicles

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Purpose

The purpose of this module is to describe the background, current activities, and future direction of the connected vehicle initiative. The module examines the anticipated roles and responsibilities of the principal participants; the major technologies and systems development efforts; the range of expected applications of the connected vehicle system; the potential institutional, policy, legal, and funding challenges facing the initiative; and the expected development and deployment timeline for a connected vehicle environment. This is not intended to be an exhaustive overview of the USDOT Connected Vehicle program, rather it is an overview of the current work being done. Links have been provided in this document to the appropriate sites where the most current work is typically posted.

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Objectives

Users of this module will understand the following:

- The history, evolution, and expected future direction of the connected vehicle program, including the major milestones;
- The partnership between government and industry as well as the roles of each partner that will be fundamental to a successful connected vehicle program;
- The basic technologies and the various core system components that must be deployed to realize the connected vehicle environment; and
- The key policy, legal, and funding issues that must be addressed to successfully deploy a connected vehicle environment.

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Introduction: Definition and Programmatic Overview

The fundamental premise of the connected vehicle environment[1] lies in the power of wireless connectivity among vehicles (referred to as vehicle-to-vehicle or V2V communications), the infrastructure (vehicle-to-infrastructure or V2I communications), and mobile devices to bring about transformative changes in highway safety, mobility, and the environmental impacts of the transportation system. Over the past decade, wireless technologies and wireless data communications have fundamentally changed the way we live our lives. Instant access to information and the proliferation of "apps" through which we are able to perform almost limitless functions have dramatically recast the ways in which we work, play, and socialize. The transportation system has not been immune to these changes.
The core technology component of the connected vehicle environment is wireless communications. Further discussion on the appropriate communications technologies and their applications is provided throughout this document. However, in summary, safety-related systems in the connected vehicle environment will likely be based on dedicated short range communications (DSRC). Non-safety applications may be based on different types of wireless technology.

Dedicated short-range communications (DSRC) is an open-source protocol for wireless communication, similar in some respects to Wi-Fi. While Wi-Fi is used mainly for wireless local area networks, DSRC is intended for highly secure, high-speed wireless communication between vehicles and the infrastructure.

The key functional attributes of DSRC are as follows:

- Low latency: The delays involved in opening and closing a connection are very short—on the order of 0.02 seconds.
- Limited interference: DSRC is very robust in the face of radio interference. Also, its short range (~1000 m) limits the chance of interference from distant sources. Additionally, DSRC is protected by the Federal Communications Commission (FCC) for transportation applications. Although purely commercial convenience applications are welcome, transportation safety applications take precedence.

- Strong performance during adverse weather conditions.

In 1999, the FCC dedicated 75 MHz of bandwidth at 5.9 GHz to be used for vehicle safety and other mobility applications[1]. DSRC operates in this band and has been developed for more than a decade by a range of stakeholders including automakers, electronics manufacturers, State transportation departments, and the Federal Government. Most work on DSRC has focused on active safety-crash avoidance using driver alerts based on sophisticated sensing and vehicle communications.

The development of the Connected Vehicle Program envisions leveraging this wireless connectivity to serve the public good in a number of ways:

- Highway crashes can be dramatically reduced when vehicles can sense and communicate the events and hazards around them.
- Mobility can be improved when drivers, transit riders, and freight managers have access to up-to-date, accurate, and comprehensive information on travel conditions and options; and it can be improved when system operators, including roadway agencies, public transportation providers, and port and terminal operators, have actionable information and the tools to affect the performance of the transportation system in real-time.
- Transportation system management and operations can be enhanced when system operators can continuously monitor the status and direct the various assets under their control.
- Environmental impacts of vehicles and travel can be reduced when travelers can make informed decisions about modes and routes, and when vehicles can communicate with the infrastructure to enhance fuel efficiency by avoiding unnecessary stops.

The vision of a national, multimodal transportation system in which there is connectivity between all types of vehicles, the infrastructure, and other mobile devices requires the participation of a broad community of stakeholders. Federal, State, and local transportation agencies; car, truck and bus manufacturers; telecommunications providers, consumer electronics manufacturers, and researchers must come together to design, develop, build, and deploy the technologies, applications, systems, and policy frameworks that will enable the connected vehicle environment. This presents a unique approach and challenge in the history of the nation's transportation system.

The effort involved in drawing together agencies, organizations, and companies from across the public and private sectors to undertake the necessary development and make the required investments is significant. The questions must therefore be asked: Why is this initiative so important, and how will the connected vehicle environment provide benefits? Significant potential benefits are expected to accrue in a number of areas.

Highway Safety – According to the National Highway Traffic Safety Administration (NHTSA) motor vehicle crashes accounted for 32,885 deaths in 2011,[2] and they are the leading cause of death for Americans between the ages of 5 and 44, according to the Centers for Disease Control.[3] The application of connected vehicle technologies is expected to offer some of the most promising, near-term opportunities for crash reductions. Research conducted by the Volpe National Transportation Systems Center for NHTSA found that deployment of connected vehicle systems and the combined use of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications have the potential to address 81 percent of unimpaired driver crashes in all vehicle types (i.e., cars and heavy vehicles).[4] Table 1 presents a breakdown of the potential crash benefits identified in this study based on 2005-2008 General Estimates System crash databases.

Table 1. Estimated Annual Frequency of Crashes that Would Potentially Be Addressed by Connected Vehicle Safety Applications[4]

V2V systems potentially address:

- 4,409,000 police-reported (PR) or 79 percent of all vehicle target crashes annually;
- 4,336,000 PR or 81 percent of all light-vehicle target crashes annually; and
- 267,000 PR or 71 percent of all heavy-truck target crashes annually.

V2I systems potentially address:

- 1,465,000 PR or 26 percent of all-vehicle target crashes annually;
- 1,431,000 PR or 27 percent of all light-vehicle target crashes annually; and

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[1] https://transition.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret9006.html

- 55,000 PR or 15 percent of all heavy-truck target crashes annually.

Combined V2V and V2I systems potentially address:

- 4,503,000 PR or 81 percent of all-vehicle target crashes annually;
- 4,417,000 PR or 83 percent of all light-vehicle target crashes annually; and
- 272,000 PR or 72 percent of all heavy-truck target crashes annually.

Traffic Congestion – the *Urban Mobility Report* prepared by the Texas A&M Transportation Institute[5] indicates that congestion in 439 urban areas during 2010 accounted for 4.8 billion hours of extra time and 1.9 billion gallons of wasted fuel, at a cost of $101 billion annually. The cost to the average commuter was $713 in 2010. While there is no comprehensive analysis of the potential impacts of connected vehicle systems on urban congestion, it can be assumed that the focus of certain applications on reducing travel delays, such as reducing congestion by mitigating traffic incidents, will ensure that benefits will accrue in this area.

Vehicle Emissions – Vehicle internal combustion engines produce emissions that include pollutants and greenhouse gases.[6] The principal pollutants of nitrous oxides, Sulfur oxides, Carbon monoxide, and particulate matter are among the causes of pulmonary diseases and premature death. Data suggest that children are especially vulnerable to air-quality-induced asthma; a leading cause of hospitalization of children according to the Centers for Disease Control and Prevention.[7] Greenhouse gases (GHGs) are not as directly harmful as pollutants, but could contribute significantly to climate change. Chief among the GHGs is carbon dioxide; others are methane and nitrous oxide. Reduction of pollutants and GHGs produced by surface transportation through reductions in fuel consumption, idling, and vehicle miles of travel is a major goal of some connected vehicle applications.

It is important to recognize that the connected vehicle initiative described in this module is almost exclusively focused on a program led by USDOT in partnership with State and local transportation agencies and various vehicle manufacturers. This Federally-led program is driven by the safety, mobility, and environmental needs identified above. The term "connected vehicle," however, has gained a broader usage in the media and within the information technology domain of the automotive industry. In these cases, the use of the term is driven by the information and communications technology industry (comprising entities such as Microsoft, Google, wireless Internet providers, etc.) and the carmakers, and it is focused on bringing 4G/Long Term Environment (LTE)-based Internet and Web-based services into cars to support infotainment and convenience applications and services. This usage of the term "connected vehicles" is not addressed in this module.

Historical Context – Getting to Today's Connected Vehicle Program

The current vision and approach for developing the connected vehicle environment has emerged from more than a decade of research. In the early 2000s, it became clear to those engaged in Intelligent Transportation Systems (ITS) research that the interaction between vehicles and between vehicles and the roadway infrastructure had significant potential to address highway safety and other challenging transportation problems. In 2003, USDOT, in partnership with other entities including the American Association of State Highway and Transportation Officials (AASHTO) and a number of light-duty vehicle manufacturers, initiated the Vehicle Infrastructure Integration (VII) program to conduct research and move ultimately to deployment.

As originally envisioned, the most dramatic safety gains were expected to come from wireless communications between vehicles, but, at the time, it was believed that the maximum safety benefits would require all vehicles (cars, trucks, and buses) to have radio devices installed to provide the necessary V2V communications capabilities.[8] However, it was further recognized that achieving this goal could take between 15 to 20 years for the vehicle fleet to turn over so that a sufficient number of vehicles would be equipped with the V2V technology to begin yielding the projected benefits.

It was therefore believed that an alternative technical approach was needed. In-vehicle devices communicating with roadside infrastructure was seen as a way to achieve safety benefits more quickly, and a VII program based on a nationwide deployment of roadside infrastructure to support communications with vehicles was adopted.

An initial technical concept for the VII program was comprehensively documented in a Concept of Operations published by USDOT in 2006.[9] This early approach called for vehicles manufactured in the United States to be equipped with on-board equipment (OBE): a communications device, a positioning device, a processing platform, and application software. The OBEs would exchange data with road side equipment (RSE), which would be deployed along major highways and at signalized intersections in metropolitan areas throughout the United States. The OBEs would also be required to communicate with other OBEs for V2V data exchange. A nationwide communications network would support the data flow among users and vehicles.

Both V2V and V2I communications within the VII program required a DSRC radio. The FCC, in response to a petition from the transportation community, allocated radio spectrum around 5.9 GHz for transportation safety applications.[10] This action provided a key technical resource for the ultimate deployment of the VII system. Although the spectrum was allocated for safety purposes, it allowed unused bandwidth to be available for other transportation mobility or convenience applications.

At this point in the VII program, a set of key questions on the technical feasibility of the VII concept emerged. These questions sought to validate assumptions that an initial deployment of a V2I-based solution would be feasible and would generate benefits, while V2V capabilities gradually became available through the increasing availability of devices in vehicles. Questions also existed regarding the suitability of DSRC communications for both safety and nonsafety applications. To address these questions, USDOT conducted a proof-of-concept (POC) test between 2008 and 2009 on specially designed test beds in Oakland County, MI, and Palo Alto, CA. The POC tests were limited in scope—comprising fewer than 30 light duty vehicles, using draft DSRC standards, and focusing on partially-developed applications—but they proved that the basic technical concept would work.

In 2008, another important change took place. While DSRC remained the only communications medium considered suitable for active safety applications, other communications media, such as cellular and Wi-Fi, were viewed as appropriate for connected vehicle mobility, environmental, and convenience applications. DSRC is the communications medium of choice for active safety systems because of its designated licensed bandwidth, primarily allocated for vehicle safety applications by the FCC Report and Order. DSRC is also the only short-range wireless technology that provides a fast network acquisition, low latency, high-reliability communications link; the ability to work with vehicles operating at high speeds; the ability to prioritize safety messages; tolerance to multipath transmissions typical of roadway environments; performance that is immune to extreme weather conditions (rain, fog, snow, etc.); and the protection of security and privacy of messages. Between 2010 and 2011, the Federal VII program evolved into the current Connected Vehicle Program.

The Connected Vehicle Program Today

With basic technical feasibility determined, the Connected Vehicle Program has moved to addressing a set of key strategic challenges:[11] To resolve remaining technical, policy, institutional, and funding challenges;

- To conduct testing to determine the actual benefits of applications;
- To determine whether overall benefits are sufficient to warrant implementation, and, if so, how the systems would be implemented; and
- To address issues of public acceptance such as maintaining user privacy and whether systems in vehicles are effective, safe, and easy to use.

A USDOT video on the use of connected vehicle test beds for ongoing research can be found at www.its.dot.gov/library/media/8testbed.htm. A second video on how Connected Vehicles are the future of transportation can be found at http://www.its.dot.gov/library/media/15cv_future.htm.

Broadly, the partners in the Connected Vehicle Program are conducting research on the applications, technologies, policy and institutional issues, and implementation strategies that are described in the following sections. Central among the research that is currently being undertaken is a determination of the potential benefits of the connected vehicle system and the evaluation of driver acceptance of vehicle-based safety systems. This component of the research program provided factual evidence needed to support the NHTSA decision on the deployment of core connected vehicle technologies for light vehicles. In addition research is underway to describe both the technical details and the policy and business issues associated with creating and operating one or more security credential management system (SCMS) entities to support the deployment of V2V safety applications in motor vehicles and other devices.

The Connected Vehicle Safety Pilot Program was a scientific research initiative to make a real-world implementation of connected vehicle safety technologies, applications, and systems using everyday drivers. The effort, which began in 2011 and lasted through the summer of 2012, tested performance, evaluated human factors and usability, observed policies and processes, and collected the empirical data needed to present a more accurate and detailed understanding of the potential safety benefits of these technologies.[12] This empirical data was critical to supporting the 2014 NHTSA decision on vehicle communications for safety.

The Safety Pilot Program included two components: the Safety Pilot Driver Clinics and the Safety Pilot Model Deployment.

Safety Pilot Driver Clinics

Between August 2011 and early 2012, the clinics began to test V2V safety applications with ordinary drivers in controlled roadway situations. The evaluations, conducted by the Crash Avoidance Metrics Partnership, a consortium of light- vehicle manufacturers, explored driver reactions to these safety applications in a variety of light-duty vehicles and under various test conditions. The clinics were conducted at six sites across the United States. The clinics were to help determine whether the new applications create any unnecessary distractions for motorists. Approximately 100 drivers participated in each driver clinic.

Safety Pilot Model Deployment

To continue the data collection under real-world conditions, a test site in Ann Arbor, MI, was selected to host approximately 2,800 vehicles equipped with V2V devices. The goal was to create a highly concentrated connected vehicle communications environment. The devices tested included embedded and aftermarket devices and a simple communications beacon. All of these devices emit a basic safety message 10 times per second, which forms the basic data stream that other in-vehicle devices will use to determine when a potential conflict exists. When this data is further combined with the vehicle's own data, it creates a highly accurate data set that is the foundation for cooperative, crash avoidance safety applications. Using a mix of cars, trucks, and transit vehicles, the Safety Pilot Model Deployment created test data sets for determining the technologies' effectiveness at reducing crashes. These capabilities will also be extended to a limited set of V2I applications. Supported by a diverse team of industry, public agencies, and academia, the Model Deployment ran from the summer of 2012 to the summer of 2013. An online video describing the Safety Pilot Model Deployment can be found at http://safetypilot.umtri.umich.edu/index.php?content=video.

NHTSA Readiness Report

In August of 2014, NHTSA issued a report on the readiness of V2V technologies entitled “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application.” [2] Based on the results of the Safety Pilot, NHTSA made an agency decision to proceed with its regulatory and research authority in the V2V context, essentially issuing a Notice of Proposed Rule Making that NHTSA would begin the process of issuing a rule to mandate the use of V2V technologies in light vehicles. Based on this decision, the USDOT (NHTSA) is proceeding with implementing a formal rule that is expected to be published for comment in 2016.

Connected Vehicle Pilot Deployment Program

In 2014, the USDOT initiated the Connected Vehicle Pilot Program through a series of public meetings and webinars. The USDOT initiated this program to move the overall connected vehicle program forward for a number of reasons:

- There were multiple organizations planning field tests of connected vehicle technologies that were not coordinated.
- The tests that were planned were small scale, as most of the organizations planning these tests were unable to do a large scale test. This meant that the state of the practice and art in connected vehicles would not advance significantly
- Many applications had cross-cutting needs that required a large scale test to enable the development and testing of those applications
- There needed to be opportunities for synergy among technologies, messages and concepts
- In the USDOT’s view, there was a clear opportunity to deploy collections of complimentary connected vehicle applications; those deployments could have a cost-beneficial impact in the short term and potentially transformative impacts in the long term.

As a result, the USDOT kicked off the Connected Vehicle Pilot Program with the vision to conduct research, promote technology transfer and facilitate the nationwide deployment of a Connected Vehicle Environment. The program goals were to accelerate an early deployment of connected vehicle technology, understand and estimate the benefits and impacts associated with deployment, and identify and solve key issues related to the technical and institutional barriers.[3]

In September of 2015, the USDOT selected three sites as Wave 1 participants in the Connected Vehicle Pilot Deployment Program. “The three sites collectively envision a broad spectrum of applications enabled by connected vehicle technologies driven by site-specific needs. The three Wave 1 sites include using connected vehicle technologies to improve safe and efficient truck movement along I-80 in southern Wyoming, exploiting vehicle-to-vehicle (V2V) and intersection communications to improve vehicle flow and pedestrian safety in high-priority corridors in New York City, and deploying multiple safety and mobility applications on and in proximity to reversible freeway lanes in Tampa, Florida. This initial wave of pilot deployments begins with an initial concept development phase lasting 12 months. Phase 1 focuses on the systematic refinement of the core concept of operations, system requirements and a comprehensive deployment plan. Robust and comprehensive deployment planning will facilitate a rapid progression to physical, real-world deployment of these concepts in Phases 2 and 3 of the program. The three pilot sites will work cooperatively amongst themselves, the USDOT, and additional stakeholders and team members

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[2] U.S. Department of Transportation, National Highway Traffic Safety Administration, "Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application" Harding, John, et. al. August 2014. Report Number DOT HS 812 014.

[3] “The Connected Vehicle Pilot Program”, Kate Hartman. http://www.its.dot.gov/presentations/pdf/CV_PilotWorkshop_Session2.pdf

as appropriate in order to maximize program productivity. This cooperative model is expected to benefit both this current effort as well as a second wave of pilot deployment sites to be identified later in the program.”[4]

The Connected Vehicle Pilot Deployment sites are currently in the early stages of planning and design. More information on these sites and the lessons learned is being published on a regular basis by USDOT at http://www.its.dot.gov/pilots/index.htm .

Smart City Challenge
In December of 2015, the USDOT announced the Smart City Challenge. The vision for the Smart City Challenge is to demonstrate and evaluate how an integrated approach to improving surface transportation within a city that included integrating transportation with other city services such as public safety, public services and energy – in essence to create a model deployment for smart cities of the future. The USDOT intends to use the selected city as a model on how to approach the merger of emerging transportation data, technologies and applications within existing city systems that would address transportation challenges.

The Smart City Challenge is an ongoing program. The USDOT grant for this program is intended to be awarded to a mid-sized city. USDOT has budgeted $40m to support the program and additional funding and in-kind contributions have been made and promised by multiple private sector organizations who see the value in using technology in transportation that is merged with other city services. The Smart City Challenge is currently in the procurement phase and 78 cities have applied for the funds. The USDOT is in the process of awarding small grants to 5 cities to help them refine their concept and in June of 2016, the USDOT is expected to announce the award winner. More information on the Smart City Challenge is being posted at https://www.transportation.gov/smartcity .

Ann Arbor Connected Vehicle Test Environment
After the conclusion of the Safety Pilot Model Deployment in Ann Arbor, the University of Michigan and the USDOT agreed to cooperatively maintain and continue operations of the Ann Arbor site to conduct additional research and advance the state of the practice. This ongoing project looks to not only maintain current operations but work with other organizations through the University of Michigan Mobility Transformation Center (MTC) to significantly expand both the infrastructure footprint of the original Safety Pilot but also to significantly increase the number of vehicles that are outfitted with connected vehicle technology. More information on the Ann Arbor Connected Vehicle Test Environment (AACVTE) can be found at http://www.mtc.umich.edu/deployments .

Connected Vehicle Core Systems (CVCS)
The USDOT has continued operations at the test bed originally established as part of the Proof of Concept testing in 2007. This site has undergone multiple technology enhancements and upgrades and while the infrastructure is still in place, the focus of the program is on the back-end systems, test equipment and tools and expertise that are available to the connected vehicle community for their use to support development, testing and operations. The Southeast Michigan test bed is currently the only full implementation of the USDOT Connected Vehicle Reference Implementation Architecture (CVRIA) and includes the Situation Data Clearinghouse (SDC), Situation Data Warehouse (SDW), Security Credential Management System (SCMS) and the Object Registration and Discovery Service (ORDS). Access to the design documents, APIs and other technical information is available through the USDOT Affiliated Test Bed program at http://www.its.dot.gov/testbed/testbed_affiliated.htm . Support for these tools can be obtained through the USDOT Test Bed Support contractor by signing up and making a request at https://cvcs.samanage.com

Connected Vehicle Certification Program
One of the issues facing deployment of Connected Vehicle devices in the field is the need for independent testing and certification to ensure that the devices meet specifications, correctly implement the standards and are interoperable both with other roadside devices and on-board equipment. The USDOT has selected three firms to work collectively to define the scope of the activities, and what test equipment and procedures will be used, with the intent that these three organizations will independently set up facilities to operate the tests. More information on the certification program can be found at http://www.its.dot.gov/connected_vehicle/cv_certproject.htm .

Research Data Exchange (RDE)
The USDOT has created the RDE to meet the needs of the Connected Vehicle research and development community. The RDE is a repository of data from projects across the country, including the Safety Pilot Model Deployment. The RDE database continues to grow as new data sources are identified and added. The RDE is available at https://www.its-rde.net/ .

Open Source Application Development Portal (OSADP)

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[4] http://www.its.dot.gov/pilots/index.htm

The OSADP is a USDOT program designed to enable application developers and users to collaborate, share insights, methods and source code on the USDOT's Dynamic Mobility Applications program. The OSADP is intended as the repository for the DMA program relics, including documentation, source code and sample data sets. The Open Source nature of the OSADP is to encourage users and developers to collaborate on code to move the DMA-sponsored work from prototypes in a research environment to commercializing those applications. The OSADP and more information on the OSADP can be found at http://www.itsforge.net/ .

Vehicle to Infrastructure Deployment Coalition

The Vehicle to Infrastructure Deployment Coalition (V2I DC) began as a concept to create a single point of reference for stakeholders to meet and discuss V2I deployment related issues. To accomplish this concept, the USDOT asked AASHTO, ITE and the Intelligent Transportation Society of America (ITSA) to collaborate on organizing and maintaining the coalition. The V2I DC project team created a vision, mission and set of objectives to guide the coalition. The V2I DC aims to support he nationwide deployment, operations and maintenance of V2I applications through developing long-term cooperation, partnership and interdependence between the infrastructure owners and operators, the automobile industry and a variety of stakeholders[5].

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Connected Vehicle Applications

Historical Context on Connected Vehicle Applications

The definition of key applications of VII data was a significant activity from the very beginning of the initiative. The VII Concept of Operations[13] identified a very comprehensive list of potential applications that would be developed by either the public sector or the automakers (see Table 2).

Table 2. Initial List of Potential VII Applications[13]

Local Use Cases	Network Use Cases

• Infrastructure-based Signalized Intersection Violation Warning
• infrastructure-based Signalized Intersection Turn Conflict Warning
• Vehicle-based Signalized Intersection Violation Warning
• Infrastructure-based Curve Warning
• Highway Rail Intersection-
• Emergency Vehicle Preemption at Traffic Signal
• Emergency Vehicle at Scene Warning
• Transit Vehicle Priority at Traffic Signal
• Stop Sign Violation Warning
• Stop Sign Movement Assistance
• Pedestrian Crossing Information at Designated Intersections
• Approaching Emergency Vehicle Warning
• Post Crash Warning
• Low Parking Structure Warning
• Wrong Way Driver Warning
• Low Bridge Warning
• Emergency Electronic Brake Lights
	• Vehicles as Probes
	    • Traffic information
	    • Weather data
	    • Road surface conditions data
	• Crash Data to Public Service Answering Point
	• Crash Data to Transportation Operations Center
	• Advance Warning Information to Vehicles
	• Electronic Payment
	    • Toll collection
	    • Gas payment
	    • Drive-thru payment
	    • Parking lot payment
	• Public Sector Vehicle Fleet/Mobile Device Asset Management
	• Commercial Vehicle Electronic Clearance
	• Commercial Vehicle Safety Data
	• Commercial Vehicle Advisory
	• Unique Commercial Vehicle Fleet Management
	• Commercial Vehicle Truck Stop Data Transfer
	• Low Bridge Alternate Routing
	• Weigh Station Clearance

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[5] http://www.transportationops.org/V2I/V2I-overview

- Visibility Enhancer
- Cooperative Vehicle-Highway Automation System
- Pre-Crash Sensing
- Free-Flow Tolling
- Cooperative Glare Reduction
- Adaptive Headlight Aiming
- Adaptive Drivetrain Management
- GPS Correction
- In-vehicle Signing
  - Work Zone Warning
  - Highway/Rail Intersection Warning
- Vehicle-to-Vehicle
  - Cooperative Forward Collision Warning
  - Cooperative Adaptive Cruise Control
  - Blind Spot Warning
  - Blind Merge Warning
  - Highway Merge Assistant
  - Cooperative Collision Warning
  - Lane Change Warning
  - Road Condition Warning
  - Road Feature Notification
- Rollover Warning (see curve warning above)
- Instant Messaging
- Driver's Daily Log
- Safety Event Recorder
- Icy Bridge Warning
- Lane Departure-inadvertent
- Emergency Vehicle Initiated Traffic Pattern Change
- Parking Spot Locator
- Speed Limit Assistant
- Cargo Tracking
- Approaching Emergency Vehicle Warning
- Emergency Vehicle Signal Preemption
- SOS Services
- Post Crash Warning
- In-vehicle AMBER Alert
- Safety Recall
- Just-in-Time Repair Notification
- Visibility Enhancer
- Cooperative Vehicle-Highway Automation System
- Cooperative Adaptive Cruise Control
- Road Condition Warning
- Intelligent On-Ramp Metering
- Intelligent Traffic Flow
- Adaptive Headlight Aiming
- Adaptive Drivetrain Management
- Enhanced Route Guidance and Navigation
  - Point of Interest Notification
  - Food Discovery and payment
  - Map Downloads and Updates
  - Location-based shopping/advertising
  - In-route Hotel Reservation
- Traffic Information
  - Work Zone Warning
  - Incident
  - Travel Time
- Off-Board Navigation
- Mainline Screening
- On-Board Safety Data Transfer
- Vehicle Safety Inspection
- Transit Vehicle Data Transfer (gate)
- Transit Vehicle Signal Priority
- Emergency Vehicle Video Relay
- Transit Vehicle Data Transfer (yard)
- Transit Vehicle Refueling
- Download Data to Support Public Transportation
- Access Control
- Data Transfer

	• Diagnostic Data • Repair-Service Record • Vehicle Computer Program Updates • Map Data Updates • Rental Car Processing • Video/Movie downloads • Media Downloads • Internet Audio/video • Locomotive Fuel Monitoring • Locomotive Data Transfer • Border Crossing Management • Stolen Vehicle Tracking

A refined list of applications was identified for evaluation through the POC test.[14] These applications were intended to be developed in prototype form to test basic, technical functionality of the VII system; however, the testing did not demonstrate the effectiveness or end user value of the identified applications. Ultimately, given the limitations regarding the scope of the POC, testing focused on evaluating message exchange between partially-developed applications.[15]

Connected Vehicle Application Development Today

Applications are the most visible part of the connected vehicle environment. The applications allow the connected vehicle systems and technologies to deliver services and benefits to a variety of users. In the current Connected Vehicle Program, the applications are divided into three broad categories:

- Safety applications;
- Mobility applications; and
- Environmental applications.

Significant research, which will include a number of prototyping efforts, is underway in USDOT's Connected Vehicle Program within the ITS Research Program. This is described in the following sections.

Connected vehicle safety applications are designed to increase situational awareness and reduce or eliminate crashes through V2V and V2I data communications. Broadly speaking, these applications will support driver advisories, driver warnings, and potentially, in the longer term, vehicle or infrastructure controls.

Vehicle-to-Vehicle Communications for Safety is the wireless exchange of data between nearby vehicles to achieve safety improvements. By exchanging anonymous, vehicle-based position, speed, and location data, V2V communications enable a vehicle to sense threats and hazards with an awareness of the position of vehicles relative to each other; calculate risk; issue driver advisories or warnings; or other actions to avoid or mitigate crashes. Central to this approach is the V2V communications of a basic safety message (BSM). This message can be derived from vehicle-based sensor data, where the location and speed data is derived from the vehicle's computer and is combined with other data such as latitude, longitude, or angle to produce a richer, more detailed situational awareness of the position of other vehicles.

The vision for V2V safety applications is that each vehicle on the roadway (inclusive of automobiles, trucks, buses, motor coaches, and motorcycles) will eventually be able to communicate with other vehicles, and that this rich set of data and communications will support a new generation of active safety applications and systems.

Since 2002, USDOT has been conducting research with automotive manufacturers to assess the feasibility of developing effective crash avoidance systems that utilize V2V communications. Applications that address the most critical crash scenarios have been demonstrated, including:

- Emergency Brake Light Warning;
- Forward Collision Warning;
- Intersection Movement Assist;

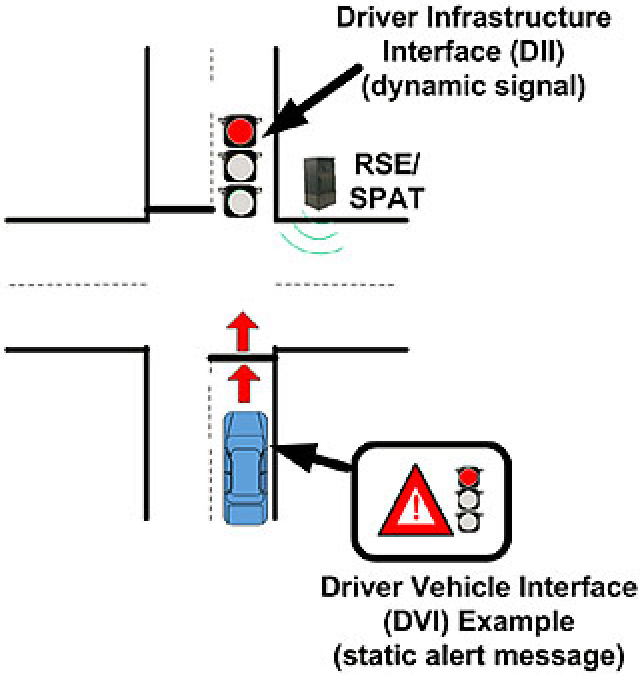
- Blind Spot and Lane Change Warning;
- Do Not Pass Warning; and
- Control Loss Warning.

The development of these applications was used to identify the functional and performance requirements for the underlying technologies, such as positioning and communications. Additional development work is needed to address more complex crash scenarios, such as head-on collision avoidance, intersection collision avoidance, pedestrian crash warning, and extending the capabilities to prevent motorcycle crashes. These capabilities may be achieved by providing V2V communications systems that complement other vehicle-based safety technologies that have been developed by the automotive industry and are becoming available to consumers.

V2I communications for safety is the wireless exchange of critical safety and operational data between vehicles and highway infrastructure, intended primarily to avoid or mitigate motor vehicle crashes. V2I safety applications transform roadway infrastructure equipment by incorporating algorithms that use data exchanged between vehicles and infrastructure elements to perform calculations that recognize high-risk situations in advance, resulting in driver alerts and warnings through specific countermeasures. One particularly important advance is the ability for traffic signal systems to communicate the signal phase and timing (SPAT) information to the vehicle to support the delivery of active safety advisories and warnings to drivers. Early implementation of SPAT-based applications may enable near-term benefits from V2I communications in the form of reduced crashes such as red-light-running collisions. V2I safety applications may provide a graduated spectrum of safety solutions from in-vehicle information and advisories to in-vehicle driver warnings of imminent crash scenarios. The USDOT Connected Vehicle Research Program is examining a number of potential V2I safety applications.[16]

The ***Red Light Warning*** application uses SPAT, geometric intersection description (GID), and global positioning system (GPS) correction information broadcast between an RSE and OBE to determine if the vehicle is in danger of violating a red light. Traffic signal logic may be used to determine if extension of an all-red phase is warranted to prevent crashes. The concept is illustrated in Figure 1.

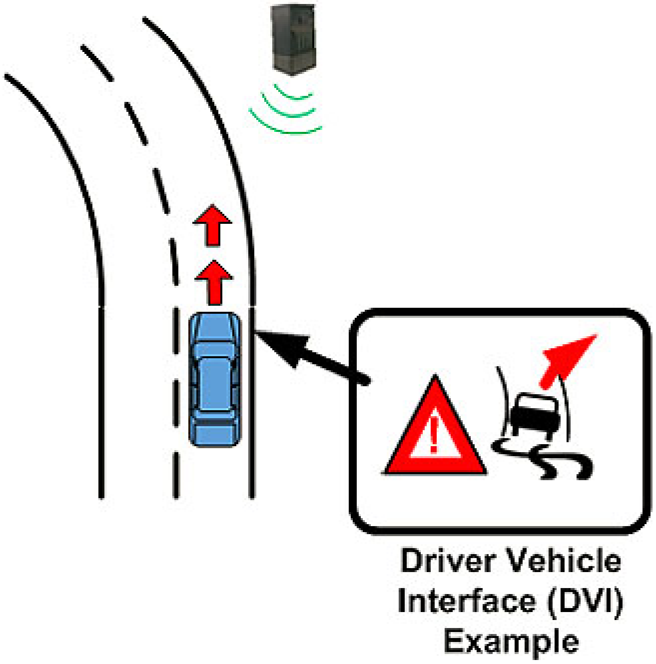
Figure 1. Red Light Warning Concept



(Extended Text Description: In this diagram, a car is depicted approaching a four-way intersection. There are two red arrows one on top of the other, pointing to the opposite side of the intersection. On that opposite side, there is a traffic light showing a red light. This traffic light is labeled "Driver Infrastructure Interface (DII) (dynamic signal)." To the right of the traffic light, just off the intersection, there is a picture of a gray box labeled RSE/SPAT. To the right of the vehicle, there is a rectangular text box pointing to the vehicle. Inside the bubble is red and white triangle with a red exclamation point inside. To the right of the triangle is a traffic light with a red. The text box is labeled "Driver Vehicle Interface (DVI) Example (static alert message).")
Source: USDOT.

The ***Curve Speed Warning*** application uses geometric and weather information in an in-vehicle device to determine the appropriate speed for that particular vehicle. Warnings can be tailored to the specific vehicle performance characteristics. Figure 2 illustrates the concept.

Figure 2. Curve Speed Warning Concept

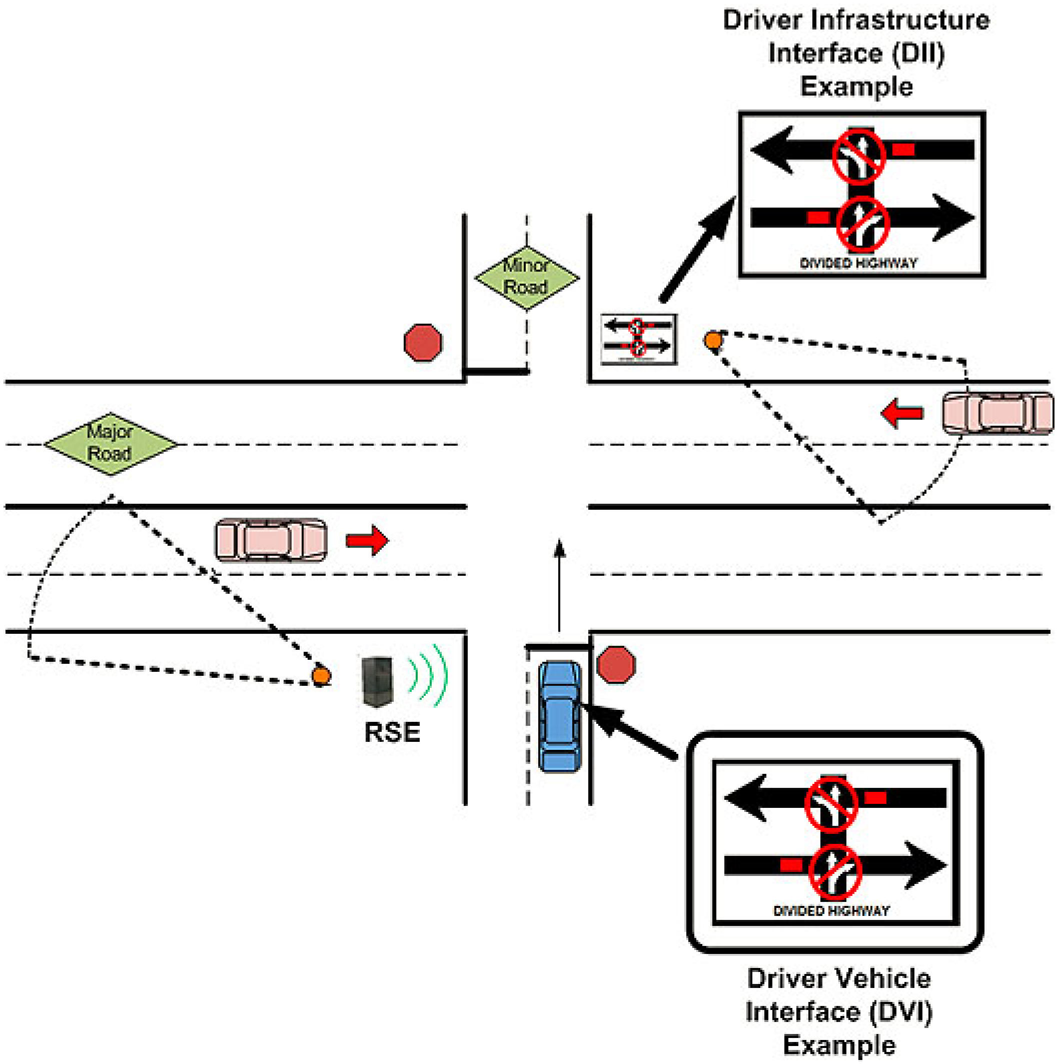


(Extended Text Description: In this diagram, a car is depicted driving on a curved road. The two red arrows pointing up in front of the vehicle indicate that the car is approaching the curve. To the right of the curve, there is a dark rectangular box, with three blue arcs being emitted from the box. A rectangular text box is on the right side of the vehicle, pointing to the car. Inside the text box is a red and white triangular warning sign with a red exclamation point in the center. The right of this sign is an icon showing a vehicle approaching a bend in the road and swerving tire tracks behind it. A red arrow goes from the car off the road, away from the curve. Underneath is says "Driver Vehicle Interface (DVI) Example.")

Source: USDOT.

The ***Stop Sign Gap Assist*** application uses roadside sensors to detect oncoming traffic and an RSE to broadcast traffic status to an in-vehicle device that will determine if there is any danger to a vehicle on the minor leg. The concept is illustrated in Figure 3.

Figure 3. Stop Sign Gap Assist Concept

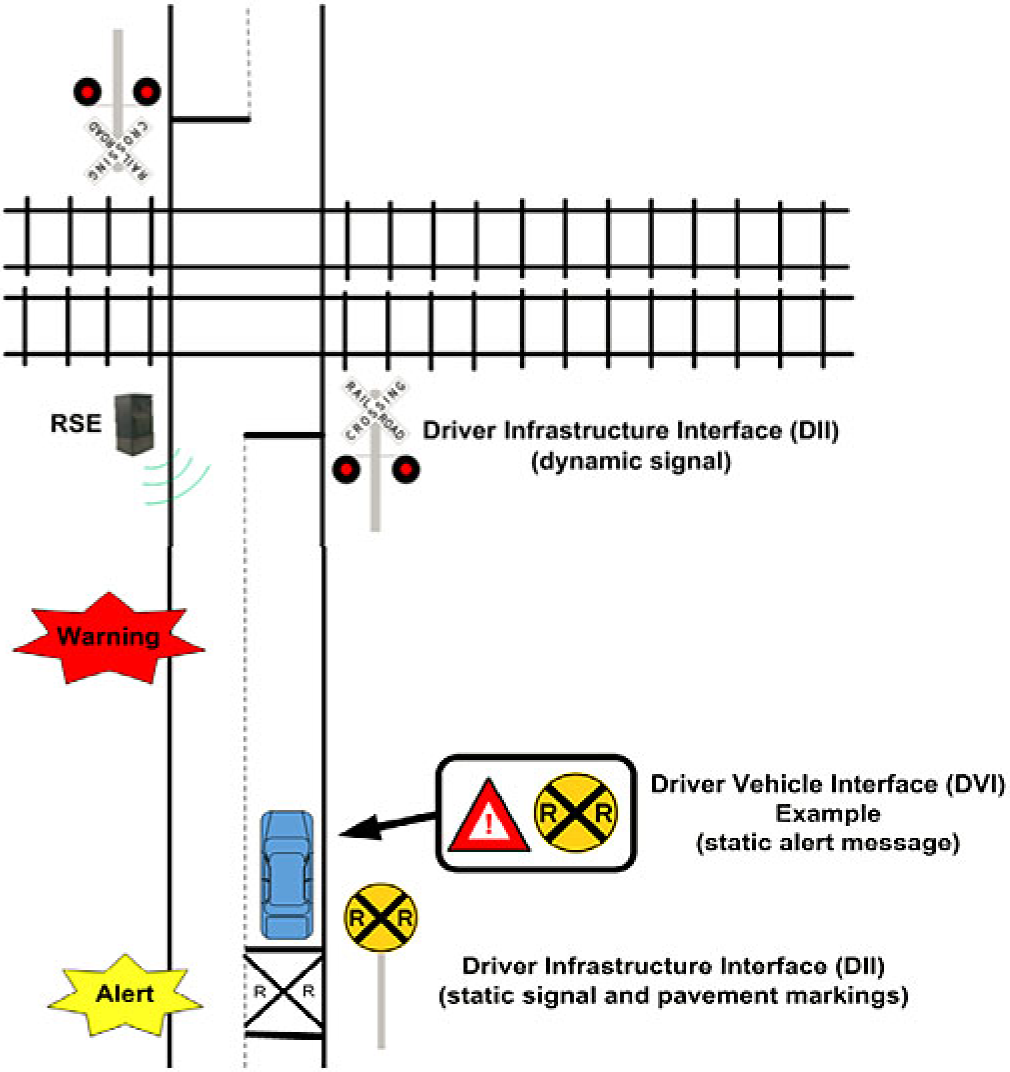


(Extended Text Description: In this diagram, a car is depicted waiting at the lower intersection in the right lane on a two-lane cross street (labeled as a Minor Road) and a four-lane main roadway (labeled as a Major Road). A black arrow points ahead to show the car will travel forward across the intersection. There is a pull out graphic box with an arrow pointing at the car. The pullout box is labeled: Driver Vehicle Interface (DVI) Example, with two black horizontal arrows pointing in opposite directions and a black line intersecting the arrow perpendicularly at the center. A red rectangle is in the black arrow to the left of the intersecting line on the lower arrow and another red rectangle in the upper black arrow to the right of the intersecting line. The words "Divided Highway" appear below the lower arrow at the point of the intersecting line. An icon of a white arrow dividing to point ahead and curving to the right appears in the lower intersection point, with a red circle with a diagonal line through it. An icon of a white arrow dividing to point ahead and curving to the left appears in the upper intersection point with a red circle with a diagonal line through it. To the right of the car at the intersection is an icon of a stop sign, and to the left is an icon of a black rectangle labeled RSE with three curved blue lines emanating from it. To the left of the RSE, a yellow dot has two diagonal dotted lines coming from it. The upper dotted line goes across the lower two lanes of traffic on the Major Roadway to about the median point. The lower dotted line goes to the lower edge of the closest lane of traffic. A slightly curved dotted line connects the ends of these two diagonal dotted lines. Another car is depicted as traveling in the inner lane on the Major Roadway with a red arrow pointing to the right. In the opposing lanes of traffic and on the right side of the intersection, another car is depicted, traveling in the outer lane, with a red arrow pointing to the left. Across from the car waiting at the intersection, the opposite side of the intersection has a stop sign icon to the right, and a small version of the Driver Vehicle Interface pullout box described above. To the right of that box, there is a yellow dot with two diagonal dotted lines coming from it. The lower dotted line cross the two nearest lanes of traffic, ending near the median point. The upper dotted line ends near the edge of the upper lane of traffic. A curved dotted line connects the two ends of the diagonal dotted lines (and the curved line crosses over the icon of the car traveling in the outer lane. There is a black arrow pointing from the small version of the DVI box to a larger version of the box, labeled Driver Infrastructure Interface (DII) Example.)

Source: USDOT.

The ***Railroad Crossing Violation Warning*** application uses roadside equipment to provide a connection from existing train detection equipment via wireless communications to an in-vehicle device to determine the probability of a vehicle conflict with an approaching train. The in-vehicle device issues an alert or warning to the driver. The concept is illustrated in Figure 4.

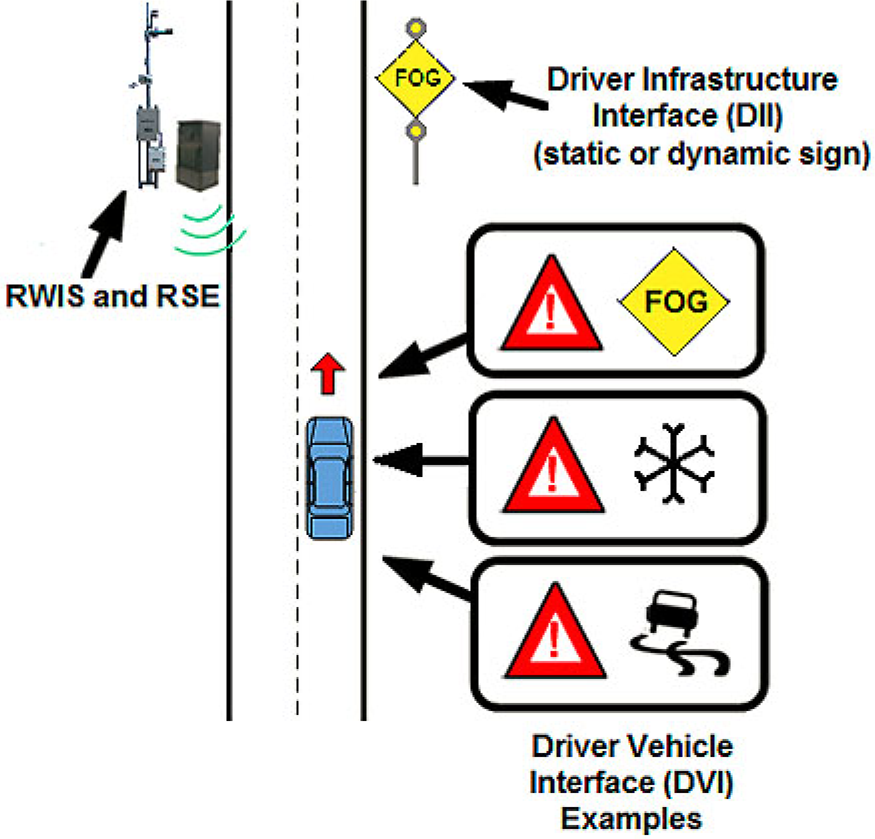
Figure 4. Railroad Crossing Violation Warning Concept



(Extended Text Description: This diagram depicts a railroad intersection with a two-lane road. A railroad is depicted running horizontally across the upper portion of the diagram. The two-lane road intersects through the center of the railroad. At the top of the diagram, the diagram depicts a railroad crossing sign, the lane divide and the horizontal stop line. On the lower part of the diagram, under the railroad and the intersection, there is a black rectangle labeled RSE to the lower left of the intersection. On the lower right of the intersection is a railroad crossing sign icon and the words "Driver Infrastructure Interface (DII) (dynamic signal). The road has a dotted line through the center and a stop line. There is a red starburst labeled Warning on the left side of the road. There is a car depicted in the right lane, positioning well before the black stop line, just after the RXR pavement marking on the roadway. To the left of the RXR pavement marking, there is a yellow starburst labeled Alert. There is a black arrow pointing to the car from a pull out box. Inside the box is a Caution symbol (red triangle with exclamation point at the center) and a RXR symbol (a yellow circle with a black X and two Rs on each side). To the side of the box are the words "Driver Vehicle Interface (DVI) Example (static alert message). To the right of the RXR pavement marking on the right lane is a RXR road sign and the words "Driver Infrastructure Interface (DII) (static signal and pavement markings).)
Source: USDOT.

The ***Spot Weather Impact Warning*** application uses a connection from a traffic management center (TMC) and other weather data collection sites to an RSE to broadcast weather events and locations to vehicles in real-time. An in-vehicle device then issues an alert or warning to driver. Figure 5 illustrates the concept.

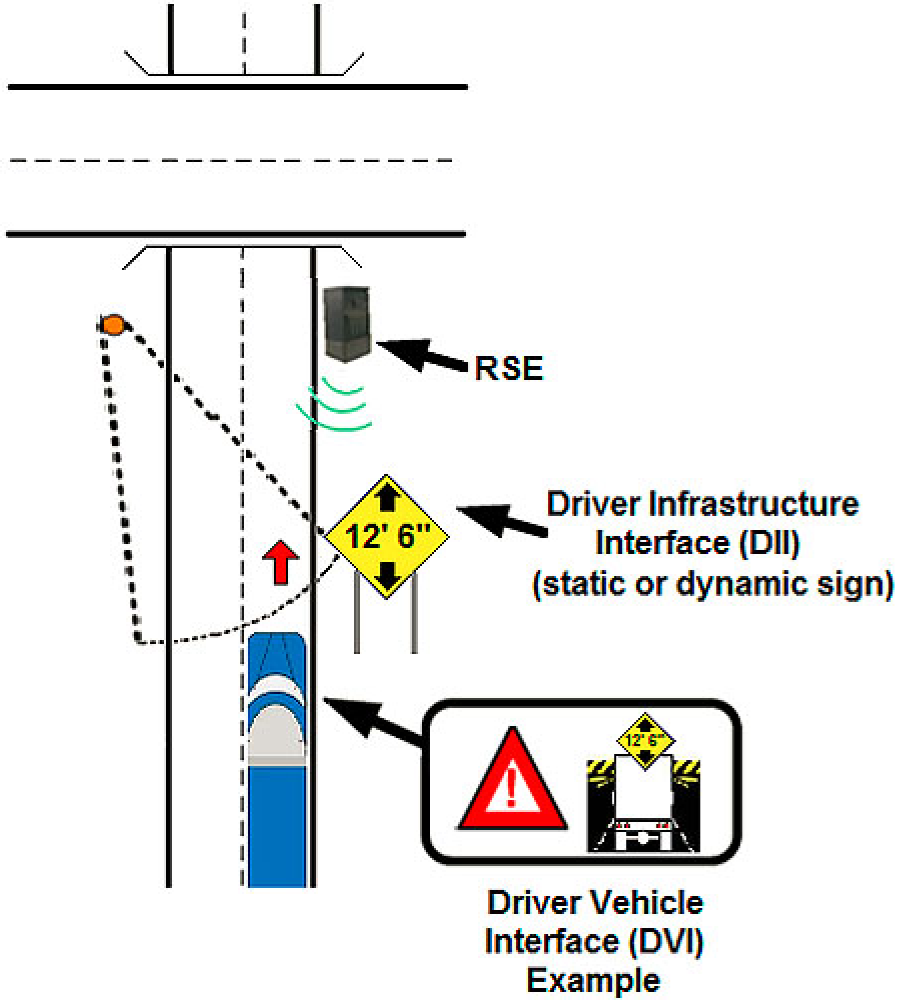
Figure 5. Spot Weather Impact Warning Concept



(Extended Text Description: This is a diagram of a car driving up a straight road. Ahead and to the left of the vehicle are pictures of anywise and RSE systems next to one another. The RWIS is represented by an image of a pole with many devices installed along the length of the pole. The RSE system is represented by a gray box with blue arcs coming from the bottom of the picture. Ahead of the vehicle to the right, there is a diamond yellow street sign. With a warning light above and below the diamond, the sign reads "FOG." This sign is labeled "Driver Infrastructure Interface (DII) (static or dynamic sign)". Pointing to the vehicle are three separate text boxes containing Driver Vehicle Interface (DVI) examples. Each of these boxes contains a red and white triangular warning sign with an exclamation point in the middle. Next to each warning sign is a different image per box. The top image is of a yellow diamond road sign that says "Fog." To the right of the warning image in the second box is a snowflake. The right of the warning sign in the third text box is a picture of a car with swerving tire marks behind it.)
Source: USDOT.

The ***Oversize Vehicle Warning*** application uses a connection from an RSE to infrastructure-based detectors to broadcast bridge and tunnel dimensions and the dimensions of a detected vehicle if the vehicle is oversize. The application either issues an alert to the driver to take an alternate route or provides a warning to stop. This concept is illustrated in Figure 6.

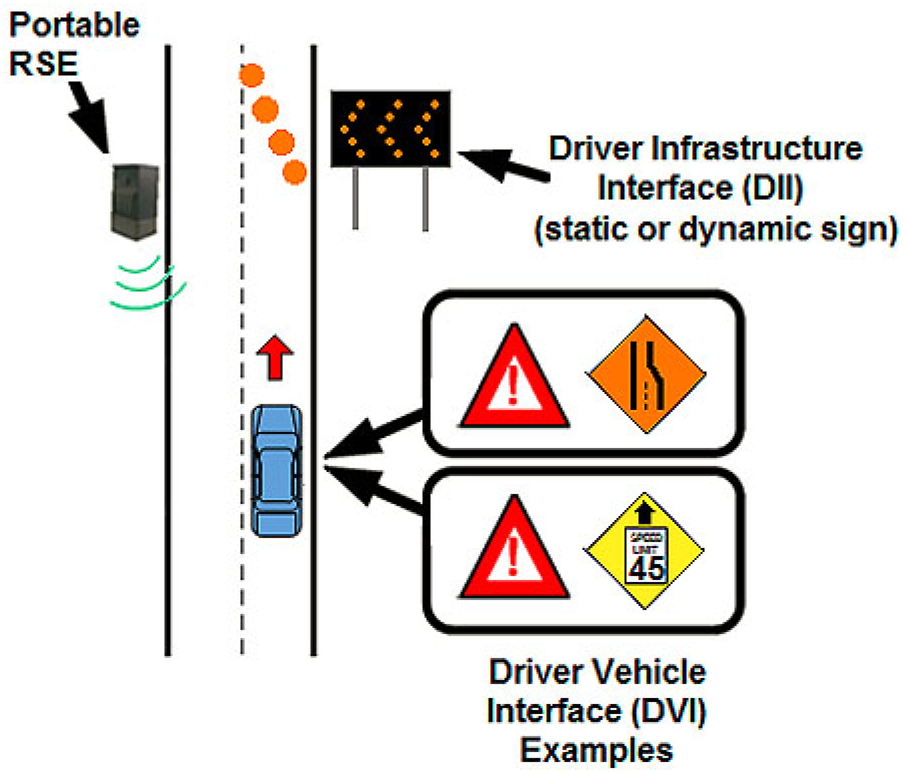
Figure 6. Oversize Vehicle Warning Concept



(Extended Text Description: In this diagram, a semi-trailer is depicted in the right lane of a two-lane roadway heading toward an intersection with another two-lane roadway. There is a box with a Caution symbol (red triangle with exclamation point at the center) and oversize vehicle warning symbol (the rear of a semi-trailer on a black road with a yellow diamond shape with 12'6" and arrows pointing up and down). The box is labeled Driver Vehicle Interface (DVI) Example and points to the depiction of the semi-trailer on the road. There is a yellow diamond-shaped sign marked 12'6" with arrows pointing up and down. The words Driver Infrastructure Interface (DII) (static or dynamic sign) is at the left with an arrow that points to the yellow sign. At the left side of the lower intersection is a black rectangle labeled RSE with three curved lines emanating from it toward the semi-trailer. On the right side of the intersection is an orange dot with two diagonal dotted lines: the upper dotted line extends to the yellow height sign on the opposite of the road; the lower dotted line extends to the edge of the outer left lane. There is a curved dotted line that connects the ends of both diagonal dotted lines.)
Source: USDOT.

The ***Reduced Speed or Work Zone Warning*** application uses an RSE connection to broadcast speed limit information and work zone information to an in-vehicle device that issues an alert to the driver to reduce speed, change lanes, or prepare to stop. The concept is illustrated in Figure 7.

Figure 7. Reduced Speed or Work Zone Warning Concept

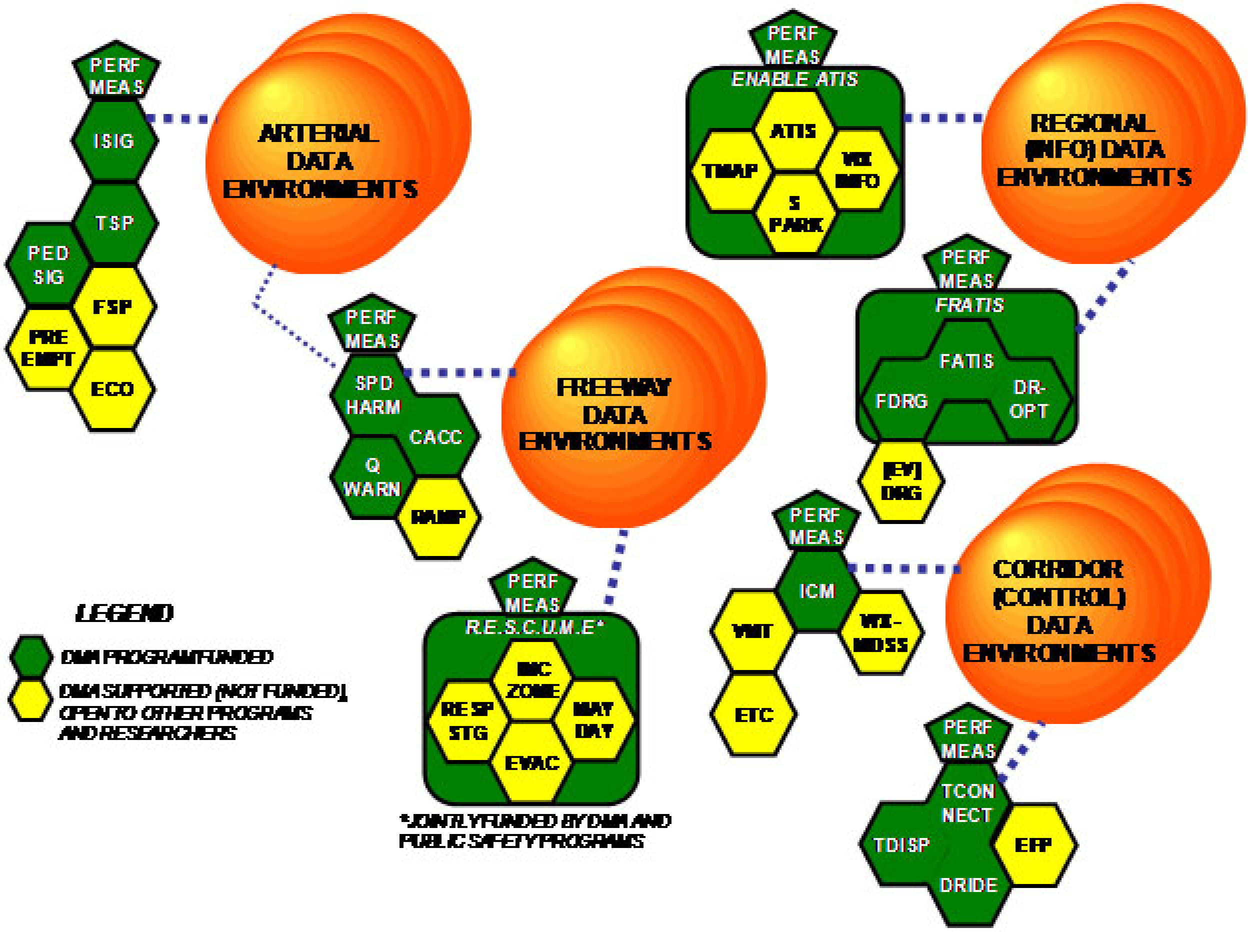


(Extended Text Description: This diagram shows a vehicle traveling up a straight road. Ahead of the vehicle are four orange circles arranged diagonally to close the lane and merge traffic. To the right is a Driver Infrastructure Interface (DII) (static or dynamic sign). In this case, the sign is black and orange with three arrow heads pointing left to communicate a need to change lanes. Ahead of the vehicle on the left is a Portable RSE, indicated by a gray box with blue arcs coming from the bottom. Pointing to the vehicle are two text boxes with examples of a Driver Vehicle Interface (DVI). Both text boxes contain a red and white warning sign with an exclamation point. To the right of the warning sign in the top box, there is an orange diamond sign with the lane-ending/merge symbol. To the right of the warning sign in the lower box, there is a yellow diamond sign with a white rectangular sign that says "Speed Limit 45".)
Source: USDOT.

Connected vehicle mobility applications will provide an interconnected, data-rich travel environment. In the connected vehicle environment real-time data will be captured from equipment located on board cars, trucks, and buses and from the network of connected vehicle field infrastructure. These data will be transmitted wirelessly and used by transportation managers in a wide range of applications to manage the transportation system for optimum performance.

USDOT's Dynamic Mobility Applications (DMA) program is exploring a number of these applications,[17] specifically focusing on those that will improve mobility by reducing delays and congestion. Figure 8 illustrates USDOT's bundling of DMAs.

Figure 8. Bundling of USDOT Dynamic Mobility Applications



(Extended Text Description: Relevant author information for this diagram: This is a diagram illustrating how the USDOT has bundled the dynamic mobility applications for various transportation system environments. The five major environments identified by the USDOT are represented by three serially overlapping orange circles. These environments include: Arterial Data Environments, Freeway Data Environments, Regional (INFO) Data Environments, and Corridor (Control) Data Environments. Connected to each of these environments by dotted blue lines are programs that fall into the environment category. Programs are shown as hexagons in either green or yellow. Green indicates the program is funded. Yellow indicates the program is supported but not funded.)
Source: www.its.dot.gov/press/2011/mobility_app.htm [last accessed January 15, 2013].
Key application bundles are described below:

Enable Advanced Traveler Information Systems (EnableATIS) is intended to provide a desired end state for a traveler information network, with a focus on multimodal integration, facilitated sharing of data, end-to-end trip perspectives, and use of analytics and logic to generate predictive information specific to users.
EnableATIS envisions a future framework that is enabled with a pool of real-time data from connected vehicles, public and private systems, and user-generated content. EnableATIS has the potential to transform how traveler information is gathered and shared and how agencies are able to use information to better manage and balance the transportation networks. It also has the potential to transform the way users obtain information about every detail of their trip. New forms of data may provide the potential for highly-personalized, intuitive, and predictive traveler information services well beyond what is experienced today.

This bundle does not define specific future applications. USDOT recognizes that there are existing businesses providing traveler information data and services. Therefore, a laissez-faire approach where build-out and enhancement of traveler information services occurs over time but with only limited influence from USDOT may be appropriate. Alternatively, the desired end-state may be a robust, multimodal, multisource traveler information environment that leverages new data sources and generates transformative uses of that information. These uses may include applications that benefit travelers as well as those that support system operations and management by agencies. This approach may require a more proactive development approach including a stronger role for USDOT.

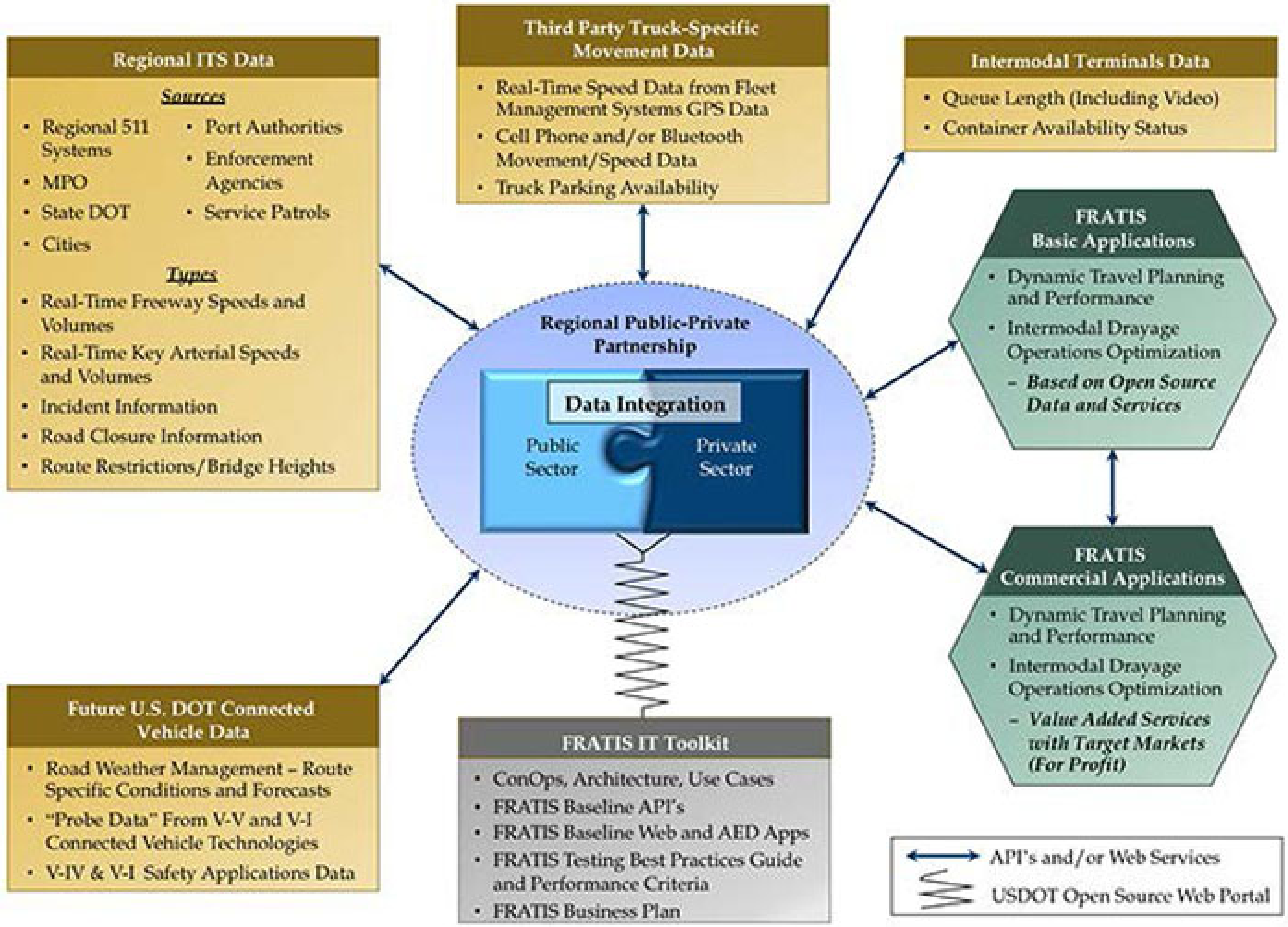
Freight Advanced Traveler Information System (FRATIS) is a bundle of applications that provide freight-specific dynamic travel planning and performance information, or that optimize drayage operations so that load movements are coordinated between freight facilities to reduce empty-load trips. Currently, freight routing, scheduling, and dispatch decisions may be made in an ad-hoc fashion, with inadequate data to make fully informed decisions. This is particularly the case for small to medium-sized firms that may not be able to invest in information technologies and systems at the level of larger firms. FRATIS seeks to integrate existing data sources in a manner oriented toward freight's distinct operational characteristics and by leveraging connected vehicle data. A video describing freight-specific needs can be found at http://vimeo.com/59703030. Further information on this subject can also be found in Module 6 "Freight, Intermodal, and Commercial Vehicle Operations."

Two separate applications comprise FRATIS in the USDOT program:

- **Freight Specific Dynamic Travel Planning and Performance.** This application seeks to include all of the traveler information, dynamic routing, and performance monitoring elements that freight users need. It is expected that this application will leverage existing data in the public domain, as well as emerging private sector applications, to provide benefits to both sectors. Data may include real-time freeway and key arterial speeds and volumes, incident information, road closure information, route restrictions, bridge heights, truck parking availability, weather data, and real-time speed data from fleet management systems.
- **Drayage Optimization** This application seeks to combine container load matching and freight information exchange systems to fully optimize drayage operations, thereby minimizing bobtails (i.e., a tractor-trailer truck running without a trailer) and wasted miles. This application is also intended to spread out truck arrivals at intermodal terminals throughout the day.

Figure 9 illustrates the FRATIS high-level design concept.

Figure 9. Proposed High-Level System Concept for FRATIS



(*Extended Text Description:* This figure illustrates the proposed, high-level system concept for the FRATIS application bundle. The image is of a circle in the middle of a number of boxes surrounding the circle. The circle represents the data integration between public and private sectors, ideally as part of a regional public-private partnership. This source of integrated data will feed a number of uses which are represented by the boxes. They include: Regional ITS Data, Third-Party Truck Specific Movement Data, Intermodal Terminal Data, the FRATIS Basic Applications, the FRATIS Commercial Applications, and Future U.S. DOT Connected Vehicle Data needs. The integrated data source or sources feed these boxes through application program interfaces or APIs. This is represented by bi-directional arrows between the circle and the boxes. The bi-directional nature means that the organizations and applications that request and use the data are also sending data back to the circle or the integrated source of data. At the bottom of this graphic is an additional link from the integrated data source to an IT Toolkit which contains all of the FRATIS documentation that has formed the basis of this design. These documents include a Concept of Operations, Architecture, Use Cases, APIs, Web and other applications, testing best practices guide, performance criteria, and business plan. At this time, these documents, or tools, are mostly still under development but will be available with the release of the FRATIS application bundle.)

Source: www.its.dot.gov/dma/dma_development.htm [last accessed January 15, 2013].

It is important to note that additional research related to commercial motor vehicles is being undertaken within the Smart Roadside Initiative (SRI).[18] The current commercial vehicle environment consists of numerous Federal, State, regional, and private-sector programs that use a combination of manual, semi-automatic, and advanced technologies. The effectiveness of these programs can be greatly improved by the Smart Roadside concept. The SRI envisions commercial vehicles, motor carriers, enforcement resources, highway facilities, intermodal facilities, toll facilities, and other nodes on the transportation system collecting data for their own purposes and sharing the data seamlessly with the relevant parties. This sharing would improve motor carrier safety, security, operational efficiency, and freight mobility, and to provide for enhanced protection and maintenance of the infrastructure. The SRI can be viewed as a mode-specific instantiation of V2I communications, and so aspects of the SRI vision are being advanced through USDOT's Connected Vehicle Program, with a primary focus on improving the effectiveness of traditional enforcement activities conducted at weigh/inspection stations by moving compliance checks to the roadside. In doing so, enforcement is better able to focus limited resources on vehicles requiring more extensive measurements and inspection.

SRI will develop new capabilities to exchange information among roadside equipment, back office systems, and commercial motor vehicles that are moving at mainline speed. These capabilities will be developed in the following four focus areas:

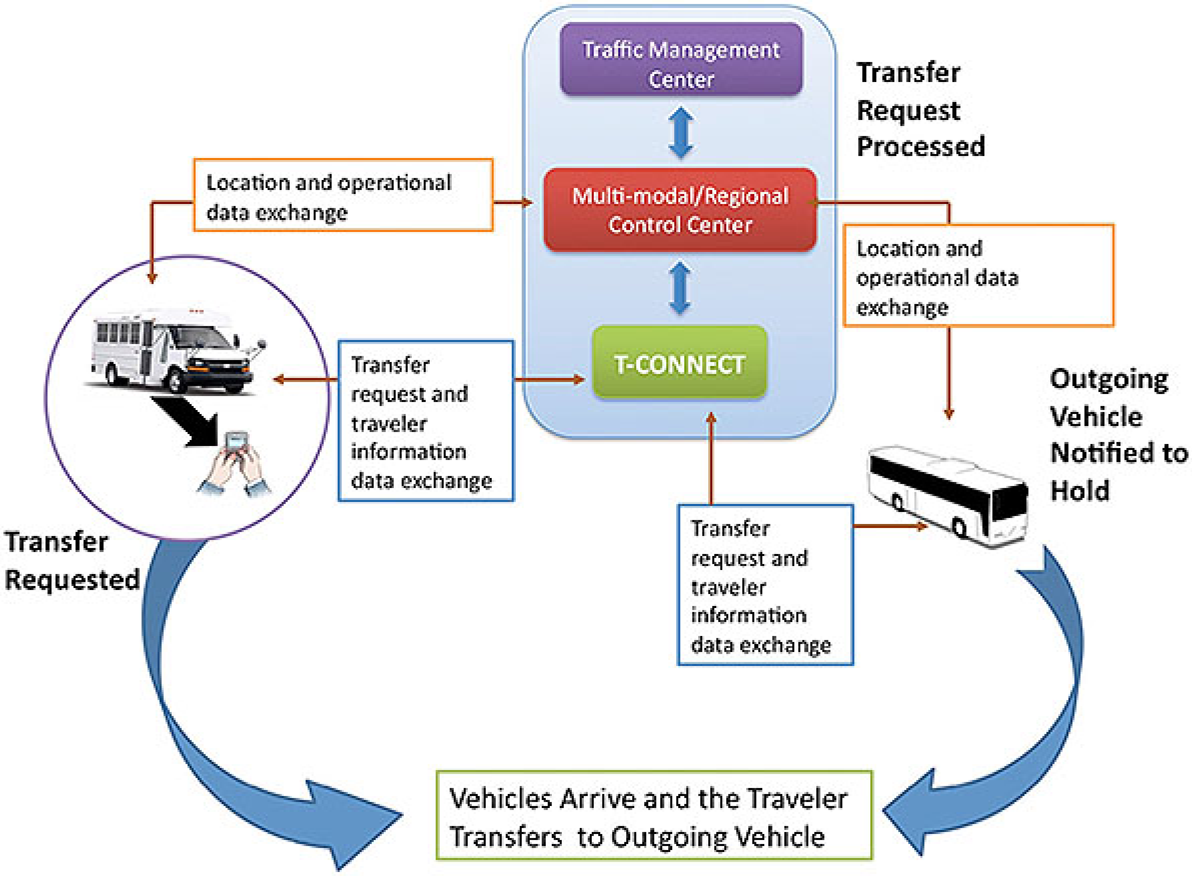
- **Universal Commercial Motor Vehicle Identification** provides the capability to identify each vehicle on the road and electronically access credentials and safety information in government and industry databases related to the vehicle, the driver, and the motor carrier. This capability would enable a variety of other capabilities, including the following:
  - **Electronic Screening/Virtual Weigh Station** provides functionality for automatically collecting data on commercial motor vehicle weight, size, and other information to facilitate efficient, high-throughput electronic screening.
  - **Wireless Roadside Inspections** are an enhanced form of electronic screening, which could include functionality to obtain and evaluate carrier, vehicle, and driver information automatically and then issue inspection reports simultaneously to roadside enforcement and motor carriers on vehicles traveling at slow and mainline speeds.
  - **Truck Parking Programs** provide drivers and carriers with a convenient, near real-time approach for accessing information about parking locations, available parking spaces, and other amenities during trips. Work in this area is being conducted through FMCSA's Smart Park research project being conducted in Tennessee, and FHWA's truck parking detection and notification system projects under development and supported through the SAFETEA-LU Section 1305 Program. There are more than $20 million in funds supporting the development of six large projects on I-95 (from Connecticut to North Carolina), I-5 in California; I-81 (in Pennsylvania from Harrisburg to the Maryland state line); I-94 in Michigan; I-94 in Minnesota; and I-94 in Wisconsin.

Upcoming work will focus on an SRI prototype system design and development.

Integrated Dynamic Transit Operations (IDTO) is the bundle of applications that transform transit mobility, operations, and services through the availability of new data sources and communications. USDOT defines the IDTO bundle as the following three applications:

- **T-CONNECT** is intended to improve rider satisfaction and reduce expected trip time for multimodal travelers by increasing the probability of automatic intermodal or intramodal connections. T-CONNECT will protect transfers between both transit (e.g., bus, subway, and commuter rail) and nontransit (e.g., shared ride) modes, and it will facilitate coordination between multiple agencies to accomplish the tasks. Figure 10 provides an overview of the concept.

Figure 10. T-CONNECT Concept Overview



(Extended Text Description: This diagram provides an overview of the T-Connect Concept. From the left, an image of a transit van notes the request made by a passenger for a transfer to a separate, outgoing vehicle. The data needed by the outgoing vehicle from the van includes location and operational status. The image shows these data points being sent with the transfer request to an application that routes the request to a multi-modal regional control center which is integrated with a traffic management center. From the control center, the image shows the request being processed and notification sent to the outgoing vehicle with the necessary data on when the van will arrive. If later than anticipated, the outgoing vehicle also receives a notice to hold until the arrival of the van; at which point, the passenger transfers and the outgoing vehicle is allowed to proceed.)
Source: www.its.dot.gov/dma/dma_development.htm [last accessed January 15, 2013].

- **T-DISP** seeks to expand transportation options by leveraging available services from multiple modes of transportation. Travelers would be able to request a trip via a handheld mobile device, phone, or personal computer and have itineraries containing multiple transportation services (including public transportation modes, private transportation services, shared-ride, walking, and biking) sent to them. T-DISP builds on existing technology systems such as computer-aided dispatch/automatic vehicle location (CAD/AVL) systems and automated scheduling software as well as expanded business and organizational structures that aim to better coordinate transportation services in a region. A physical or virtual central system such as a travel management coordination center (TMCC) would dynamically schedule and dispatch trips.
- **D-RIDE** is an approach to carpooling in which drivers and riders arrange trips within a relatively short time in advance of departure. Through the D-RIDE application, a person could arrange daily transportation to reach a destination, including those that are not serviced by transit. The D-RIDE system would usually be used on a one-time, trip-by-trip basis, and it would provide drivers and riders with the flexibility of making real-time transportation decisions. The two main goals of the D-RIDE application are to increase the use of nontransit ride-sharing options including carpooling and vanpooling, and to improve the accuracy of vehicle capacity detection for occupancy enforcement and revenue collection on managed lanes.

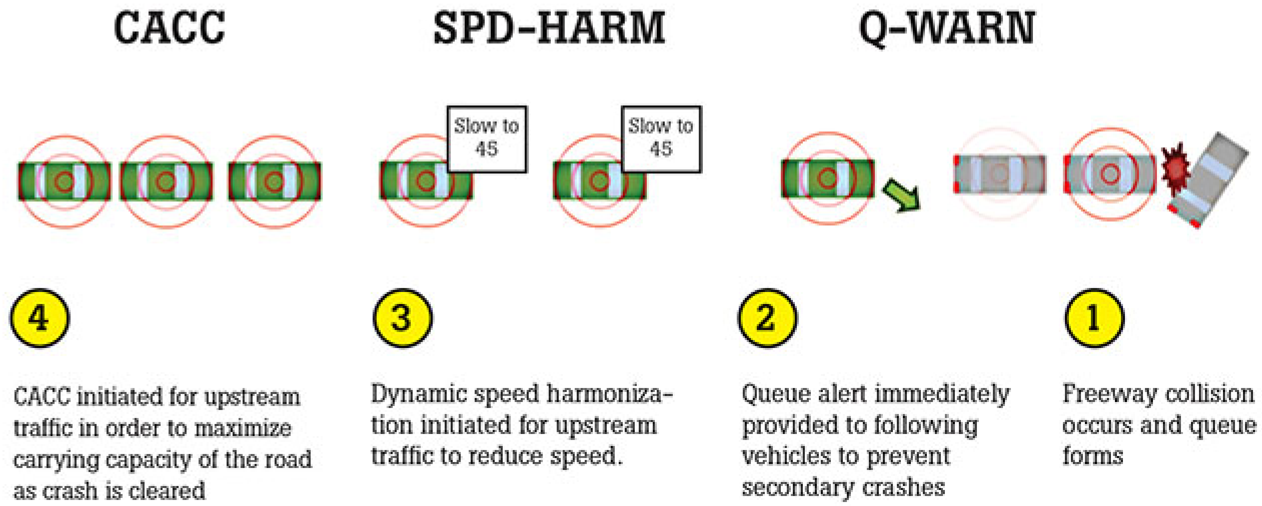
The ***Intelligent Network Flow Optimization (INFLO)*** bundle consists of applications related to queue warning, speed harmonization, and cooperative adaptive cruise control. It aims to maximize roadway throughput, reduce crashes, and reduce fuel consumption through the use of data drawn from connected vehicles, mobile devices, and the infrastructure.

Current practices for queue detection and warning and speed harmonization are fundamentally limited by their exclusive reliance upon infrastructure-based detection and warning. A connected vehicle system is both vehicle and infrastructure-based and has the potential to provide a broader and more dynamic set of data and data exchange. These three applications comprise INFLO:

- **Queue Warning (Q-WARN)** will warn a vehicle operator about an impending queue backup in time to brake safely, change lanes, or modify the route such that secondary collisions can be minimized or eliminated. Q-WARN is distinct from collision warning, which pertains to events or conditions that require immediate or emergency actions. The Q-WARN application aims to minimize the occurrence and impact of traffic queues by using V2I and V2V communications so that vehicles can automatically broadcast their queue status information (e.g., rapid deceleration, disabled status, lane location) to nearby upstream vehicles and to infrastructure-based central entities (such as a TMC).
- **Dynamic Speed Harmonization (SPD-HARM)** is intended to dynamically adjust and coordinate maximum appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions in order to maximize traffic throughput and reduce crashes. A dynamic SPD-HARM system will be successful at managing upstream traffic flow by being able to reliably detect the location, type, and intensity of downstream congestion (or other relevant) conditions; formulate an appropriate response plan (i.e., vehicle speed and/or lane recommendations) for approaching vehicles; and disseminate such information to upstream vehicles readily. The SPD-HARM application will use V2V and V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles.
- **Cooperative Adaptive Cruise Control (CACC)** will dynamically and automatically coordinate cruise control speeds among platooning vehicles in order to significantly increase traffic throughput. By tightly coordinating in-platoon vehicle movements, headways among vehicles can be significantly reduced, thus smoothing traffic flow and improving traffic flow stability. The CACC concept represents an evolutionary advancement of conventional cruise control (CCC) systems and adaptive cruise control (ACC) systems by utilizing V2V and V2I communication to automatically synchronize the movements of many vehicles within a platoon. This should be considered a long term research initiative until a better understanding of the technical feasibility, social acceptance, and product liability issues are completed.

Figure 11 illustrates how all three applications used in conjunction can help minimize the impact of a freeway incident on traffic flow.

Figure 11. Combined Q-WARN/SPD-HARM/CACC Illustration



(Extended Text Description: This diagram illustrates the combined Q-WARN/SPD-HARM/CACC process. This is a four-part process. The first part involves the occurrence of a highway collision, which results in queue formation. In the second part or phase, a queue warning message is immediately provided to following vehicles in order to prevent secondary crashes. In the third part, dynamic speed harmonization is initiated for upstream traffic to reduce their speed. In the fourth phase, CACC is initiated for upstream traffic in order to maximize carrying capacity of the road as the crash is cleared.)
Source: USDOT.

The ***Multimodal Intelligent Traffic Signal Systems (MMITSS)*** application bundle is the next generation of traffic signal systems that will provide a comprehensive framework to serve all modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets, pedestrians, and bicyclists. The vision for MMITSS is to provide overarching system optimization that accommodates transit and freight signal priority, preemption for emergency vehicles, and pedestrian movements while maximizing overall arterial network performance.
The fundamental logic and operations of the traffic signal controller have not changed in the past 50 years. Most systems today depend on loop detectors or video-based systems at fixed locations to call or extend signal control phases. These detection systems provide basic information such as vehicle count, occupancy, or presence/passage information. Such systems limit the use of advanced logic that could potentially be built into modern signal controllers. Connected vehicle technologies could potentially provide real-time information on vehicle class (e.g., passenger, transit, emergency, or commercial), position, speed, and acceleration on each approach and provide coverage for other users, including pedestrians and cyclists.

The MMITSS applications bundle incorporates the following arterial traffic signal applications:

- **Intelligent Traffic Signal System (ISIG)** uses data collected from vehicles through V2V and V2I communications as well as pedestrian and non-motorized travelers to control signals and maximize flows in real time. The ISIG application also plays the role of an overarching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall network performance.
- **Transit Signal Priority (TSP)** allows transit agencies to manage service by granting buses priority based on a number of factors, such as schedule adherence or passenger loads. The proposed application provides the ability for transit vehicles to communicate passenger count data, service type, scheduled and actual arrival time, and heading information to roadside equipment via an on-board device.
- **Mobile Accessible Pedestrian Signal System (PED-SIG)** integrates information from roadside or intersection sensors and new forms of data from pedestrian-carried mobile devices. Such systems will be used to inform visually impaired pedestrians when to cross and how to remain aligned with the crosswalk.
- **Emergency Vehicle Preemption (PREEMPT)** will integrate V2V and V2I communication to account for the needs of multiple emergency vehicles operating simultaneously through the same traffic network.

- **Freight Signal Priority (FSP)** provides signal priority near freight facilities based on current and projected freight movements. The goal is to reduce delays and increase travel time reliability for freight traffic, while enhancing safety at key intersections.

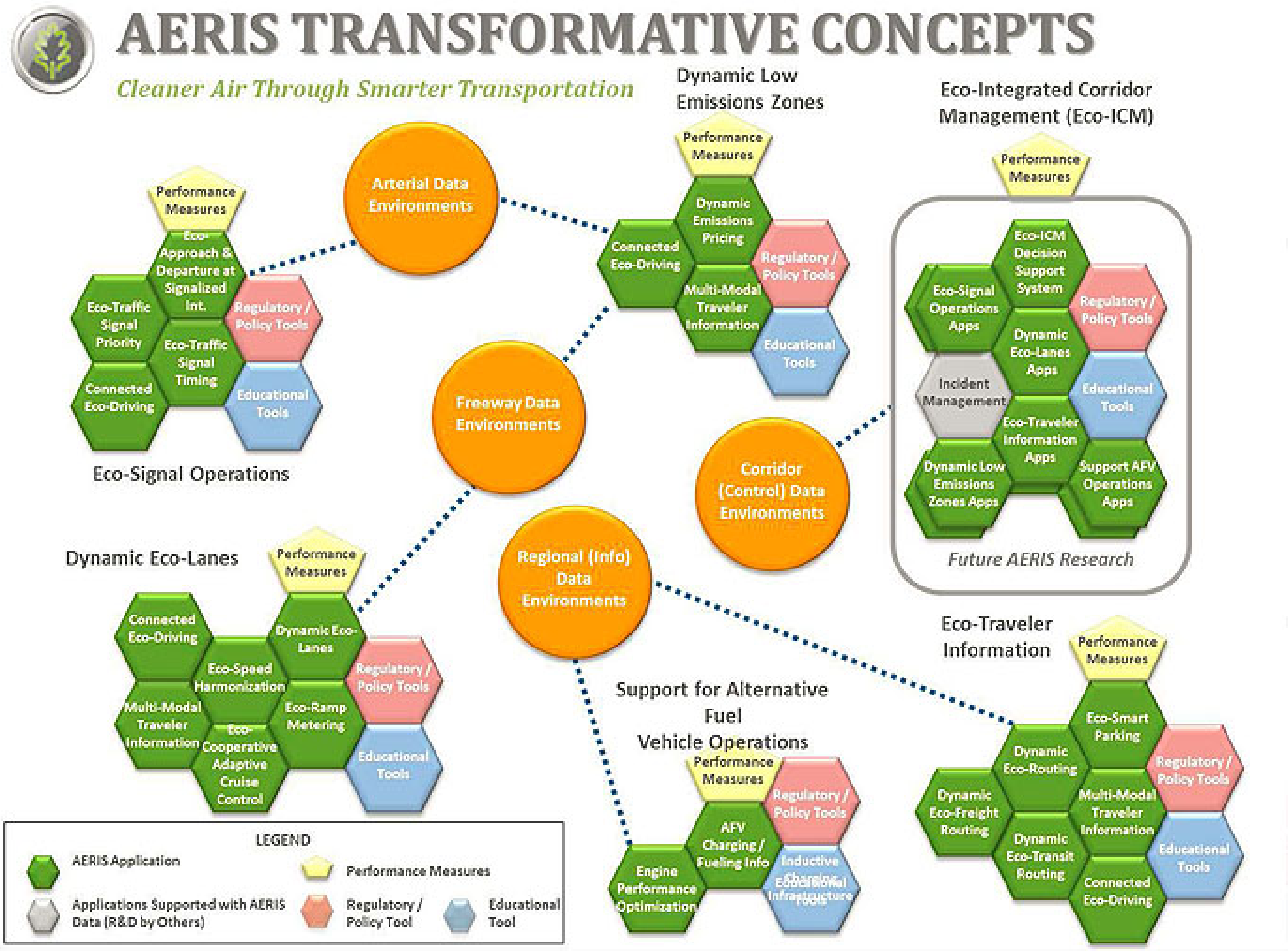
The ***Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)*** bundle of applications will leverage wireless connectivity, center-to-center communications, and center-to-field communications to solve problems faced by emergency management agencies, emergency medical services (EMS), public agencies, and emergency care givers, as well as people requiring assistance. R.E.S.C.U.M.E. applications are intended to support two broad categories of situation: traffic incidents and mass evacuations. Collectively, the R.E.S.C.U.M.E applications will provide capabilities such as quickly detecting and assessing traffic incidents and their effects on traffic flow; modeling evacuation flows; pushing information to evacuees; and helping emergency responders identify the best available resources and the ways to allocate them in the timeliest manner. Government officials who deal with traffic incidents or conduct evacuations will have a common operational picture, enhanced by greater communication with vehicles and roadside equipment, public safety personnel in the field, and the public itself. Public safety personnel in the field who are increasingly using portable communications devices (such as tablets and smartphones to supplement radios, cell phones, and mobile data terminals) will be able to provide real-time information to operations centers and TMCs which will improve traffic and route guidance during incidents and evacuations.

The USDOT defines the R.E.S.C.U.M.E. bundle as the following applications:

- **Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)** provides information to public safety responders while en route to help guide them safely and efficiently to an incident scene. It can also help establish incident work zones that are safe for responders, travelers, and crash victims by providing input regarding routing, staging, and secondary dispatch decisions; staging plans; satellite imagery; GIS data; current weather data; and real-time modeling outputs.
- **Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)** has two components: one warns drivers that are approaching temporary work zones at unsafe speeds or trajectory; the other audibly warns public safety personnel and other officials working in such zones about potential vehicle incursions.
- **Emergency Communications and Evacuation (EVAC)** addresses the needs of two different evacuee groups:
  - For those using their own transportation, EVAC provides dynamic route guidance information, current traffic and road conditions, location of available lodging, and location of fuel, food, water, cash machines, and other necessities.
  - For those requiring assistance, EVAC provides information to identify and locate the people most likely to need guidance and assistance, and it identifies existing service providers and other available resources.
- **Advanced Automated Crash Notification Relay (AACN–RELAY)** applications are anticipated to help transmit a range of data via other vehicles and roadside hot spots that can help to enhance incident response. This information can then be forwarded to a public safety answering point. These data elements may include the following:
  - Data generated through in-vehicle systems that can assist responders, including vehicle location, number of passengers, seat belt usage, airbag status, point of impact, risks inherent with the type of vehicle (e.g., use of alternative fuels), air-bag deployment, delta velocity of vehicles involved in the crash, likelihood of injury, the vehicle's final resting position (e.g., overturned), exact vehicle location (e.g., immediately adjacent to waterway), and infrastructure damage (e.g., bridge support).
  - Relevant medical information and patient history used to expedite lifesaving care.
  - Electronic manifest data collected from commercial vehicles that are involved in incidents, used to identify load contents and hazmat risks.

Connected vehicle environmental applications are intended to generate and capture environmentally-relevant, real-time transportation data, and use this data to create actionable information to support environmentally-friendly transportation choices. These applications will also support system users and operators in making decisions about green transportation alternatives or options, thereby reducing the environmental impacts of each trip. Using these applications, travelers may decide to avoid congested routes, take alternate routes, public transit, or reschedule their trip—all of which can make their trip more fuel-efficient and eco-friendly. Data generated from connected vehicle systems can also provide operators with detailed, real-time information on vehicle location, speed, and other operating conditions. This information can be used to improve system operation. On-board equipment may also advise vehicle owners on how to optimize the vehicle's operation and maintenance for maximum fuel efficiency. Within the USDOT connected vehicle research program, the development of environmental applications is taking place through the Applications for the Environment: Real-Time Information Synthesis (AERIS) program. AERIS has identified six Transformative Concepts[19] or bundles of applications. These are identified in Figure 12 and described in the following sections. In some instances the AERIS Transformative Concepts represent the environmental versions of other mobility applications.

Figure 12. AERIS Transformative Concepts and Applications



(Extended Text Description: This diagram illustrates the AERIS Transformative Concepts: Cleaner Air Through Smarter Transportation. A circular logo with a leaf at the center is in the upper left corner. The main part of diagram is a series of components connected via dotted lines and grouped together. The Legend (at the lower left) has the following information: A green hexagon is an AERIS Application; a gray hexagon is Applications Supported with AERIS Data (R&D by Others); a yellow pentagon is Performance Measures; a red hexagon is a Regulatory/ Policy Tool; and a blue hexagon is an Educational Tool. The grouping at the upper right side of the diagram is labeled Eco-Signal Operations and has a grouping of four green hexagons (Eco-Traffic Signal Priority, Connected Eco-Driving, Eco-Approach & Departure at Signalized Int., Eco-Traffic Signal Timing), Regulatory/Policy Tool, Educational Tools and Performance Measures. A dotted line leads to a larger orange circle to the right labeled Arterial Data Environments. Another dotted line leads from the circle to the right to the next grouping, labeled Dynamic Low Emissions Zones, with three green hexagons (Connected Eco-Driving, Dynamic Emissions Pricing, Multi-Modal Traveler Information), Regulatory/Policy Tool, Educational Tools and Performance Measures. There is a dotted line leading down and to the left to an orange circle labeled Freeway Data Environments. A dotted line leads from the

circle to a grouping to the lower left, labeled Dynamic Eco-Lanes, with six green hexagons (Connected Eco-Driving, Multi-Modal Traveler Information, Eco-Speed Harmonization, Eco-Cooperative Adaptive Cruise Control, Dynamic Eco-Lanes, Eco-Ramp Metering), Regulatory/Policy Tool, Educational Tools and Performance Measures. From the upper right corner is a grouping labeled Eco-Integrated Corridor Management (Eco-ICM). The grouping is inside a gray outline box with six green hexagons (Eco-ICM Decision Support System, Eco-Signal Operations Apps, Dynamic Eco-Lanes Apps, Eco-Traveler Information Apps, Dynamic Low Emissions, Support AFV Operations Apps), a gray hexagon labeled Incident Management, Regulatory/Policy Tool, Educational Tools and Performance Measures (placed outside the gray box outline). A dotted line leads to the left to an orange circle labeled Corridor (Control) Data Environments. In the lower right corner of the diagram, there is a grouping labeled Eco-Traveler Information with six green hexagons (Dynamic Eco-Freight Routing, Dynamic Eco-Routing, Dynamic Eco-Transit Routing, Eco-Smart Parking, Multi-Modal Traveler Information, Connected Eco-Driving), Regulatory/Policy Tool, Educational Tools and Performance Measures. There is a dotted line leading up and to the left to an orange circle labeled Regional (Info) Data Environments with a dotted line leading down to another grouping labeled Support for Alternative Fuel Vehicle Operations with two green hexagons (Engine Performance Optimization, AFV Charging Fueling Info), Regulatory/Policy Tool, Educational Tools and Performance Measures.)

Source: www.its.dot.gov/aeris/pdf/AERIS_Transformative%20Concepts%20and%20Applications%20Descriptions%20v10.pdf [Last accessed January 15, 2013].

The ***Eco-Signal Operations Transformative Concept*** is intended to use connected vehicle technologies to decrease fuel consumption, GHG, and criteria air pollutant emissions by reducing idling, the number of stops, and unnecessary accelerations and decelerations and improving traffic flow at signalized intersections.

This concept uses wireless data communications between vehicles and roadside infrastructure, including the broadcast of SPAT data to vehicles. Using this information, the **Eco-Approach and Departure at Signalized Intersections** application performs calculations to provide speed advice to the driver of the vehicle. This advice allows the driver to adapt the vehicle's speed to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner.

The **Eco-Traffic Signal Timing** applications are similar to current adaptive traffic signal systems; however, the objective would be to optimize traffic signals for the environment using connected vehicle data. This application collects data from vehicles, such as vehicle location, speed, GHG, and other emissions data to determine the optimal operation of the traffic signal system.

Eco-Traffic Signal Priority applications allow either transit or freight vehicles approaching a signalized intersection to request signal priority. These applications consider the vehicle's location, speed, and vehicle type (e.g., alternative fuel vehicles) and associated GHG and other emissions to determine if priority should be granted. Other information, such as a transit vehicle's adherence to its schedule or number of passengers, may also be considered in granting priority.

Connected Eco-Driving applications provide customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions while driving on arterials. This advice may include recommended driving speeds, optimal acceleration, and optimal deceleration profiles based on prevailing traffic conditions and interactions with nearby vehicles.

The ***Dynamic Eco-Lanes Transformative Concept*** features dedicated lanes optimized for the environment through the use of connected vehicle data to target low-emission, high-occupancy, freight, transit, and alternative fuel vehicles (AFVs). Drivers of suitable vehicles are able to opt in to these dedicated eco-lanes.

Central to this Transformative Concept is an administrative application that supports the operation of **Dynamic Eco-Lanes,** including establishing criteria for entering the lanes and defining or geo-fencing the eco-lane boundaries. Criteria may include the types of vehicles allowed in the eco-lanes, emissions criteria for entering the eco-lanes, number of lanes available at any time, and the start and end points of the eco-lanes.

Dynamic Eco-Lanes would leverage operational strategies implemented by the operating entity (e.g., a TMC) to reduce vehicle emissions in the lanes. This includes operational strategies such as **Eco-Speed Harmonization and Eco-Ramp Metering**. Once in the eco-lanes, drivers would be provided with speed limits optimized for the environment. These eco-speed limits would be implemented to help to reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing GHG and other emissions. Eco-Ramp Metering applications determine the most environmentally efficient operation of metering signals at freeway on-ramps to manage the rate at which vehicles enter the freeway.

Eco-Cooperative Adaptive Cruise Control applications would allow individual drivers to opt in to applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions. These applications consider terrain, roadway geometry, and vehicle interactions to determine a driving speed for a given vehicle.

Finally, **Connected Eco-Driving Applications** provide customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions while driving on the freeway.

The ***Dynamic Low Emissions Zone Transformative Concept*** includes a geographically defined area that seeks to restrict or deter access by specific categories of high-polluting vehicles in order to improve the area's air quality. Low-emissions zones can be dynamic, allowing the operating entity to change the location, boundaries, fees, or time of the low-emissions zone.

Central to this Transformative Concept is a **Dynamic Emissions Pricing** application that uses connected vehicle technologies to dynamically determine fees for vehicles entering the low-emissions zone. These fees may be based on the vehicle's engine emissions standard or emissions data collected directly from the vehicle using V2I communications.

This concept also enables the low-emissions zone to be dynamic, allowing the operating entity to change the location or time of the low-emissions zone. For example, this would allow the **Dynamic Low Emissions Zone** to be commissioned based on various criteria, such as atmospheric conditions, weather conditions, or special events.

Pre-trip and En-route Traveler Information is also a critical component of this concept, including information about criteria for vehicles to enter the low-emissions zone, expected fees and incentives for their trip, current and predictive traffic conditions, and the geographic boundaries of the low-emissions zone. Finally, Connected Eco-Driving applications would be encouraged inside the low-emissions zone. Once inside the zone, real-time data from the vehicle would show if it is being driven in a manner that reduces emissions, and the driver could be given an economic reward.

The ***Support for Alternative Fuel Vehicle Operations Transformative Concept*** supports the operation of vehicles that do not solely use oil-based fuels, such as electric cars, hybrid-electric vehicles, and fuel-cell vehicles.

This concept includes applications that would collect pertinent environmental data and adjust engine operations to optimize both fuel economy and emissions performance. Information about prevailing traffic conditions, weather conditions, or road grade may also be used as input for optimizing the engines' performance. For example, engine adjustments would be made in real-time on the vehicle to reduce emissions during high ozone alert days or during extremely hot or cold temperatures.

AFV Charging/Fueling applications would provide travelers with information about the locations of AFV charging/fueling stations, allow users to make reservations at charging/fueling stations, and allow for electronic payment using connected vehicle technologies. These applications could also transmit AFV-specific information as part of a crash notification message from an AFV when it is involved in an incident or requires emergency assistance.

The ***Eco-Traveler Information Transformative Concept*** would enable development of new traveler information applications through integrated, multisource, multimodal data.

Eco-Routing applications would determine the most eco-friendly route, in terms of minimum fuel consumption or emissions, between a trip origin and a destination for individual travelers. The application could use historical, real-time, and predictive traffic and environmental data using connected vehicle technologies to determine the vehicle's optimal eco-route between its origin and destination.

Eco-Smart Parking applications would provide travelers with real-time parking information including information about the location, availability, type (e.g., AFV-only, street parking, or garage parking), and price. The application could reduce the time required for drivers to search for a parking space, thereby reducing emissions.

The ***Eco-Integrated Corridor Management (Eco-ICM) Transformative Concept*** includes the integrated operation of a major travel corridor to reduce transportation-related emissions on arterials and freeways. Integrated operations means partnering among operators of various surface transportation agencies to treat travel corridors as an integrated asset, coordinating their operations simultaneously with a focus on decreasing fuel consumption, GHG emissions, and criteria air pollutant emissions. Central to this concept is a real-time data-fusion and decision support system that uses multisource, real-time V2I data on arterials, freeways, and transit systems to determine which operational decisions have the greatest environmental benefit to the corridor.

Connected vehicle road-weather management 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. Such applications could fundamentally change the manner in which weather-sensitive transportation system management and operations are conducted. The broad availability of road weather data from mobile sources, including light vehicles, heavy vehicles, and specialized vehicles operated by public agencies (such as snow plows and other maintenance vehicles) 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.

Central to the connected vehicle activities in the Road Weather Management Program is the development of a vehicle data translator (VDT). The VDT is a system that ingests and processes mobile data available on the vehicle and combines this with ancillary weather data sources. The VDT inputs two types of data:

- Mobile data originating from a vehicle, whether native to the controller access network bus (CANBus) or as an add-on sensor (e.g., pavement temperature sensor mounted to a vehicle).
- Ancillary data, such as surface weather stations, model output, satellite data, and radar data.

Current development efforts indicate that the VDT will function best where a minimum set of data elements are available. These consist of environmental and vehicle status data elements from the vehicle, including 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, plus ancillary data elements of radar, satellite, and surface station data from fixed data sources.

Once data are acquired by the VDT, they undergo quality checking followed by the application of various algorithms to create useful road weather information. Algorithms developed through VDT Version 3.0 include the following:

- A precipitation algorithm that will provide an assessment of the type and intensity (amount per hour) or accumulation rate of precipitation that is falling to the road surface by road segment. It is anticipated that the algorithm will identify four precipitation types: rain, snow, ice/mixed, and hail, and it will distinguish between light/moderate and heavy rates of each precipitation type.
- A pavement condition algorithm is being developed to derive the pavement condition on a segment of roadway from the vehicle observations. Pavement conditions being considered are the following: dry, wet, road splash, snow, icy/slick, and hydroplaning risk.
- 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. This approach is intended to report visibility as normal or low and potentially identify specific hazards, including dense fog, heavy rain, blowing snow, and smoke.

Six high-priority connected vehicle road weather applications have been identified[20] by the FHWA Road Weather Management Program. The applications can be summarized as follows:

- **Enhanced Maintenance Decision Support System** (MDSS) will expand the amount of data from connected vehicles provided by the existing Federal prototype MDSS. Snow plows, other agency fleet vehicles, and other vehicles operated by the general public will provide road-weather connected vehicle data to the Enhanced-MDSS, which will use this data to generate improved plans and recommendations to maintenance personnel. In turn, enhanced treatment plans and recommendations will be provided back to the snow plow operators and drivers of agency maintenance vehicles.
- **Information for Maintenance and Fleet Management Systems**. In this concept, connected vehicle information is more concerned with non-road-weather data. The data collected may include powertrain diagnostic information from maintenance and specialty vehicles; the status of vehicle components; the current location of maintenance vehicles and other equipment; and the types and amounts of materials onboard maintenance vehicles. The data would be used to automate the inputs to maintenance and fleet management systems year-round. In addition, desirable synergies can be achieved if selected data relating to winter maintenance activities, such as the location and status of snow plows or the location and availability of de-icing chemicals, can be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies.
- **Weather-Responsive Traffic Management.** Two weather-responsive traffic management applications are developed. First, connected vehicle systems provide opportunities to enhance the operation of variable speed limit systems and dramatically improve work zone safety during severe weather events. Additional road-weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed limits to reflect prevailing weather and road conditions. Second, connected vehicle systems can support the effective operation of signalized intersections when severe weather impacts road conditions. Information from connected vehicles can be used to adjust timing intervals in a signal cycle, or to select the special signal timing plans that are most appropriate for the prevailing conditions.
- **Motorist Advisories and Warnings.** Information on segment-specific weather and road conditions is not broadly available, even though surveys suggest that travelers consider this information to be significantly important. The ability to gather road and weather information from connected vehicles will dramatically change this situation. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to travelers through a variety of means as alerts and advisories within a few minutes. In combination with observations and forecasts from other sources and with additional processing, medium-term advisories of the next 2 to 12 hours and long-term advisories for more than 12 hours can also be provided to motorists.

- **Information for Freight Carriers.** The ability to gather road-weather information from connected vehicles will significantly improve the ability of freight shippers to plan and respond to the impacts of severe weather events and poor road conditions. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to both truck drivers and their dispatchers. In combination with observations and forecasts from other sources and with additional processing, medium- to long-term advisories can also be provided to dispatchers to support routing and scheduling decisions. Since these decisions must consider a variety of other factors, such as highway and bridge restrictions, hours-of-service limitations, parking availability, delivery schedules, and, in some instances, the permits held by the vehicle, it is envisioned that the motor carrier firms or their commercial service providers will develop and operate the systems that use the road-weather information generated through this concept.
- **Information and Routing Support for Emergency Responders.** Emergency responders, including ambulance operators, paramedics, and fire and rescue companies, have a compelling need for the short, medium, and long time horizon road-weather alerts and warnings. This information can help drivers safely operate their vehicles during severe weather events and under deteriorating road conditions. Emergency responders also have a particular need for information that affects their dispatching and routing decisions. Information on weather-impacted travel routes, especially road or lane closures due to snow, flooding, and wind-blown debris, is particularly important. Low latency road-weather information from connected vehicles for specific roadway segments, together with information from other surface weather observation systems such as those that monitor flooding and high winds, will be used to determine response routes, calculate response times, and influence decisions to hand off an emergency call from one responder to another responder in a different location.

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Connected Vehicle Technology

The connected vehicle environment will require the deployment of a mixture of roadside, in-vehicle, network, and back office systems and technologies. These systems needed to support connected vehicle operations can be divided into six broad categories:

- **OBE or mobile equipment.** The OBE or mobile equipment represent the systems or devices through which most end users will interact with the connected vehicle environment in order to gain the benefits of the anticipated safety, mobility, and environmental applications. In addition, other technologies associated with vehicles or mobile devices participating in the connected vehicle environment are necessary to provide basic information used in the various connected vehicle applications. This information includes vehicle or device location, speed, and heading that is derived from GPS or other sensors. Additional data from other vehicle sensors, such as windshield wiper status, anti-lock braking system activation, or traction control system activation, may be beneficial in certain connected vehicle applications.
- **RSE.** This equipment will support three main types of functionality. First, it connects vehicles and roadside systems, such as systems integrated with traffic signal controllers, which allow users to participate in local applications such as intersection collision avoidance. Second, the RSE provides the connectivity between vehicles and network resources that are necessary to implement remote applications—for example, for supporting the collection of probe vehicle data used in traveler information applications. Third, the RSE may be required to support connected vehicle security management.
- **Core systems.** These are the systems that enable the data exchange required to provide the set of connected vehicle applications with which various system users will interact. The core systems exist to facilitate interactions between vehicles, field infrastructure, and back office users. Current thinking envisions a situation

of locally and regionally oriented deployments that follow national standards to ensure that the essential capabilities are compatible no matter where the deployments are established.

- **Support systems.** These include the SCMSs that allow devices and systems in the connected vehicle environment to establish trust relationships. Considerable research is underway to describe both the technical details and the policy and business issues associated with creating and operating a security credentials management system.
- **Communications systems.** These comprise the data communications infrastructure needed to provide connectivity in the connected vehicle environment. This will include V2V and V2I connectivity and network connectivity from RSEs to other system components. These system components will include core systems, support systems, and application-specific systems. The communications systems will include the appropriate firewalls and other systems intended to protect the security and integrity of data transmission.
- **Application-specific systems.** This refers to the equipment needed to support specific connected vehicle applications that are deployed at a particular location, rather than the core systems that facilitate overall data exchange within the connected vehicle environment. An example could be software systems and servers that acquire data from connected vehicles, generate travel times from that data, and integrate those travel times into TMC systems. Existing traffic management systems and other ITS assets can also form part of an overall connected vehicle application.

Selected technology topics are discussed in the following sections.

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Dedicated Short Range Communications (DSRC)

DSRC technologies were developed specifically for vehicular communications and have been closely associated with the Connected Vehicle Program and its predecessors. In 1997, ITS America petitioned the FCC to allocate 75 MHz of spectrum in the 5.9-GHz band. In 1999, the FCC allocated spectrum in the 5.9GHz range for Intelligent Transportation Systems uses[6]. In 2004, the FCC published a Report and Order that established standard licensing and service rules for DSRC in the ITS Radio Service in the 5.850 to 5.925-GHz band (5.9-GHz band), to be used for the purpose of protecting the safety of the traveling public.[21]

DSRC is a communications protocol developed to address the technical issues associated with sending and receiving data among vehicles and between moving vehicles and fixed roadside access points. DSRC is a specialized form of Wi-Fi, and, as with Wi-Fi, it is a derivative of the basic IEEE 802.11 standard, which is a set of standards developed by the Institute of Electrical and Electronics Engineers (IEEE) for implementing wireless local area network computer communications. DSRC is governed by the IEEE 802.11p and 1609 standards. Unlike Wi-Fi, however, DSRC uses a communications protocol that allows each terminal to generate its own IP and MAC addresses. This effectively eliminates the network attach time.

DSRC also includes the Wireless Access in Vehicular Environments Short Message protocol defined in the IEEE 1609 standard that allows terminals to broadcast messages to all other devices in radio range. This is highly efficient because any given terminal does not need to learn the network identities of any other terminal.

The typical range of a DSRC access point is about 300 meters, although ranges up to about 1 kilometer have been observed. Typical installations are expected to be at intersections and other roadside locations.

In 2008, USDOT framed the definition of connectivity in the connected vehicle environment to include both DSRC and non-DSRC technologies, such as cellular or Wi-Fi communications, as a means of providing an open communications platform. However, USDOT has remained committed to the use of DSRC technologies for active safety for both V2V and V2I applications. DSRC is the communications medium of choice for active safety systems because of its designated licensed bandwidth, primarily allocated for vehicle safety applications by the FCC Report and Order. DSRC is also the only short-range wireless technology that provides the following: a fast network acquisition, low-latency, high-reliability communications link; the ability to work with vehicles operating at high speeds; the ability to prioritize safety messages; tolerance to multipath transmissions typical of roadway environments; performance that is immune to extreme weather conditions (e.g., rain, fog, and snow); and security and privacy of messages.[22] Figure 13 illustrates how DSRC meets the latency requirements of various connected vehicle active

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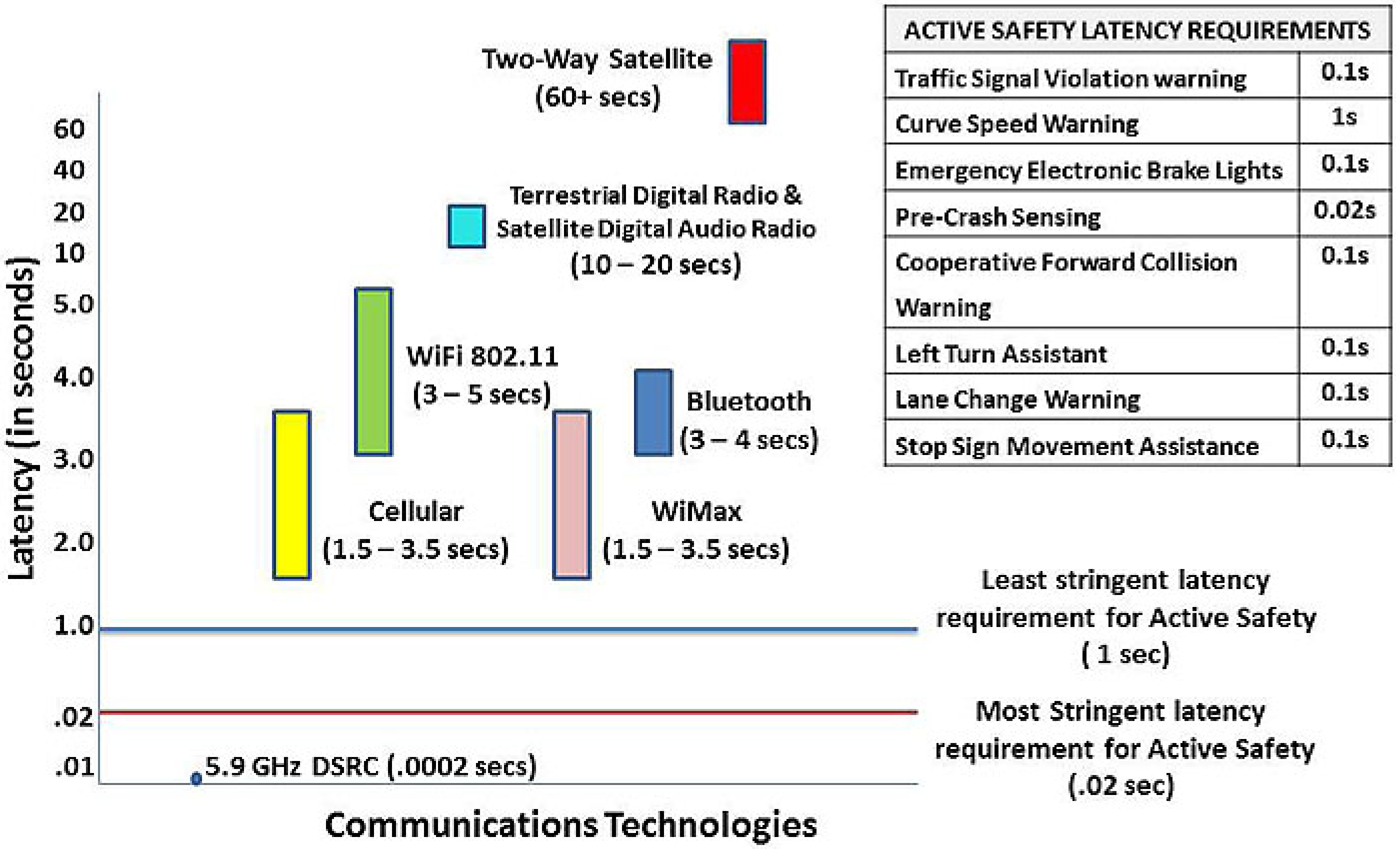
[6] https://transition.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret9006.html

safety applications compared to other communications technologies. Beyond the commitment to DSRC for active safety applications, USDOT has also reaffirmed its intention to explore all wireless technologies for their applicability to other safety, mobility, and environmental applications.

Figure 13. Latency Requirements of Active Safety Applications



ACTIVE SAFETY LATENCY REQUIREMENTS	
Traffic Signal Violation warning	0.1s
Curve Speed Warning	1s
Emergency Electronic Brake Lights	0.1s
Pre-Crash Sensing	0.02s
Cooperative Forward Collision Warning	0.1s
Left Turn Assistant	0.1s
Lane Change Warning	0.1s
Stop Sign Movement Assistance	0.1s

(Extended Text Description: This figure illustrates how DSRC meets the latency requirements of various Connected Vehicle Active Safety applications in comparison to other communications technologies. The figure shows a bar graph comparing Communications Technologies (x axis) with Latency (in seconds) (y axis). In the bar graph, various communications technologies are indicated showing the range of latencies, including Cellular (1.5-3.5 secs), WiMax (1.5-3.5 secs), WiFi (3-5 secs), Bluetooth (3-4 secs), Terrestrial Digital Radio & Satellite Digital Audio Radio (10-20 secs) and Two-Way Satellite (60+ secs). It compares these to the least stringent latency requirement for Active Safety (1 sec) and Most Stringent latency requirement for Active Safety (0.2 sec), and shows a dot with 5.9GHz DSRC at the bottom at .0002 secs. To the right of the graph is a table with the following data:

Active Safety Latency Requirements	
Traffic Signal Violataion warning	0.1s
Curve Speed Warning	1s
Emergency Electronic Brake Lights	0.1s
Pre-Crash Sensing	0.02s
Cooperative Forward Collision Warning	0.1s
Left turn Assistant	0.1s
Lane Change Warning	0.1s
Stop Sign Movement Assistance	0.1s

Source: USDOT.)

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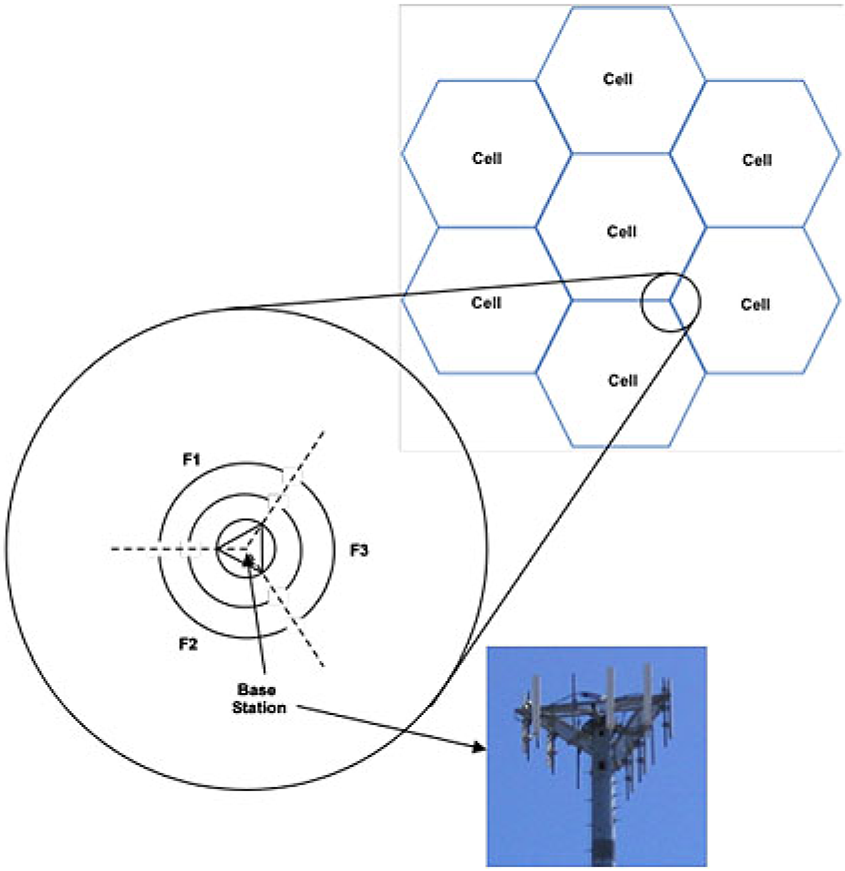
Cellular Communications

Cellular communications is a candidate for some safety applications as well as mobility and environmental applications in the connected vehicle environment. Cellular communications use a series of base stations to provide voice and data over relatively large areas. Typically each base station serves several sectors that are arranged to use slightly different frequencies to minimize interference. This also assures that reasonable channel bandwidth is available to the users in any given sector.[23] A typical cellular arrangement is shown in Figure 14.

Figure 14. Typical Cellular System Arrangement[23]



(Extended Text Description: This diagram demonstrates a typical cellular system arrangement. There is an illustration with four concentric circles (three at the center close together, the outer fourth circle farther out). There is an equilateral triangle, labeled as the Base Station, in the center of the smallest inner circle, and three bisecting lines emerging from that triangle through the three inner circles. This creates three sections, labeled F1, F2 and F3. Two diagonal lines connect from the outer circle to a small circle overlaid on a connection point in a honeycomb pattern to the right, with each space in the honeycomb pattern labeled as "Cell." There is a small photograph of a base station, which appears as a triangular structure with several attached devices, at the top of a pole.)

Because of the popularity of mobile telephones, cellular technologies have advanced rapidly. The rise of smartphones and other wireless consumer devices has further fueled this growth. The technologies are still evolving but the latest LTE cellular technologies can provide very high speed data transfer rates to a large number of subscribers simultaneously. In general, cellular communications systems are commercially operated, so all data transactions involve some type of usage fee. For most users, this is a simple service subscription, although other models exist.

Cellular communications systems are intended to serve mobile users, so they are designed to provide high data bandwidth to users in motion. They are also widely deployed so that users can access the service wherever they go. Generally, all urban areas have cellular coverage provided by multiple carriers. Most major highways also have coverage though it is not ubiquitous.

Since cellular technology can provide relatively high bandwidth communications capability over wide areas, it is conceptually suitable for V2I applications. It is less effective for V2V applications. Table 3[24] summarizes the strengths and weaknesses of cellular communications technology for V2V and V2I applications based on the status of these technologies in 2011-2012.

Table 3. Cellular Strengths and Weaknesses for Connected Vehicle Applications[24]

Application	Strengths	Weaknesses	Comments
V2V	None	Only provides addressed point to point communications; limited broadcast capability that is seldom implemented by carriers.	To send a message, it is thus necessary to include the IP address of the recipient along with the message. Using cellular for V2V requires that any given OBE learn the IP address of the vehicles nearby before it can send them a message. Since the vehicles around any given OBE are moving and changing all the time, the task of somehow maintaining an active IP address list for each OBE is overwhelming.
V2I	Wide area coverage means existing infrastructure can be used for many situations	Requires vehicles to request V2I data based on location. This increases the overall data load because of many requests that result in null data responses. Also, messages must be sent uniquely to each vehicle on request.	This approach was used in the SafeTrip 21 Networked Traveler project with good results. It is unclear how well it can scale to large numbers of users.
General	Highly available and low cost	Requires payment for data usage	The greatest weakness of cellular systems is that to obtain access a device must be registered with a cellular carrier. This typically requires some form of user agreement, contract and payment.

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Security Credential Management Systems

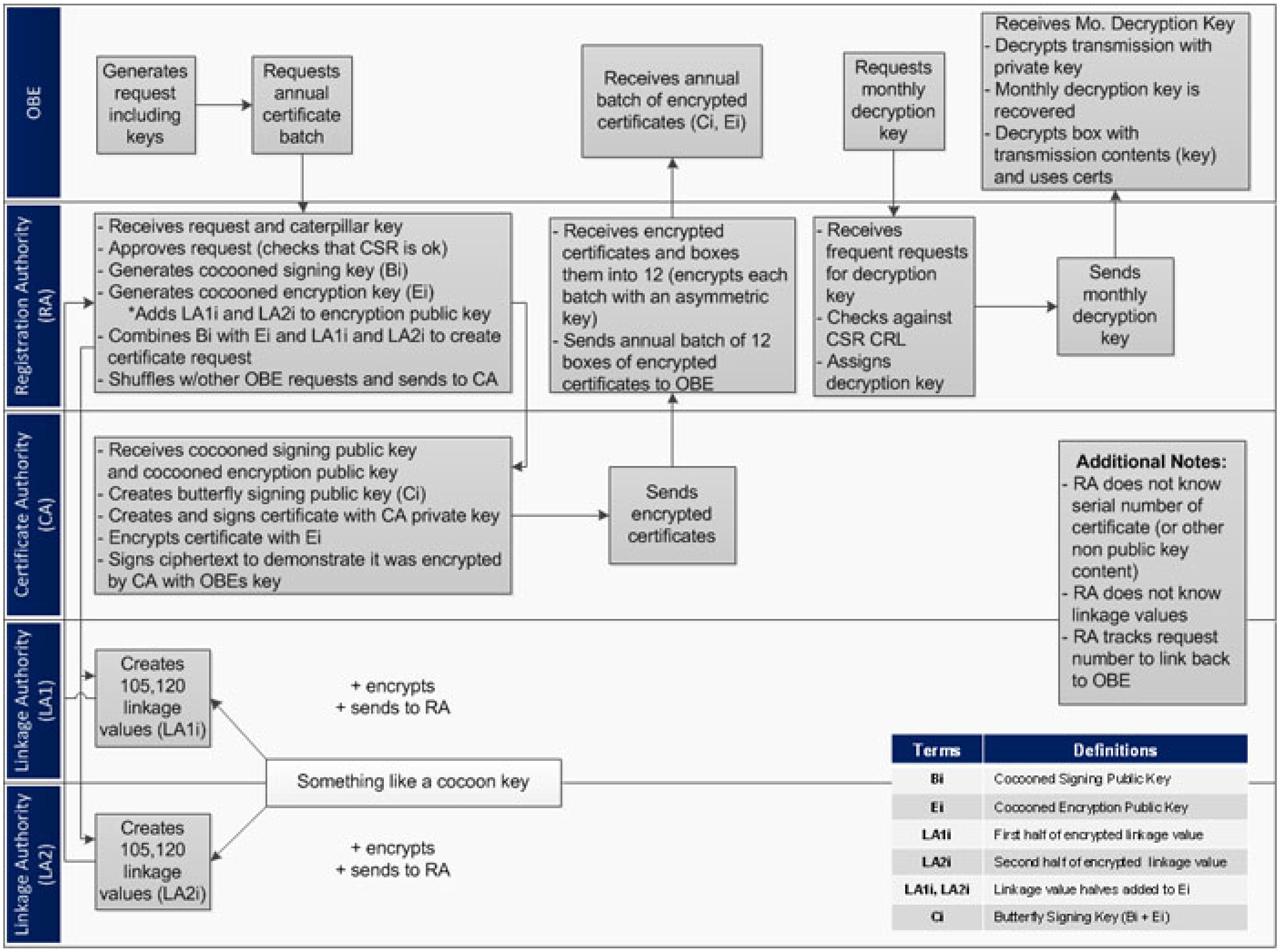
The Connected Vehicle Program will rely on a secure communications system to support V2V and V2I communications to enable safety, mobility, and environmental applications. For the system to work effectively, users of the network must be able to trust the validity of messages received from other system users. Establishing the basis of this trust network is a key element of a security design for the Connected Vehicle Program[25]. At the same time, users want to have a reasonable assurance of appropriate privacy in the system. Research to date has indicates that use of a Public Key Infrastructure (PKI) security system, involving the exchange of digital certificates among trusted users, can support both the need for message security and for providing appropriate anonymity to users while in transit. These digital certificates are used to sign the messages that pass between vehicles in the connected vehicle environment, and these certificates therefore allow the receiver to verify that the message came from a legitimate source

Certificate management entities (CMEs) perform the back office functions required to administer a PKI security system, such as registering users and issuing and revoking certificates. The term "security credential management system" (SCMS) is also used to refer to all CME organizations, or the certificate management system as a whole.

PKI is the governing paradigm of communications security within the connected vehicle environment. PKI is a certificate management system that features a central authority, known as the certificate authority (CA), that verifies that users in a system are trustworthy based on certain credentials. This allows users to trust one another and to interact, even if they have had no prior interaction, by virtue of their trust in the CA.

In general, vehicle-based mobile terminals will contact a registration authority (RA) to request and obtain security certificates. The mobile terminal and the RA will also have a trusted relationship. This means that the RA knows the identity and has sufficient information about the mobile terminal to determine that the certificate request came from a legitimate source. However, to preserve the privacy of the mobile terminal, the RA randomizes requests from many devices, before requesting the CA to issue PKI-encrypted certificates. These PKI-encrypted certificates are further signed by a separate entity called a linkage authority (LA). One of two or more LAs then adds an encrypted Linkage ID (Link-ID) to groups of already-encrypted certificates issued by the CA. Groups of multiple certificates with common Link-IDs are then issued to each mobile terminal that requests certificates from the RA. The mobile terminal can then use the certificates to sign messages, and the receiver of the message can verify that the message came from a legitimate source. A process flow diagram for a generic SCMS[26] is illustrated in Figure 15.

Figure 15. Process Flow Diagram for an SCMS[26]



(Extended Text Description: This is a flow diagram to show the process for an SCMS. There is a terms key in the lower right corner: Bi – Cocooned Signing Public Key; Ei – Cocooned Encryption Public Key; LA1i – First half of encrypted linkage value; LA2i – Second half of encrypted linkage value; LA1i, LA2i – Linkage value halves added to Ei; Ci – Butterfly Signing Key (Bi + Ei). The flow chart is separated into five rows, labeled (top to bottom): OBE, Registration Authority (RA), Certificate Authority (CA), Linkage Authority (LA1), Linkage Authority (LA2). The text box elements within the row labeled OBE are first, "Generates request including keys" which has an arrow pointing to the second element "Requests annual certificate batch" which has an arrow pointing to the first text box element in the row below (described below). The third element in OBE is "Receives annual batch of encrypted certificates (Ci, Ei)" and is pointed to from the second element below (described below). The fourth element in OBE is "Requests monthly decryption key" which has an arrow pointing down to the third element in the next row (described below). The last element in OBE is "Receives Mo. Description Key – Decrypts transmission with private key, - Monthly decryption key is recovered, - Decrypts box with transmission contents (key) and uses certs," which is pointed to by the last element in the next row (described below). The second row is labeled Registration Authority (RA), and has the following text box elements. The first elements is "- Receives request and caterpillar key, - Approves request (checks that CSR is ok), - Generates cocooned signing key (Bi), - Generates cocooned encryption key (Ei) *Adds LA1i and LA2i to encryption public key, - Combines Bi with Ei and LA1i and LA2i to create certificate request, - Shuffles w/other OBE requests and sends to CA." This element is pointed to from the second element in OBE (described above). It also points to the first elements in the next three rows (described below). The second element in the second row is "- Receives encrypted certificates and boxes them into 12 (encrypts each batch with an asymmetric key), - Sends annual batch of 12 boxes of encrypted certificates to OBE" and points up to the third element in the first row (described above). The third element in the second row is "- Receives frequent requests for decryption key, - Checks against CSR CRL, - Assigns decryption key," which is pointed to by the fourth element of the first row (described above), and also points to the last element in the second row, which is "Sends monthly decryption key." This final element points up to the final element in the first row (described above). The third row is Certificate Authority (CA)

with the following elements. The first is "- Receives cocooned signing public key and cocooned encryption public key, - Creates butterfly signing public key (Ci), - Creates and signs certificate with CA private key, - Encrypts certificate with Ei, - Signs ciphertext to demonstrate it was encrypted by CA with OBEs key" and is pointed to by the first element in the second row (described above) and points to the final element in the third row, which is "Sends encrypted certificates." This final element in the third row points up to the second element in the second row (described above). The fourth row is Linkage Authority (LA1). The element in this row is "Creates 105, 120 linkage values (LA1i)" which is pointed to by the first element in the second row (described above) and is pointed to a pullout box "Something like a cocoon key" that is placed between the fourth and fifth rows. The words "+ encrypts" and "+ sends to RA" appears to the right of the text element in this row. The fifth row is Linkage Authority (LA2). The text element in this fifth row is "Creates 105, 120 linkage values (LA2i)," which points to the first element in the second row and is pointed to by that same element (described above). It is also pointed to by the pullout box "Something like a cocoon key." It has the phrases "+ encrypts" and "+ sends to RA" to the right of the text element in this row. There is a pullout box on the right side that reads: Additional Notes: - RA does not know serial number of certificate (or other non-public key content), - RA does not know linkage values, - RA tracks request number to link back to OBE.") Certificates typically include a specified lifespan. After a certificate has expired, it is no longer valid, and it is expected to be refused by any recipient. Certificates may also be revoked if the CA determines that the terminal no longer satisfies the certification criteria. Typically, cause for revocation would be based on observed misbehavior (whether accidental, caused by faulty equipment, maliciously transmitting false messages, etc.), notification of retirement of a vehicle (e.g., due to scrapping a vehicle after a serious crash or when the vehicle reaches the end of its life), or possibly the transfer of the terminal to a new user. By communicating revocation information to all system participants, the CA can notify users not to accept revoked certificates. The mechanism for this is typically known as a certificate revocation list (CRL). It is important to note that the strategies ultimately adopted for CRL distribution will have significant effects on the cost and performance of the connected vehicle system because of the large amounts of data that may need to be distributed.

In addition to anonymity, recommended privacy principles for the connected vehicle environment require that there be no way to determine the path taken by a vehicle by following the certificates used. The specific issue here is that each certificate has an identifier (not tied to the user or terminal), so unless the certificate is changed every few minutes it might be possible to track the route a user has followed (by looking for the same certificate used in different places). To prevent such tracking, various mechanisms for limiting the time a certificate is in use (thereby limiting the distance over which a vehicle might be tracked by its use of the same certificate) have been proposed.

In 2012, the USDOT stood up the first prototype of the SCMS for use in the Safety Pilot Model Deployment and by others performing research, development and testing activities that required security certificates. In 2016, the USDOT is expected to stand up the Proof of Concept SCMS that has been under development by CAMP and NHTSA.

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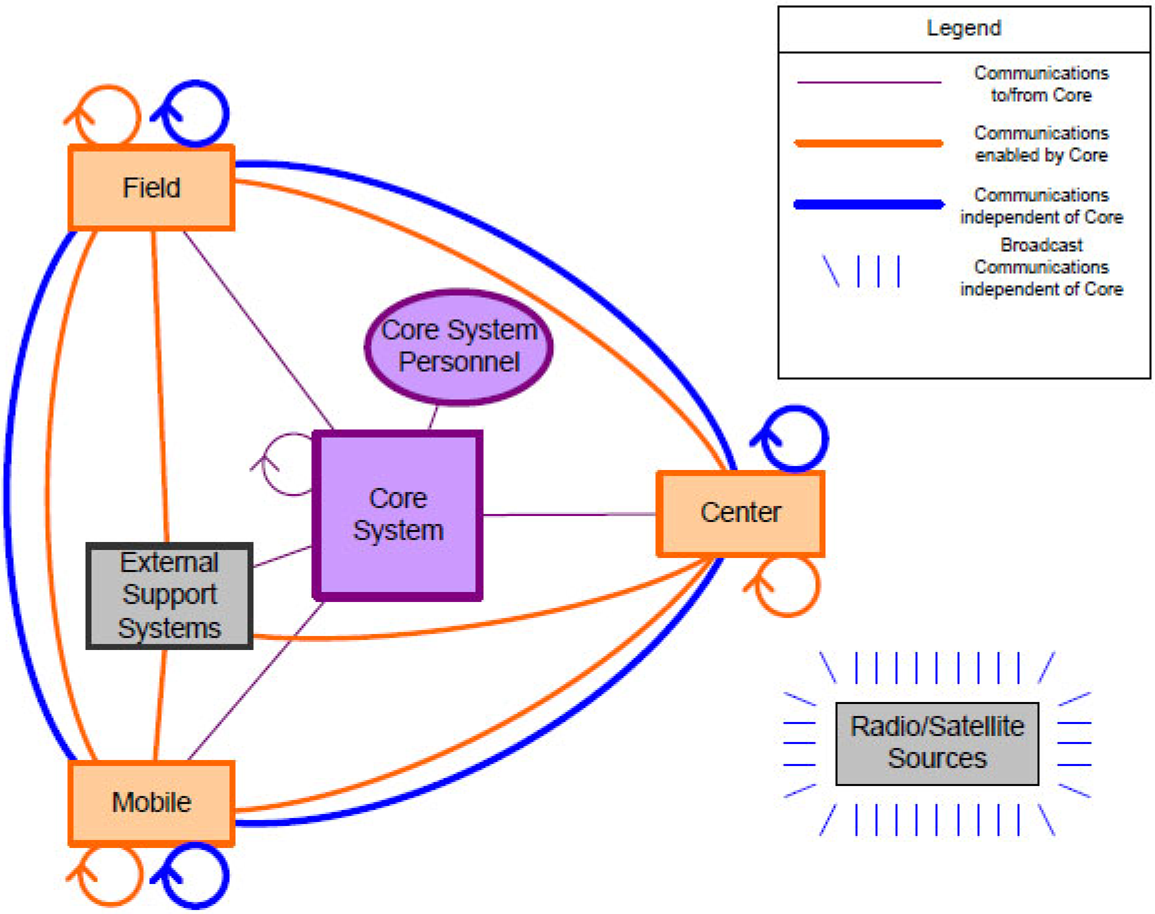
The Connected Vehicle Core Systems

Broadly speaking, the Connected Vehicle Core Systems are the systems that enable the trusted and secure data exchange required to provide the set of connected vehicle applications with which various system users will interact.[27] A context diagram for the Core System[28] is illustrated in Figure 16. An understanding of the Core System concept requires that the discussion be set in context with the communications systems and connected vehicle applications.

Figure 16. Core System Context Diagram[28]



(Extended Text Description: This diagram demonstrates the core system context. There is a legend in the upper right corner that shows a purple line represents Communications to/from Core, an orange line represents Communications enabled by Core, a blue line represents Communications independent of Core and a series of vertical short lines represents Broadcast Communications independent of Core. The main diagram has three sections in orange: Field at the top, Center to the right, Mobile at the bottom. Each of these sections has a blue and orange circular arrows, and orange and blue lines connecting each section to the next. Inside the curved triangular shape that this creates, there are three additional sections inside. External Support Systems appears in gray and connects to the outer sections with orange lines. Also, Core System Personnel and Core System appear in purple, connected by a purple line to each other, and with purple lines to all the other inner and outer sections. There is a circular purple arrow connected to the Core System section. To the lower right of the entire main part of the diagram, is a section labeled Radio/Satellite Sources in gray, surrounded by blue radiating short lines.)
The communications systems are the wireless or, potentially, wired services that allow the Core System to communicate with the various connected vehicle safety, mobility, and environmental applications. The communications mechanisms that are implemented in each deployment of a Core System will vary and could include cellular or DSRC, for example. Applications provide benefits in the area of safety, mobility, or the environment to connected vehicle system users. Applications use the Core System to facilitate their interactions with other applications or users.

The Core System also interacts with a number of other entities:

- Mobile entities, including vehicles and other platforms, such as portable personal devices, used by travelers to provide and receive transportation information.
- Field devices distributed along the transportation network which perform surveillance, traffic control, information provision, or fee-based transactions.
- Centers which include the back office that provide management, administrative, information dissemination, and support functions.

- Personnel who operate and maintain the Core System, including network managers, operations personnel, and developers.

The Core System also interacts with other Core Systems. More than one Core System will exist in the connected vehicle environment, each providing services over given geographic or topical areas, or providing backup services for others. USDOT documents[29]envision that the Core System (as well as the communications systems and applications) will be deployed locally and regionally, not nationally, in an evolutionary fashion.

USDOT documentation envisions that a Core System will use external support systems to obtain services that it needs to deliver its functions, but which are more appropriately managed, maintained, and shared between multiple Core Systems due to overriding institutional, performance, or functional constraints. The USDOT documents identify the most likely candidate for a support system to be an external certificate management authority, because of the need to coordinate certificate distribution and revocation activities between all Core Systems.

The Connected Vehicle Core Systems program has been further enhanced through the development of the Connected Vehicle Reference Implementation Architecture (CVRIA) and the Southeast Michigan implementation of the CVRIA that was used to test and exercise the CVRIA. The Connected Vehicle Reference Implementation Architecture is a basis for identifying standards. The architecture identifies the key interfaces of a connected vehicle environment which will support further analysis to identify standards. The CVRIA development included a set of system architecture viewpoints that describe the functions, physical and logical interfaces, enterprise relationships and application dependencies within the connected vehicle environment. The CVRIA development effort was substantially completed in 2014 (although updates continue as lessons are learned through deployment and operations activities) and the CVRIA team has established a web site that hosts the architecture viewpoints for all 88 connected vehicle applications. The web site for the CVRIA documentation is http://www.iteris.com/cvria. In addition, the CVRIA team has developed a software tool that integrates drawing and database tools with the CVRIA to support users in developing project architectures for pilots, test beds and early deployments. The tool, called the Systems Engineering Tool for Intelligent Transportation (SET-IT), is available at http://www.iteris.com/cvria/html/resources/tools.html . SET-IT requires Microsoft Visio.

The CVRIA and SET-IT tool create a set of uniform views of the architecture for the project that is being developed. The first view is the physical view which provides an overview and the specifics of objects and the information flows between them, showing different levels of detail as needed. The second view is the enterprise view which are the people associated with a connected vehicle project. This view includes the installation, operations, maintenance and certification diagrams for each physical component and diagram. The final set of views are the communications views that show the flow of data through the entire system.

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Connected Vehicle Policy and Institutional Issues

Connected vehicle policy and institutional issues are those topics that may limit or challenge successful deployment. The vision for the Connected Vehicle Program is one of a collaborative effort among USDOT, key industry stakeholders, vehicle manufacturers, State and local governments, representative associations, citizens, and others. Therefore, the policy and institutional foundation supporting the successful deployment of connected vehicle technologies and applications must respond to the collective needs of this group.

USDOT has identified critical issues that may hinder or present challenges to successful deployment of V2V and V2I technologies, applications, and systems. These policy issues and their associated research needs fall into four categories:

- **Implementation Policy Options**: These require analysis and development of a range of viable options for financial and investment strategies; analysis and comparisons of different communications systems for data delivery; model structures for governance with identified roles and responsibilities; and analyses that are required to support NHTSA's 2013 and 2014 agency decisions, which include a cost-benefit analysis, a value proposition analysis, and a market penetration analysis.
- **Technical Policy Options**: These require analysis of the technical choices for V2V and V2I technologies and applications to identify whether those options require new institutional models or whether they can leverage existing assets and personnel. The technical analyses in this category will also result in policies related to the

Connected Vehicle Core System, a policy framework on necessary interfaces, and policies on the use of device certification and standards.

- **Legal Policy Options**: These entail analyses and policy options that support decisions on the Federal role and authority in connected vehicle system development and deployment, liability and limitations to risk, policy and practices regarding privacy, and policies on intellectual property and data ownership within the connected vehicle environment.
- **Implementation Strategies**: With decisions made in each of the previous categories, the chosen options can be combined into implementation scenarios. Further comparative analyses can be provided to stakeholders to ensure that the most effective strategies are available for implementation. These analyses will result in guidance to the various implementing entities that will need to understand the resources needed for implementation, operations, and maintenance, including the knowledge, skills, and ability of personnel.

Beyond USDOT's connected vehicle policy and institutional issues research, other related issues are of particular importance to the State and local transportation agencies. Chief among these is funding for connected vehicle infrastructure deployment. State and local DOTs will have to decide the extent to which they will take advantage of connected vehicle technology and applications. In making that decision, State and local DOTs will need to assess several factors. For example, benefits may be substantial, providing new opportunities to address safety, mobility, and environmental challenges. Costs too must be considered, including the costs of installing, operating, and maintaining the connected vehicle infrastructure.

Among the key tasks facing State and local DOTs that intend to deploy a connected vehicle infrastructure is the need to identify a funding mechanism for the capital and ongoing operations and maintenance costs. Depending on the type of connected vehicle infrastructure and the applications it supports, agencies can consider various funding categories to support deployment. For example, connected vehicle systems are a form of ITS technology, so an agency might use an ITS budget or any category of Federal or State funds for which ITS is eligible. Connected vehicle systems are expected to have significant impacts on vehicle and highway safety, so deployment with funds intended for safety systems might be appropriate. Mobility impacts of connected vehicle technologies and consequent emission reductions could warrant funding some deployments with funds set aside for congestion mitigation or air quality improvement.

There will be ongoing day-to-day operation costs (e.g., staffing as well as power and backhaul communications from connected vehicle field sites), maintenance costs (both scheduled and unscheduled), and the costs of replacement of field and back-office equipment at the end of its life. For connected vehicle systems, agencies may explore public–private partnerships or asset and revenue sharing mechanisms to acquire the desired connected vehicle infrastructure.

Key principles for the connected vehicle environment have been developed by USDOT and will guide the connected vehicle policy research.[30] The central principles are summarized below.

Purpose

- Transportation safety is USDOT's top priority for the connected vehicle environment. The system must
    - Prevent or mitigate the severity of crashes;
    - Minimize driver workload;
    - Ensure no increase to driver distraction;
    - Encompass all road users; and
    - Ensure that mandatory safety applications cannot be turned off or overridden.
- Uses beyond safety applications, especially for mobility and environmental purposes, are permissible and encouraged as long as they do not detract from safety.

Coverage/Scale

- System implementation must be national in scale and extensible across North America.
    - Implementation can start at discrete locations but is envisioned to include all major roadways with timing to coincide with the roll-out of technology in vehicles.

User Protections

- USDOT is committed to protecting consumers from unwarranted privacy risks through appropriate privacy controls: transparency; individual participation and redress; purpose specification; limitations on use of information; data minimization and retention; data quality and integrity; security; and accountability and auditing. For example:
    - The environment must provide consumers with appropriate advance notice of, and (for opt-in systems) opportunity to provide consent for, information collection, use, access, maintenance, security, and disposal.
    - The environment will limit the collection and retention of personally identifiable information to the minimum necessary to support stakeholder and operational needs.
- The system must be secure to an appropriate level. The system will
    - Ensure that information exchange among users is secure and trusted;
    - Provide protection from hacking and malicious behavior; and
    - Maintain data integrity.

Implementation and Oversight

- An organization, which may be private, public, or a private/public hybrid, will be required to manage and operate the system responsible for ensuring security and other functions of the connected vehicle system.
- Applications from sources outside the governance structure should be allowed on the connected vehicle system as long as they comply with all established system principles, including security and operational requirements.
- If State and local agencies are involved in system implementation, the system should be designed so that building, operating, and maintaining them is cost beneficial to these agencies.
- USDOT is receptive to all sustainable financing options that do not violate other principles. In the event that that the only viable financing option relies on financing from participating organizations, companies, or entities, the common operating costs for the system, including security, governance, and other costs, should, to the extent feasible, be shared.
- There can be no consumer subscription fees for mandatory safety applications. However, this principle does not preclude the use of mandatory, universally applicable taxes or fees to finance the system. Subscription or other fees for non-mandatory, opt-in applications are possible.[31]

Technical Functionality

- Functionality of the system requires compliance with nationwide, universally accepted, non-proprietary communication and performance standards.
    - Interoperability of equipment, vehicles, and other devices is necessary to enable mandatory safety applications as well as applications supporting mobility, economic competitiveness, and sustainability.
    - Standards must be maintained to ensure technical viability.
- The system must be technically adaptable and viable over time.
    - It must be backward compatible.
    - The system must be able to evolve over time as new technologies become available.
- Communication technology for safety applications must be secure, low-latency, mature, stable, and able to work at highway speeds.
    - Currently, DSRC is the only known viable technology for safety critical applications.
    - DSRC or other communication technologies could be used for safety applications that are not for crash-imminent situations, mobility, and environmental applications.
- Use of the spectrum must comply with established requirements for non-interference.

- Safety applications take priority over non-safety applications.
- Public sector applications take precedence over commercial applications.

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Connected Vehicle Implementation Strategies

This section will describe emerging strategies and anticipated milestones in the deployment of a connected vehicle field infrastructure, integration of connected vehicle systems into the vehicle fleet, and operational approaches for the overall connected vehicle environment.

Over the course of the Connected Vehicle Program and its predecessors, several analyses have been performed to address the scale and approaches for connected vehicle deployment. The original VII Concept of Operations[32] laid out a phased VII deployment approach. This approach assumed a period of pre-deployment planning and testing, leading to a go/no-go decision on VII deployment taking place in 2008. Beyond that date, deployment would have proceeded in two phases.

Phase 1 would have provided a core level of VII infrastructure deployment necessary to enable so-called Day One applications. The goal of Phase 1 was to provide infrastructure covering half of signalized intersections in the 50 largest U.S. metropolitan areas. In addition, metropolitan freeways and Interstate highways would have been covered, as well as rural Interstate highways, but at a lower density of infrastructure than in urban areas.

Phase 2 would have begun in 2012 to coincide with the assumed date at which vehicle manufacturers would have begun rolling out VII-equipped vehicles. At this time the public would have been able to use the defined Day One applications. During Phase 2, the VII infrastructure would have been expanded to cover all 452 urbanized areas with a population of 50,000 or greater. Phase 2 would have seen approximately 70 percent of the nation's signalized intersections, as well as additional rural highways, added to VII infrastructure.

Subsequent analyses[33, 34] defined the scale of the required nationwide VII infrastructure deployment, as follows:

Table 4. Estimated Size of a Nationwide VII Infrastructure Deployment[33]

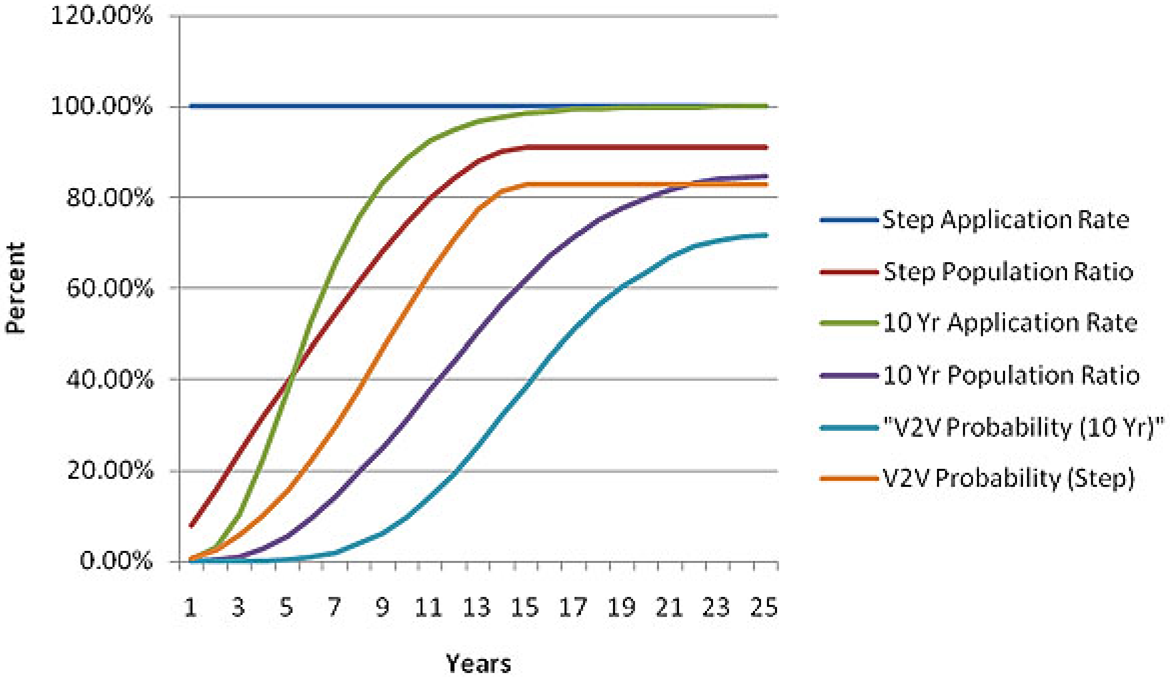
RSE Location		Estimated # of Sites		
Urban	Arterial Traffic Signal	210,000	235,000	252,000
	Arterial (no signal)	0		
	Highway/Freeway/ Interstate	25,000		
Rural	Interstate/Other NHS Routes	17,000	17,000	

In 2010-2011, AASHTO performed a Connected Vehicle Field Infrastructure Deployment Analysis[35] to begin to analyze the potential approaches for deploying the infrastructure components of connected vehicle systems by State and local transportation agencies. The analysis assumed that the infrastructure deployment decisions of State and local agencies would be based on the nature and timing of the benefits that would accrue to the agencies from connected vehicle system applications. The analysis also assumed that, in turn, these benefits would depend on the availability of connected vehicle equipment installed in vehicles, either as original equipment installed by the manufacturer or through the availability of aftermarket, nomadic, or retrofit devices purchased by vehicle owners. Projections of future market growth for connected vehicle systems were, therefore, a core component of the AASHTO deployment assessment. These projections depended heavily on the presumed underlying market mechanics. For example, safety-related anti-lock braking system and traction control system were not mandated, but grew organically based on consumer demand. These followed a market growth curve of 15 years to 90 percent deployment in vehicles. In contrast, airbags followed an initial organic curve that accelerated via mandate.

The long life and large installed base of light vehicles in the United States means that changes in the fleet occur slowly. At the production rate of around 15 million units per year, the fleet is theoretically replaced every 13 years. However, some vehicles are retired early, and some vehicles last longer than the average. In general, new features are not adopted immediately across the entire annual build, so the rate of adoption of a feature in the vehicle population can lag substantially behind the introduction of the feature.

Figure 17 illustrates these characteristics. In this model there is an assumed vehicle life span distribution with an average of 13 years and a power-law survival distribution in which a small fraction of vehicles do not survive the first year and some vehicles last more than 25 years. The figure shows the population ratio of a feature (i.e., the percentage of vehicles with the feature) based on both a step function introduction (i.e., that all new vehicles are built with the feature) and a more typical S-curve application rate characteristic in which the feature is introduced into the fleet over time. In the case of connected vehicles, a step function would occur if the NHTSA agency decision resulted in a mandate to install DSRC radios in all new light vehicles in the U.S.

Figure 17. Characteristics of New Feature Introduction in the Vehicle Fleet[35]



(Extended Text Description: This figure shows the Connected Vehicle Market Growth, comparing Percentage on the y axis with Years on the x axis. The figure shows lines indicating the Step Application Rate (a straight line at 100% across all years 1-25), Step Population Ratio (a curve that rises from less than 10% and peaks at 90% by approximately year 15), 10Yr Application Rate (a curve that rises from 0% and approaches a peak of 100% by approximately year 17), 10Yr Population Ratio (a curve that rises more gently from 0% and approaches a peak of approximately 85% by approximately year 23), V2V Probability (10Yr) (a curve that rises more gently from 0% and approaches a peak of approximately 70% by approximately year 23), and V2V Probability (Step) (a curve that rises from 0% and peaks at approximately 83% by approximately year 13). Additional Author notes: This figure illustrates projections of future market growth for Connected Vehicle systems and the effect of this market growth on receiving benefits from V2V safety applications.)

The S-curve growth rate used in the figure assumes that the application rate grows over time from zero to 90 percent in about 10 years, with initial growth relatively slow, maximum growth in the middle years and then flattening out in later years. This application rate is slightly faster than most automotive features, so it is possible that the growth rate could be slower, and this would lead to longer time spans to reach the same fleet penetration rates.

The figure shows that a step feature introduction requires about 13 years to result in 90 percent of the entire U.S. light vehicle fleet being equipped. In contrast, the more typical phased introduction over a 10-year period results in a delay of 20 years before 90 percent of the U.S. light vehicle fleet is equipped. This phased introduction reaches 50 percent of the U.S. light vehicle fleet in about 14 years.

These characteristics of the automotive market have important consequences for connected vehicle system deployments. Specifically, any deployment that relies on automotive production will not see a sizable equipped population for more than a decade. For V2V safety this is especially problematic. While equipped vehicles would produce immediate benefits through V2I services, V2V benefits would only occur when both interacting vehicles are equipped. Figure 17 shows that the probability of obtaining benefits from V2V communications is less than 50 percent for more than 17 years after initial introduction of the feature. For a step function introduction of the feature, this point is reached at about 10 years.

Connected vehicle equipment may be introduced into vehicles in one of three principal ways: (1) fully-integrated OEM-installed systems; (2) systems retrofitted by OEM dealers or OEM licensed third-parties; or (3) aftermarket or nomadic devices carried into the vehicle by drivers. Retrofit, aftermarket, and nomadic devices have been suggested as a means of more quickly deploying connected vehicle applications. If the objective is to deploy connected vehicle systems through consumer interest, deployment would likely occur through leveraging and extending existing product categories. Many of the postulated connected vehicle applications are already available or readily achievable as existing product extensions.

The existing product categories relevant to connected vehicle deployments are diverse but converging. The computing capabilities of small consumer electronics continue to expand. The number of consumer electronic devices with data connections has exploded in recent years. Both transportation agencies and commercial providers have released new software applications and data feeds for several transportation modes.

In 2014, AASHTO, in conjunction with the USDOT and Transport Canada, developed a Connected Vehicle Field Infrastructure Footprint Analysis to provide supporting information to transportation decision makers[7]. The intent of the document was to provide background information on the connected vehicle program, develop a number of deployment scenarios to demonstrate the installation needs associated with connected vehicle field infrastructure and develop estimates for the cost of a national deployment based on data gathered from existing deployments around the country. The report is currently hosted at the AASHTO Subcommittee on Transportation Systems Management and Operations web site at http://stsmo.transportation.org/Documents/AASHTO%20Final%20Report%20_v1.1.pdf .

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Other Emerging Opportunities

Since the connected vehicle environment as envisioned in the preceding discussion has not yet been widely deployed, it can be argued that this entire module represents an emerging opportunity for improving transportation safety, mobility, and environmental impact. However, another area of emerging technology—autonomous vehicles—may converge with the connected vehicle initiative.

An autonomous vehicle is one that is capable of sensing its environment and navigating without human input. A human may select a destination but is not required to mechanically operate the vehicle. Autonomous vehicles sense their surroundings with such techniques as radar, LIDAR, GPS technology, or computer vision. Advanced control systems on board the vehicle then interpret the sensor information to identify the appropriate navigation paths and obstacles and interpret the relevant signs.

In recent years, significant advances have been made in both technology and legislation relevant to autonomous vehicles. Several major companies have developed working autonomous prototypes, including Google, Nissan, Toyota, and Audi. In June 2011, the State of Nevada was the first jurisdiction in the United States to enact legislation concerning the operation of autonomous vehicles for testing purposes using professional drivers.

Autonomous vehicles have the potential to generate benefits that are consistent with the objectives of the connected vehicle initiatives, such as reducing traffic crashes and congestion and improving the fuel efficiency and reduction of vehicle emissions. Opportunities for collaborative development and deployment must therefore be seen to exist.

Other state and local agencies are aggressively courting the research, development and testing of connected and autonomous vehicle technologies. As a result, a number of test sites have been developed over the past few years in addition to the formal sites identified earlier. These include MCity at the University of Michigan (http://www.mtc.umich.edu/test-facility) and GoMentum station in Contra Costa County, California (http://gomentumstation.net/). As these and other sites are brought online, matched with the legislative and policy work being done by many state agencies to encourage testing and development, new lessons will continue to be learned and the technologies will continue to develop at a rapid pace.

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Summary

- The connected vehicle environment uses wireless connectivity among vehicles, the infrastructure, and mobile devices to bring about transformative changes in highway safety, mobility, and the environmental impacts of the transportation system.
- The vision of a national multimodal connected vehicle environment requires participation of a broad community of stakeholders: Federal, State, and local transportation agencies; car, truck and bus manufacturers; telecommunications providers and consumer electronics manufacturers; and researchers.
- Benefits from the connected vehicle environment are expected to accrue in a number of areas:

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[7] National Connected Vehicle Field Infrastructure Footprint Analysis. June 27, 2014. James Wright, et. al. Report Number FHWA-JPO-14-125.
http://stsmo.transportation.org/Documents/AASHTO%20Final%20Report%20_v1.1.pdf

  - Combined use of V2V and V2I communications has the potential to address 81 percent of unimpaired driver crashes in all vehicle types.
  - Connected vehicle systems have the potential to reduce urban traffic congestion, travel delays, and vehicle emissions as well as improve vehicle fuel efficiency.
- Strategic challenges remain in the Connected Vehicle Program:
  - To resolve remaining technical challenges;
  - To conduct testing to determine the actual benefits of applications;
  - To determine whether overall benefits are sufficient to warrant implementation, and, if so, how the systems would be implemented;
  - To address issues related to funding and identifying who will deploy, operate, and maintain the roadside equipment and the SCMS; and
  - To address issues of public acceptance, such as maintaining user privacy and whether systems in vehicles are secure, effective, safe, and easy to use.
- The Connected Vehicle Safety Pilot is a scientific research initiative to collect the data needed to understand the safety benefits of these technologies. This data was critical to supporting the 2014 NHTSA decision on the deployment of connected vehicle core technologies for light vehicles.
- Although the Safety Pilot Model Deployment testing is complete, testing, development and data collection activities continue.
  - The USDOT Connected Vehicle Pilot Deployment project kicked-off in September of 2015 with the planning and design for test beds in Wyoming, New York City and Tampa, Florida.
  - The USDOT Smart City Challenge includes a connected vehicle component that is expected to kick-off in late 2016
  - The Ann Arbor Connected Vehicle Test Environment continues research and development in Ann Arbor, MI where the Safety Pilot Model Deployment research left off.
  - There are other USDOT support projects that are ongoing, including the Connected Vehicle Reference Implementation Architecture, the Connected Vehicle Core Services, the Research Data Exchange and the Open Source Applications Data Portal.
- Applications are the most visible part of the connected vehicle environment. Applications allow the connected vehicle systems and technologies to deliver services and benefits to users.
- Connected vehicle applications are typically divided into three broad categories, with each category comprised of bundles of individual applications. The categories are
  - Safety applications (including those based on V2V communications and those based on V2I communications);
  - Dynamic mobility applications; and
  - Environmental applications.
- The connected vehicle environment will require the deployment of technologies falling into six broad categories:
  - In-vehicle or mobile equipment;
  - Roadside equipment;
  - Core systems;
  - Support systems;
  - Communications systems; and

  - Applications-specific systems.
- DSRC technologies were developed specifically for vehicular communications and are reserved for transportation safety applications by the FCC.
- USDOT is committed to the use of DSRC communications for active safety in both V2V and V2I applications. However, other media, such as cellular communications, are being explored for their applicability to other safety, mobility, and environmental applications.
- The connected vehicle program will rely on secure communications: Users of the system must be able to trust the validity of messages from other system users.
  - Current research indicates that the use of a PKI security system, involving the exchange of digital certificates among trusted users, can support the need for both message security and appropriate anonymity for users.
- Connected vehicle policy and institutional issues are topics that may limit or challenge successful deployment. Key principles for the connected vehicle environment have been identified by USDOT to guide policy research. Policy issues that require research have been identified in four categories:
  - Implementation policy issues;
  - Technical policy issues;
  - Legal policy issues; and
  - Implementation strategies.
- Work conducted by AASHTO through a connected vehicle field infrastructure deployment analysis indicates that the infrastructure deployment decisions of State and local transportation agencies will be based on the nature and timing of benefits that will accrue to the agencies. In turn, these benefits will depend on the availability of connected vehicle equipment installed in vehicles, either as original equipment or as after-market devices.

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Additional Resources

AASHTO Subcommittee on Transportation Systems Management and Operations
website: http://stsmo.transportation.org/Pages/default.aspx

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"Connected vehicles" refers to the ability of vehicles of all types to communicate wirelessly with other vehicles and roadway equipment, such as traffic signals, to support a range of safety, mobility, and environmental applications of interest to the public and private sectors. Vehicles include light, heavy and transit vehicles. The concept also extends to compatible after-market devices brought into vehicles and to pedestrians, motorcycles, cyclists, and transit users carrying compatible devices. Collectively, these components form the connected vehicle environment.

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