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# Overview of Vehicle Infrastructure Integration (VII) Applications

**Chris Hedges and Doug Welk**
Delphi Electronics & Safety

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# Overview of Vehicle Infrastructure Integration (VII) Applications

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## ABSTRACT

Vehicle Infrastructure Integration (VII) is an initiative of the US Department of Transportation to provide communications among vehicles and between vehicles and roadside infrastructure in order to increase the safety and productivity of transportation systems. It makes use of but is not restricted to the 5.9 GHz Dedicated Short Range Communication (DSRC) spectrum.

There are 3 major categories of applications for VII – Highway Safety, Vehicular Mobility, and Consumer & Commercial Services.

There are currently approximately 42,000 traffic fatalities a year in the United States. Reducing deaths, injuries and property damage is of the highest priority in the development of VII applications. Electronic Brake Warning, Signal Phase and Timing, and Collision Detection are among the applications dedicated to improving highway safety.

Increasing traffic volume is outpacing the addition of new roadway capacity, resulting in increasing delays, congestion and frustration. Vehicle Mobility applications are intended to address these concerns. Example applications include Traveler Information and Off-board navigation with real-time traffic updates.

The deployment of a large-scale, standards-based infrastructure enables ubiquitous applications for both public and private enterprises. Beyond Electronic Tolling and Fleet Management, it allows Remote Diagnostics and Software Updates to be provided nationwide.

This paper provides overviews of several VII applications and describes the benefits provided to commercial vehicles and other operators.

## INTRODUCTION

The U.S. Department of Transportation, working together with the auto industry and other key stakeholders, initiated the Vehicle Infrastructure Integration (VII) program to improve vehicle safety and mobility through the use of modern mobile communication technology[1]. Proof-of-concept (POC) networks have been deployed in Detroit, MI and the San Francisco Bay area in California[2][3]. As depicted in Figure 1, The VII system architecture consists of three major segments: the vehicle segment, the roadside segment and the backend segment.

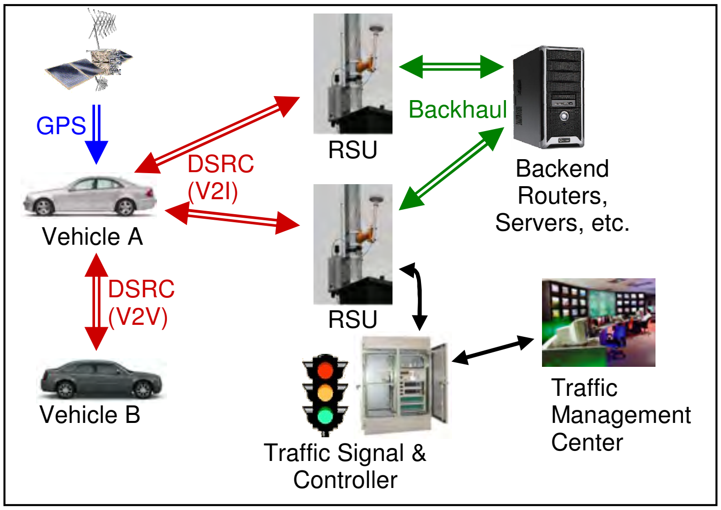


Figure 1: VII System Architecture

As its name implies, the vehicle segment consists of the vehicles that traverse the roadway network. Each vehicle is outfitted with an on-board unit (OBU), a GPS receiver, a driver HMI and a DSRC/WAVE transceiver. As implemented for the Detroit test area, the OBU is a Linux-based computer that runs all of the in-vehicle application components, manages HMI interactions with the driver, and manages communications with the roadside segment.

Communication between the vehicle segment and the roadside segment utilizes a variant of WiFi known as WAVE or DSRC operating at 5.9 GHz. This spectrum has been allocated for Intelligent Transportation System (ITS) applications by the Federal Communications Commission and is therefore relatively free of interference. The communication physical and protocol layers are standardized by IEEE as IEEE 802.11p and IEEE 1609.

The roadside segment consists of road side units (RSU) that are strategically located throughout the deployment areas ensuring that adequate communication capacity is available for the vehicles. RSUs are typically located at signalized intersections and freeway access points. The primary function of an RSU functions is to be an intelligent network access point and relay data between the vehicles and the backend segment.

The backend segment consists of various networking and data processing equipment such as routers, firewalls, network storage, data servers, and application servers. This segment of the architecture is responsible for the appropriately filtering, processing and storing data received from the vehicle. It also analyzes the data, combines it with data from other sources and transmits information back to the vehicles. Due to the data intensive nature, this segment is the most complex one.

What can a VII system do? More than 110 different use cases have been identified in order to answer that question[4]. A short list of the more important use cases is included below.

- Brake Light Warning
- Traffic Signal Violation Warning
- Stop Sign Violation Warning
- Curve Speed Warning
- Display Local Signage
- Off-Board Navigation
- Real Time Traffic Information
- Finding Parking Locations
- Electronic Payments – Parking
- Electronic Payments – Tolling
- Traveler Information
- Fleet Management
- Ramp Metering
- Signal Timing Optimization
- Pothole Detection
- Winter Maintenance
- Corridor Planning Assistance
- Corridor Load Balancing
- Weather Information Notification
- Improved Weather Measurement
- Vehicle Load Measurement
- Slippery Road
- Commercial Vehicle Clearance
- Border Crossing Information
- School Zone Warning

There are three major categories of VII use cases: Highway Safety, Vehicular Mobility and Consumer and Commercial Services. For the POC test beds, several system applications have been developed in each of these major categories. These system applications normally consist of software components in each of the three system segments that function together to implement a specific use case. This paper will explore a few of these applications and provide examples of the benefits to the commercial vehicle industry.

## MAIN SECTION – VII APPLICATIONS

### HIGHWAY SAFETY

There are currently approximately 42,000 traffic fatalities a year in the United States. Reducing deaths, injuries and property damage is of the highest priority in the development of VII applications. Many safety applications employ on-board sensors such as radar to detect proximity to other vehicles. The reliability and cost of these sensors can be a burden to these autonomous safety systems. Weather conditions can also affect sensor performance. Sharing vehicle dynamics information such as position and velocity over an inexpensive short range radio link has been publicly demonstrated by others[5]. One result of this capability is that the dedicated vehicle sensors can be augmented or possibly even replaced by an inexpensive DSRC radio. If DSRC becomes an industry accepted practice, its penetration into commercial fleets will grow rapidly.

Electronic Brake Light (EBL) Warning, Signal Phase and Timing, and Collision Detection are among the applications dedicated to improving highway safety.

### ELECTRIC BRAKE LIGHT (EBL) WARNING

The basic operation of EBL is that when a vehicle detects that it is experiencing excessively hard braking, it broadcasts a message to other nearby vehicles. The message used is the J2735 Basic Safety Message[6] and includes basic information such as the vehicle's location, heading, speed and the fact that it is experiencing a hard breaking situation. The surrounding vehicles receive the message and present a warning to the driver if appropriate. This operation can potentially reduce the driver's overall reaction time and creating an extra margin of safety. This is especially true if the braking vehicle is not directly visible.

Additionally, vehicles receiving the excessive braking notification can rebroadcast the original message in order to ensure that a warning can be presented to all potentially affected drivers. Obviously, indiscriminate retransmission will result in excessive and wasteful bandwidth utilization through broadcast of duplicated messages and broadcasting to unaffected vehicles. Therefore, each vehicle utilizes an algorithm based on parameters such as relative heading, distance, time, and severity in order to decide whether or not the message should be rebroadcast. For example, vehicles moving away from the braking vehicle will not rebroadcast. This results in a propagation wave that moves out behind the braking vehicle, but not ahead of it. In other cases, the messages may simply be too old or too far away to be meaningful – is it really useful to know that a vehicle ½ mile ahead braked hard 3 seconds ago? Simply discarding the message in these cases results in a natural termination of the message propagation wave front.

## SIGNAL PHASE AND TIMING

In the simplest form of the signal phase and timing application, a vehicle approaching a signalized intersection receives the current light phase (red, yellow, green, etc.) and the time remaining until the next phase from the signal controller. In the vehicle, knowledge of upcoming signal changes can be combined with the gross vehicle weight and other factors in order to warn the driver about an imminent red light violation. In addition, a display could also let the driver know how long a red signal will last and could also indicate if it would be appropriate to shut the vehicle down in order to save fuel, and when to start up again to be ready for the signal change to green.

In more advanced implementations of the application, the vehicle and the signal controller work together to mitigate potentially dangerous situations. Vehicles continually transmit a “heartbeat” containing position, heading, speed, brake-pedal status, etc.[6] The signal controller transmits its current state and a countdown to its next state change and processes the heartbeat messages from vehicles approaching the intersection. If the controller determines that a vehicle will not be able to stop for an imminent red signal, it can delay the change to green for cross traffic. In addition, an intersection collision warning can be issued by the signal controller to vehicles when it determines that there is a high probability of a collision. Similar mechanisms can also be utilized to support signal preemption for emergency vehicles or other high-priority traffic.

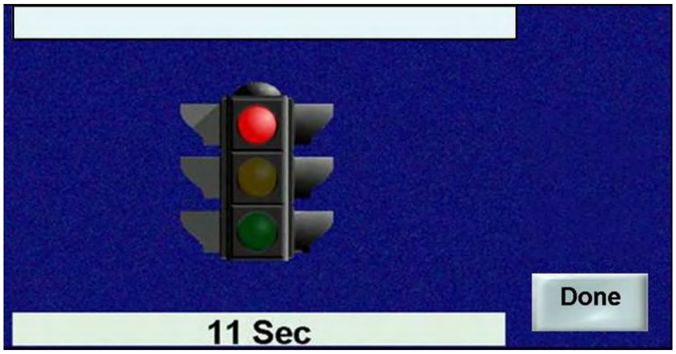


Figure 2: Example Signal Phase and Timing Display

## AUTONOMOUS COLLISION DETECTION

In the Signal Phase and Timing application, the signal controller performs all of the necessary collision detection computations and generation of the warning messages. Autonomous Collision Detection extends this concept so that collision detection is performed by individual vehicles with the implication that collision detection can take place any time two or more vehicles are in close proximity. In the simplest form, intercept vectors are computed for each of the surrounding vehicles based on the heartbeat messages and the vehicle’s own position and projected path. If a high potential threat is detected a strong warning is presented to the driver via a Human Machine Interface (HMI) and active vehicle control (steering, braking, etc.) can possibly be initiated.

For commercial vehicles, threats resulting from a vehicle in the blind spot are perhaps the most common of all potential collisions that can be warned about in this manner.

## VEHICULAR MOBILITY

Increasing traffic volume is outpacing the addition of new roadway capacity, resulting in increasing delays, congestion and frustration. Obviously, these delays cost commercial operations time and money. A December 2006 report[7] estimates the economic impact of congestion in the New York City area alone as up to $13B annually and up to 51,512 lost jobs. Vehicle Mobility applications are intended to address these concerns. Example applications include Traveler Information and Off-Board Navigation with real-time traffic updates.

## TRAVELER INFORMATION AND IN-VEHICLE SIGNAGE

Traveler Information enables the transmission of advisory messages to a driver based upon location and other situationally-relevant information. Examples include traveler advisories such as traffic information, traffic incidents, major event information, and evacuation notifications as well as normal road signs. Traveler advisories are dynamic and temporary in nature. Conversely, road sign messages emulate their physical counterparts with static content and a high degree of permanence. Messages are typically broadcast by roadside equipment which is usually located in the general region of the affected areas. When these messages are received by passing vehicles, they are simply stored for future use. Subsequently during normal driving, each vehicle continually compares its position, heading and the time of day to the corresponding attributes of the broadcast messages. When a match is detected, the driver is alerted through text, graphics, or audio cues. The specific presentation of the message should be tailored by the individual vehicle manufactures in order to conform to their overall vehicle HMI designs.

Messages are broadcast in the Traveler Information format defined by SAE J2735. In order to facility the broadcast of several information messages or signs from a single piece of roadside equipment, each message contains a physical region description that defines the active area for the message. For example, a general "freezing rain" advisory may have a city-wide active region, while a particular "low bridge warning" will have a relatively small active region. A particular message has no meaning outside of its active region. Additional attributes such as effective direction and time of day limitations are used to further filter which messages need presented to the driver. As a result, a commercial driver will be presented with travel advisories only when they affect traffic on the road he is on and in the proper direction of travel.


Figure 3: Example Advisory Message Display

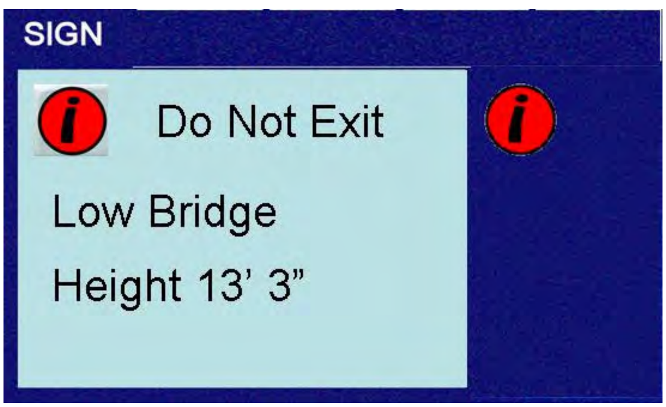


Figure 4: Example Road Sign Message Display

OFF BOARD NAVIGATION

Navigation devices are readily available and are very popular with everyday consumers. Some of the issues with this type of navigation are the staleness of the map data and the ability to take into account the current and projected traffic and road conditions when performing route calculations. Currently there are several providers of traffic data (see http://www.traffic.com for example), but coverage is typically limited to major roads in bigger cities. The Off Board Navigation application uses the vehicle's connectivity to enhance the navigation experience by making this information available for more areas. After the vehicle destination has been selected and entered, the system uses the DSRC radio to communicate to an outside service, which is operated by NAVTEQ. The NAVTEQ service performs the route calculation using the most up to date maps, traffic, and construction information available and sends the route back to the vehicle. The in-vehicle application then provides route guidance as normal. During driving, the in-vehicle application is also querying the NAVTEQ service to see if conditions have changed and a different route is now optimal. If so, the new route can be downloaded to the vehicle.

Performing the main calculations off board, also allows advanced routing options that aren't available with a normal navigation device. For example, a route can be computed that avoids a stadium just after a big game is over. In addition, traffic management centers can more readily adjust traffic flow patterns, such as reversing interstate travel directions during a hurricane evacuation situation.


Figure 5: Example Navigation Screen

CONSUMER & COMMERCIAL SERVICES

The deployment of a large-scale, standards-based infrastructure enables ubiquitous applications for both public and private enterprises. Beyond Electronic Tolling and Fleet Management, it allows Remote Diagnostics and Software Updates to be provided nationwide.

ELECTRONIC TOLLING

The payment of tolls has been improved with the use of electronic payment systems allowing the vehicle to continue through a toll point without stopping. One of the goals of the VII system is to establish a standard that could be applied across the country enabling a single system to be used for all tolling. The system could also be adapted for used to provide access to high occupancy vehicle (HOV) lanes. When capacity permits, a vehicle could use the HOV and pay a toll allowing flexibility to adapt to current traffic conditions.

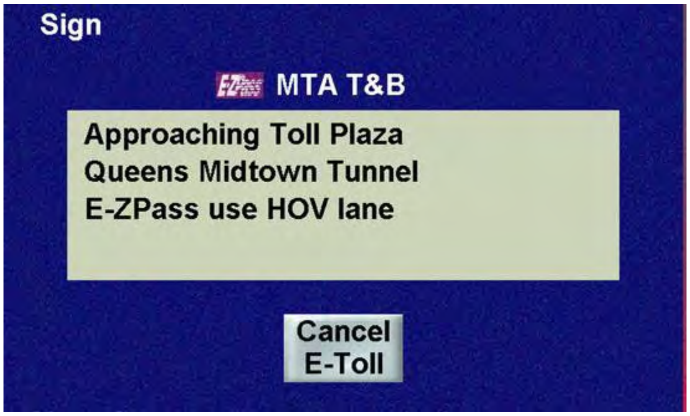


Figure 6: Example Tolling Display

FLEET MANAGEMENT AND DIAGNOSTICS

The VII system allows vehicle data to be transmitted through the roadside equipment back to a private server system. The information transmitted from the vehicle can include the detailed information on vehicle operation that is available on the vehicle data bus as well as the distance and locations traveled. This information can be utilized to help efficiently manage the vehicle fleet, to reduce costs by allowing maintenance to be performed only when necessary, and to simplify fuel tax calculations.

SOFTWARE UPDATES

The ability to update in vehicle electronic modules (such as the VII OBU) with new applications, features or bug fixes has significant value. Normally, these types of updates require replacement of the entire module or at least a shop visit to load new software. One of the goals of the VII system is to safely enable updating the OBU software over the air, while maintaining appropriate application and protocol security. The implication is that it is now possible to safety and securely update software on a truck while it is in the field.

## CONCLUSION

The applications and system described here will enable vehicles to be connected in ways that improve safety, improve mobility and enhance overall operation. Vehicle safety will be improved with the goal of reducing highway accidents. The Information from the vehicles will enable real time traffic information to be used to improved traffic flow, provide more accurate route information, and reduce congestion. The traffic information can also be looked at over time to assist in corridor management. The door will be open for many new applications and services for consumer and commercial users that will enhance the driving experience and reduce operational costs

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## CONTACT

Chris Hedges
Delphi Electronics and Safety
P.O. Box 9005, M/C E110
Kokomo, IN 46904-9005
(765) 451-9159
Chris.A.Hedges@delphi.com

Doug Welk
Delphi Electronics and Safety
P.O. Box 9005, M/C E110
Kokomo, IN 46904-9005
(765) 451-9159
Douglas.L.Welk@delphi.com

## ACRONYMS & ABBREVIATIONS

**DSRC** Dedicated Short Range Communication

**EBL** Electric Brake Light (Warning)

**FCC** Federal Communication Commission

**GPS** Global Positioning Service

**HMI** Human Machine Interface

**HOV** High Occupancy Vehicle Lane

**IEEE** Institute of Electrical and Electronics Engineers

**OBU** On-Board Unit

**RSU** Road Side Unit

**SAE** Society of Automotive Engineers

**V2V** Vehicle to Vehicle

**VII** Vehicle Infrastructure Integration

**WAVE** Wireless Access in Vehicular Environment