# Vehicle Safety Communications – Applications VSC-A

## Second Annual Report
## January 1, 2008 through December 31, 2008

**CAMP**
*Vehicle Safety Communications 2*

Mercedes-Benz
Research & Development North America, Inc.

GM

TOYOTA

HONDA
Honda R&D Americas, Inc.

Ford

*Intelligent Transportation Systems*

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16. Abstract

The Vehicle Safety Communications – Applications (VSC-A) project is a three year project (December 2006 - December 2009) to develop and test communications-based vehicle-to-vehicle safety systems to determine if Dedicated Short Range Communications (DSRC) at 5.9 GHz, in combination with vehicle positioning, can improve upon autonomous vehicle-based safety systems and/or enable new communications-based safety applications. The VSC-A project is being conducted by the Vehicle Safety Communications 2 Consortium (VSC2). Members of VSC2 are Ford Motor Company, General Motors Corporation, Honda R & D Americas, Inc., Mercedes-Benz Research and Development North America, Inc., and Toyota Motor Engineering & Manufacturing North America, Inc. This document presents the second annual report of the VSC-A project.

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# List of Acronyms

| | |
|---|---|
| ABS: | Anti-Lock Braking System |
| API: | Application Programming Interface |
| BSS: | Basic Service Set |
| BSW: | Blind Spot Warning |
| BSM: | Basic Safety Message |
| CAMP: | Crash Avoidance Metrics Partnership |
| CAN: | Controller Area Network |
| CCH: | Control Channel |
| CICAS-V: | Cooperative Intersection Collision Avoidance System - Violation |
| CLW: | Control Loss Warning |
| COTR: | Contracting Officer's Technical Representative |
| COTS: | Commercial Off-the-Shelf |
| CPH: | Concise Path History |
| CVIS: | Cooperative Vehicle-Infrastructure Systems |
| DGPS: | Differential Global Positioning System |
| DMU: | Dynamics Measurement Unit |
| DNPW: | Do Not Pass Warning |
| DSRC: | Dedicated Short Range Communications |
| DVI: | Driver-Vehicle Interface |
| DVIN: | Driver-Vehicle Interface Notifier |
| EEBL: | Emergency Electronic Brake Lights |
| EGUI: | Engineering Graphical User Interface |
| ENET: | Ethernet |
| ETSI: | European Telecommunications Standards Institute |
| FCC: | Federal Communications Commission |
| FCW: | Forward Collision Warning |
| FLC: | Forward Looking Camera |
| FOT: | Field Operational Test |
| GID: | Geometric Intersection Description |
| GM: | General Motors |

| | |
|---|---|
| GNSS: | Global Navigation Satellite System |
| GPS: | Global Positioning System |
| HMI: | Human-Machine Interface |
| HVPP: | Host Vehicle Path Prediction |
| HW: | Hardware |
| IEEE: | Institute of Electrical and Electronics Engineers |
| I-V or I2V: | Infrastructure-to-Vehicle |
| IMA: | Intersection Movement Assist |
| IPv6: | Internet Protocol version 6 |
| ISO: | International Organization for Standardization |
| ITS: | Intelligent Transport Systems |
| JPO: | Joint Program Office |
| LCW: | Lane Change Warning |
| MAC: | Medium Access Control (layer) |
| MoVeNet: | Mobile Vehicle Networks |
| NHTSA: | National Highway Traffic Safety Administration |
| NS-2: | Network Simulator 2 |
| NMEA: | National Marine Electronics Association |
| NTSC: | National Television System Committee |
| NYC: | New York City |
| OBE: | On-Board Equipment |
| OEM: | Original Equipment Manufacturer |
| OTA: | Over-The-Air |
| OTP: | Objective Test Procedures |
| PATH: | Partners for Advanced Transit and Highways |
| PC: | Personal Computer |
| PER: | Packet Error Rate |
| PHY: | Physical (layer) |
| PI: | Principal Investigator |
| PP: | Path Prediction |
| RITA: | Research and Innovative Technology Administration |
| RS: | Radio Services |
| RTCM: | Radio Technical Committee for Maritime (Services) |

| RTK: | Real-Time Kinematic |
|------|---------------------|
| SAE: | Society of Automotive Engineers |
| SDH: | Sensor Data Handler |
| SP: | Single Point (method) |
| SPaT: | Signal Phase and Timing |
| SR: | Scenario Replicator |
| SW: | Software |
| TA: | Threat Arbitration |
| TC: | Target Classification |
| TESLA: | Timed Efficient Stream Loss-tolerant Authentication |
| TGp: | Task Group p |
| TMT: | Technical Management Team |
| TPS: | Time and Position Services |
| UDP: | User Datagram Protocol |
| USB: | Universal Serial Bus |
| USDOT: | United States Department of Transportation |
| UTC: | Coordinated Universal Time |
| VGA: | Video Graphics Array |
| VII: | Vehicle Infrastructure Integration |
| VII-C: | Vehicle-Infrastructure Integration – Consortium |
| VIS: | Vehicle Interface Services |
| VSC: | Vehicle Safety Communications |
| VSC2: | Vehicle Safety Communications 2 (consortium) |
| VSC-A: | Vehicle Safety Communications – Applications |
| V-V or V2V: | Vehicle-to-Vehicle |
| WAAS: | Wide Area Augmentation System |
| WAVE: | Wireless Access in Vehicular Environments |
| WC: | World Congress |
| WMH: | Wireless Message Handler |
| WSM: | WAVE Short Messages |
| WSU: | Wireless Safety Unit |

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# 1    Introduction

The United States Department of Transportation (USDOT) has conducted extensive research on the effectiveness of vehicle-based collision countermeasures for rear-end, road departure, and lane change crashes. Field Operational Tests (FOT) of rear-end and road departure collision warning systems have shown measurable benefits in reduction of crashes. However, the systems have inherent shortcomings that reduce their effectiveness and limit driver acceptance. These shortcomings include misidentification of stopped cars and in-path obstacles for rear-end collision warning systems, as well as map errors and misidentified lane markings for road departure crash warning systems. Vehicle-to-vehicle (V2V) wireless communications and vehicle positioning may enable improved safety system effectiveness by complementing or, in some instances, providing alternative approaches to autonomous safety equipment.

The USDOT and the Crash Avoidance Metrics Partnership–Vehicle Safety Communications 2 (CAMP—VSC2) Consortium (Ford, General Motors (GM), Honda, Mercedes-Benz, and Toyota) have initiated a 3-year collaborative effort in the area of wireless-based safety applications under the Vehicle Safety Communications – Applications (VSC-A) project. The goal of VSC-A is to develop and test communications-based vehicle safety systems to determine if Dedicated Short Range Communications (DSRC) at 5.9 GHz, in combination with vehicle positioning, can improve upon autonomous vehicle-based safety systems and/or enable new communications-based safety applications.

To address the goal of the VSC-A program as stated above, the program has the following list of objectives:

- Assess how previously identified crash imminent safety scenarios in autonomous systems could be addressed and improved by DSRC+Positioning systems.

- Define a set of DSRC+Positioning based vehicle safety applications and application specifications including minimum system performance requirements.

- In coordination with NHTSA and VOLPE, develop a well understood and agreed upon benefits versus market penetration analysis and potential deployment models for a selected set of communication-based vehicle safety systems.

- Develop scalable, common vehicle safety communication architecture, protocols and messaging framework (interfaces) necessary to achieve interoperability and cohesiveness among different vehicle manufacturers. Standardize this messaging framework and the communication protocols (including message sets) to facilitate future deployment.

- Develop accurate and affordable vehicle positioning technology needed, in conjunction with the 5.9 GHz DSRC, to support most of the safety applications with high-potential benefits.

- Develop and verify a set of Objective Test Procedures (OTP) for the vehicle safety communications applications.

This report reflects the activities and accomplishments that have been made under the VSC-A program for the 2<sup>nd</sup> year of the program.

# 2    Task 1 Summary: Program Management

To help achieve the objectives of the project as stated in Section 1, the VSC-A project activities were divided into 11 tasks, and where appropriate sub-tasks, and are listed in Table 1. The tasks define a structure for the work to be done in the program.

**Table 1: VSC-A Task Breakdown**

| Task # | Task Title | Sub-Task(s) |
|---|---|---|
| 1 | Program Management | NA |
| 2 | Coordination with Standards Development Activities and Other USDOT Programs | NA |
| 3 | Vehicle Safety Communications and Autonomous Safety Systems | 3.1: Identify the set of generic shortcomings that affects rapid deployment of autonomous safety systems<br>3.2: Identify root causes behind shortcomings<br>3.3: Identify subset of shortcoming and root causes that can be addressed with the addition of DSRC+Positioning<br>3.4: Identify and analyze new crash imminent scenarios addressed by DSRC+Positioning safety system and analyze advantages of the system |
| 4 | Vehicle Safety Communication System Definition | 4.1: Identify DSRC+Positioning methods to address root causes of autonomous safety system shortcomings<br>4.2: Identify safety features of vehicle safety communication system<br>4.3: Define safety system structures |
| 5 | DSRC+Positioning Only Safety System Structure Development | 5.1: System concepts of operation, requirements and minimum performance specifications<br><br>5.2: VSC system architecture, communication architecture, standardized messages, and |

| Task # | Task Title | Sub-Task(s) |
|---|---|---|
| | | protocols<br>5.3: Relative vehicle positioning development (for V-V safety applications)<br>5.4: Integration of forward looking camera for vehicle positioning aiding |
| 6 | DSRC+Positioning and Autonomous Sensing Safety System Analysis | NA |
| 7 | Vehicle Safety Communication System Test Bed | NA |
| 8 | Objective Test Procedures | NA |
| 9 | System Testing and Objective Test Procedure Validation | NA |
| 10 | Benefits Analysis Support | NA |
| 11 | Program Administration | NA |

For further details on the VSC-A task structure, description and project timing, the reader is referred to the "VSC-A First Annual Report" [1], available at: *http://www.vehicle-infrastructure.org/applications/cicas/09042008-vsc-a-report.pdf*.

Throughout the 2nd Year of the program, the Principal Investigator (PI) managed all the technical activities between the five automotive Original Equipment Manufacturers (OEM) under the VSC-A project. In addition to overseeing the Technical Management Team (TMT) members' weekly meetings and face-to-face workshops, to ensure they were organized so that adequate work progress was being achieved, the major activities undertaken as part of Task 1 included:

- Preparation and execution of VSC-A Progress Briefings Five through Eight for the USDOT along with the OEM management team.

- Submission of the following VSC-A project deliverables to the USDOT:

  - The "VSC-A First Annual Report" (this is a public document, see [1])

  - The "VSC-A 4th Quarterly Status Report"

  - The "VSC-A 5th Quarterly Status Report"

  - The "VSC-A 6th Quarterly Status Report"

  - The "VSC-A Task 4 Interim Report Vehicle Safety Communications - System Definition"

- Organization of a two-day workshop focusing on the discussion the details of Global Positioning System (GPS) Real-Time Kinematic (RTK) positioning techniques as applicable to the VSC-A relative positioning software solution.

- Participation in the Society of Automotive Engineers (SAE) Government/Industry meeting in Washington DC in May 2008.

- Completion of the VSC-A Milestone: VSC-A Level I Test Bed implementation demonstrating V2V interoperability between Ford, General Motors, Honda, Mercedes-Benz, and Toyota.

- Demonstration of the VSC-A Level I Test Bed for the USDOT, with the OEMs management team, at the Dearborn Development Center Test Track.

- Organization of vehicle wireless communications security technical workshop between the VSC-A Team and Vehicle-Infrastructure Integration - Consortium (VII-C).

- Participation at the 15th Annual Intelligent Transport Systems (ITS) World Congress (WC) in New York City (NYC) in November 2008.

# 3    Task 2 Summary: Coordination with Standards Development Activities and Other USDOT Programs

The activities conducted under Task 3 through 10 are expected to result in findings that need to be standardized, coordinated and/or communicated with other organizations, programs, and standardization activities. Task 2 has been using these findings to prepare material to be shared with standards development activities and other relevant organizations to ensure support of potential future V2V safety applications deployment and to ensure effective coordination with other programs.

An important goal of the VSC-A project is the standardization of the message sets, message composition approach, and communication protocols for 5.9 GHz DSRC-based vehicle safety communication. To further this goal, the 2008 Task 2 activities followed the Standards Support Plan developed by the Team in 2007.  This plan calls for significant VSC-A participation in the following three standards development groups:

- Institute of Electrical and Electronics Engineers (IEEE) 802.11 Task Group p (TGp)

- IEEE 1609

- SAE DSRC Technical Committee

Figure 1 illustrates the standards that are of greatest importance for DSRC.  Those with a green shading (i.e., SAE J2735, IEEE 1609, and IEEE 802.11) are in active development and received direct participation from the VSC-A Team in 2008. The others are either stable or of less direct interest to the VSC-A project.
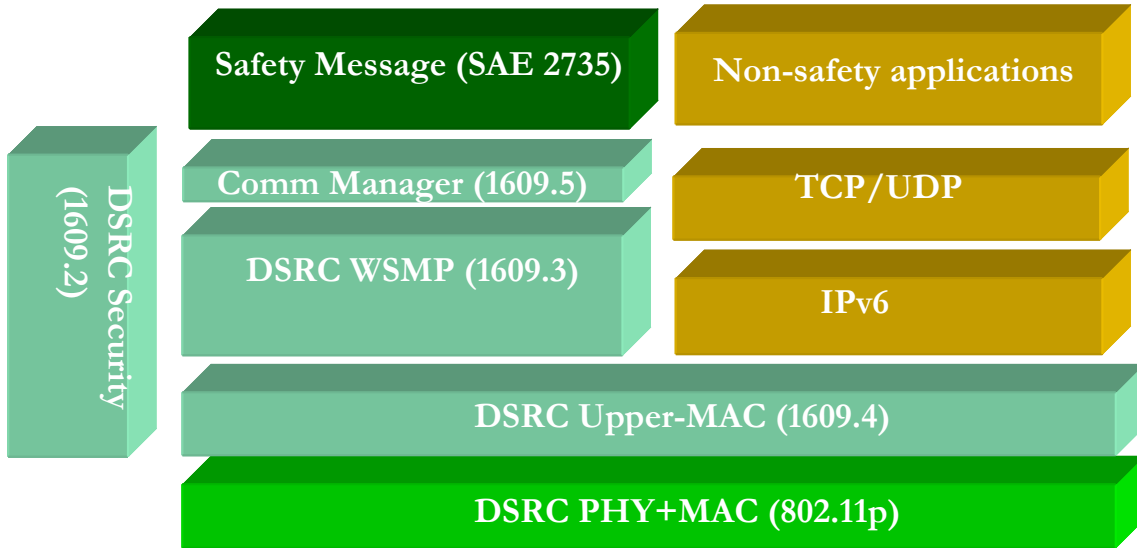
contributed by representatives of VSC-A. These representatives took responsibility for generating comment resolutions for the important Clause 5 of the amendment, which introduces the concept of WAVE communication outside the context of a Basic Service Set (BSS), explains the basic operating procedures, and outlines the constraints for a device engaging in such communication. VSC-A participation contributed directly to a much improved document in 2008.

## 3.2  IEEE 1609.x

The IEEE 1609 Family of Standards defines the "middle layers" of the protocol stack for WAVE corresponding roughly to the Network and Transport layers in a traditional layered architecture. These standards define both the data plane and management plane. In 2006 a core set of standards, 1609.1 through 1609.4, were published with a "trial-use" designation. In 2008 the Group began reviewing the results of the trial period, with a goal of improving the standards and re-publishing them with a "full-use" designation. The group met three times in 2008 and plans to meet more frequently in 2009. Representatives of the VSC-A project participated actively in these meetings, as discussed below.

Of the trial-use standards, the VSC-A project is primarily concerned with the following standards:

- 1609.2 – Security Services

- 1609.3 – Network Services

- 1609.4 – Multi-channel Operation

The VSC-A project is also monitoring the other standards activities within the 1609 Group, including the 1609.0 – Architecture and the 1609.5 – Communications Manager, but expects to take a less active role in the development of these standards.

### 3.2.1  1609.2 – Security Services

During 2008, VSC-A representatives presented three alternative message authentication procedures (see [2], [3] and [4]) to the IEEE 1609 Group, as well as a preliminary assessment of the performance and operating characteristics of the incumbent and the three alternatives. The material presented was based on the Task 5.2 activities discussed in Section 5.2.2 of this report. The VSC-A Team expects to provide further input in 2009, including the results of network simulations of the various mechanisms, and an indication of the VSC-A Team's recommendation for full vehicle safety messaging use under the 1609.2 standard.

### 3.2.2  1609.3 – Network Services

VSC-A project representatives are also engaged in evaluating the trial-use 1609.3 standard. This is undergoing moderate changes to maintain alignment with the evolving IEEE 802.11p amendment discussed in the previous section and also to introduce improvements recommended by members. The VSC-A project is primarily interested in ensuring that the full-use 1609.3 standard is consistent with 802.11p and is efficient in its use of over-the-air bandwidth.

### 3.2.3 1609.4 – Multi-Channel Operation

The Task 5.2 activities discussed in Section 5.2.6 of this report have been analyzing the channel switching protocol defined in the trial-use 1609.4 standard and researching alternatives. The VSC-A Team expects to provide details of this work to the 1609 Group in 2009, including an analysis of candidate channel switching approaches and an indication of the VSC-A project's preference for the full-use 1609.4 standard.

## 3.3 SAE DSRC J2735

The SAE J2735 Data Set Dictionary standard specifies message sets and data elements that allow interoperability at the application layer without the need to standardize applications. This approach supports innovation and product differentiation through the use of proprietary applications while maintaining interoperability in the exchange of critical information over-the-air (OTA). The message sets specified in the SAE J2735 standard are communicated wirelessly using lower layer protocols like those that are being defined in the IEEE 802.11p and IEEE 1609.x standards.

The VSC-A project is primarily interested in one of the standard message sets, the Basic Safety Message (BSM). The BSM provides a means for communication of a vehicle's essential state information to a set of neighboring vehicles over a given range. The safety applications in those neighbors process the incoming BSM data to determine the threat of collision with the sending vehicle under a variety of scenarios (e.g., blind spot, intersection, forward path collision). The BSM takes advantage of the large overlap in vehicle state information needed by various safety applications while avoiding the need for application-specific messages and saving over-the-air bandwidth.

In 2008 the SAE DSRC Technical Committee met 11 times with VSC-A Team participation at all 11 meetings and made significant progress in preparing the SAE J2735 document for balloting early in 2009. The next published version will change the designation of the document from a "recommended practice" to a "standard." As a standard, there will be an implication that future versions will maintain backward compatibility with previous versions. The VSC-A project contributed to the progress of J2735 in two significant ways during 2008. First, VSC-A analyzed the BSM in light of project requirements and made a specific proposal to SAE for modifications. This proposal, introduced in June and improved in collaboration with other interested parties through the remainder of the year, is reflected in the version of the BSM that will be placed into ballot. The second VSC-A contribution was the development of an informative annex illustrating how the BSM can be used to support several collision-avoidance applications based on vehicle-to-vehicle communication. Refer to Section 5.2.1 for details on the activities behind these contributions.

In addition to the frame structure of the OTA messages, the VSC-A project is developing recommendations both for message content and message update rates which are currently not part of the standard. To this end, the VSC-A Team proposed to the SAE DSRC—TC that a new standards activity be started to document minimum communication requirements for the support of vehicle safety applications. That recommendation was informally accepted at the December 2008 SAE meeting and this new standards activity

is expected to be started in 2009. The VSC-A Team intends to participate in this activity and submit its recommendations.

## 3.4 2008 ITS World Congress

The CAMP—VSC 2 consortium along with the USDOT agreed to participate in the 15th-World Congress on Intelligent Transport Systems (ITS WC) that took place in NYC in November. The following activities, as they relate to the VSC-A project, were performed:

- Participation in the 11th Avenue Theatre Show

- Development of a VSC-A program video which was displayed on the indoor video wall

- Presentation of a project update as part of the ITS Annual Meeting technical session 'Active Safety Systems Supported by Vehicle-to-Vehicle Communications'

## 3.4.1 11th Avenue Theatre Show

At ITS WC a 5-block section of 11th Avenue, in front of the convention hall, was closed to traffic for Infrastructure-to-Vehicle (I2V), V2V, and autonomous application demonstrations that took place daily as part of an integrated, narrated, theatre-like show. For this show the CAMP—VSC2 consortium identified three application scenarios to demonstrate a sub-set of the capabilities for one or more of the safety applications being developed as a part of the VSC-A program. The scenarios demonstrated were as follows:

- Forward Collision Warning with Emergency Electronic Brake Lights

- Lane Change Warning

- Do Not Pass Warning

Figure 2, Figure 3 and Figure 4 illustrate the 5 OEM VSC-A test vehicles performing the above scenarios while showcasing the system interoperability.



**Figure 2: Stopped Lead Vehicle and FCW Scenario**

**Figure 3: Lane Change and Blind Spot Warning Scenario**



**Figure 4: Decelerating Lead Vehicle and EEBL Scenario**

For each of these scenarios the following information was developed and provided to ITS WC to be used in developing the CAMP—VSC2 portion of the overall integrated show:

- A statement of the crash problem

- The demonstrated safety application scenario solution to the crash problem

- A description of the scenario to be demonstrated

- Detailed scenario steps and maneuvers to perform

The five VSC-A project vehicles were shipped to NYC for ITS WC and were used daily in the integrated show to execute the scenario descriptions as provided to ITS WC.

### 3.4.2  VSC-A Video Development

The VSC-A Team along with NHTSA developed a video to be played at ITS WC on an indoor video wall inside the demonstration hall and at the USDOT booth. The main goals of the video were to get across the following key points that, when taken in combination, will enable V2V communications safety applications to be developed to assist drivers in avoiding crashes:

1. NHTSA and the automotive OEMs (Ford, General Motors, Honda, Mercedes-Benz, and Toyota) are working together in a joint effort between the government and industry to enhance vehicle safety through V2V cooperative systems.

2. These V2V cooperative systems are being enabled through 5.9GHz DSRC technology, which is similar to Wi-Fi.

3. The automotive OEMs (Ford, General Motors, Honda, Mercedes-Benz, and Toyota) are working together with NHTSA and the standards organizations on the creation of industry standards to achieve OEM interoperability allowing vehicles from different automotive OEMs to communicate and understand each other.

A draft video script was developed by the VSC-A Team that incorporated these key points along with brief demonstrations of the VSC-A safety applications. This draft script was provided to a video company to be used as a starting point in the video development process. The final product was a nine-minute video, developed by the production company, which incorporated a hired on-air personality along with key members of the CAMP—VSC2 consortium to help the viewer understand the following concepts:

- How this technology is important in the realm of vehicle safety

- How this technology works at this time via demonstrations of key aspects of five of the six VSC-A safety applications

- What some of the required next steps are before the technology can be brought to market

The final video was provided to ITS WC and was played daily in a continuous loop on an indoor video wall in the main convention hall.

### 3.4.3 Technical Session Presentation

In addition to the Integrated Show and Video Development activities the VSC-A Team participated in the ITS Annual Meeting technical session 'Active Safety Systems Supported by Vehicle-to-Vehicle Communications' taking place at ITS WC. The topics of the presentation focused on the following aspects of the VSC-A project:

- Vehicle Safety Communications - Applications project overview

- Crash Scenarios and Safety Applications

- System Design and Test Bed Implementation

- Communications and Standards Status

- Security for Vehicle Safety Messages

Each CAMP—VSC2 OEM Consortium member was assigned one of the topics listed above to present.

## 4    Task 4 Summary: Vehicle Safety Communication System Definition

The majority of the work for Task 4 was accomplished in the previous calendar year with the remaining Task 4 items completed in 2008. These items included:

- Identifying the technical and non-technical methods to address root causes of autonomous safety system shortcomings

- Developing a DSRC+Positioning and Autonomous Sensing Vehicle Communication Safety System Structure

With the completion of the above items, the Task 4 activities then primarily centered around consolidating the work that had been done in this task into the Task 4 Interim Report which was submitted to the USDOT during the Third Quarter. Task 4 of the VSC-A project was closed following this submission. The following sections provide a summary of the remaining activities that took place under this task.

## 4.1 Technical Root Causes Addressed with the Addition of DSRC+Positioning

Vehicle safety communication systems based on DSRC+Positioning allow for new concepts to be implemented over what can be offered by autonomous-only vehicle safety systems. Under this task technical approaches were identified that could potentially address the root causes of autonomous-only safety system shortcomings for the following three crash scenarios which can be addressed by existing autonomous safety systems:

- Lead Vehicle Stopped

- Lead Vehicle Decelerating

- Vehicle(s) Changing Lanes—Same Direction

The following list summarizes the potential DSRC technical solutions identified that could be used to address the technical root causes of the shortcomings of autonomous-only sensing systems:

- Transmission of vehicle status information to include: brake status, deceleration value, and turn status indication

- Transmission of vehicle position

- Calculation and transmission of vehicle path history

- Calculation and transmission of vehicle path prediction

In addition, following are some of the technical benefits of DSRC that are not easily obtained by use of autonomous-only sensing systems:

- Provides for 360 degree virtual field of view

- Line-of-sight with neighbor vehicles is not required

- Message transmission is not expected to be effected by adverse weather conditions

## 4.2 Non-Technical Root Causes Addressed with the Addition of DSRC+Positioning

There also exist non-technical root causes that are shortcomings for autonomous system deployment that are also important factors hindering fast and large-scale deployment of these systems. DSRC+Positioning technology has the potential to overcome some of those limitations and enable large scale deployment which was also explored in this task. Some of the possible autonomous safety system non-technical shortcomings identified were as follows:

- High Engineering Costs

- High Component Costs

- High Warranty Costs

- Increase in Vehicle Weight and Packaging Issues

- Increase in System Complexity

- Increase in System Integration Testing

Potential DSRC solutions to these shortcomings were primarily identified to be the potential ability of multiple safety applications being developed as an integrated system able to share the same HW potentially leading to a reduction in all of the shortcomings listed above.

## 4.3 DSRC+Positioning and Autonomous Sensing Vehicle Communication Safety System Structure

A potential advantage of DSRC-based vehicle safety communications is that cooperative communications may provide additional information about the driving situation that goes beyond the capabilities of object sensing used in autonomous safety systems. Conversely, the utilization of traditional autonomous sensing safety systems may aid in overcoming some of the performance concerns related to DSRC+Positioning systems such as:

- Urban Canyon Conditions

- Multi-path Phenomenon

- Weak DSRC or Positioning Signals

A potential hybrid system framework, comprised of both DSRC+Positioning and autonomous sensing systems (Figure 5), was defined as a means of these two systems both potentially complementing as well as overcoming the shortcomings of each other.
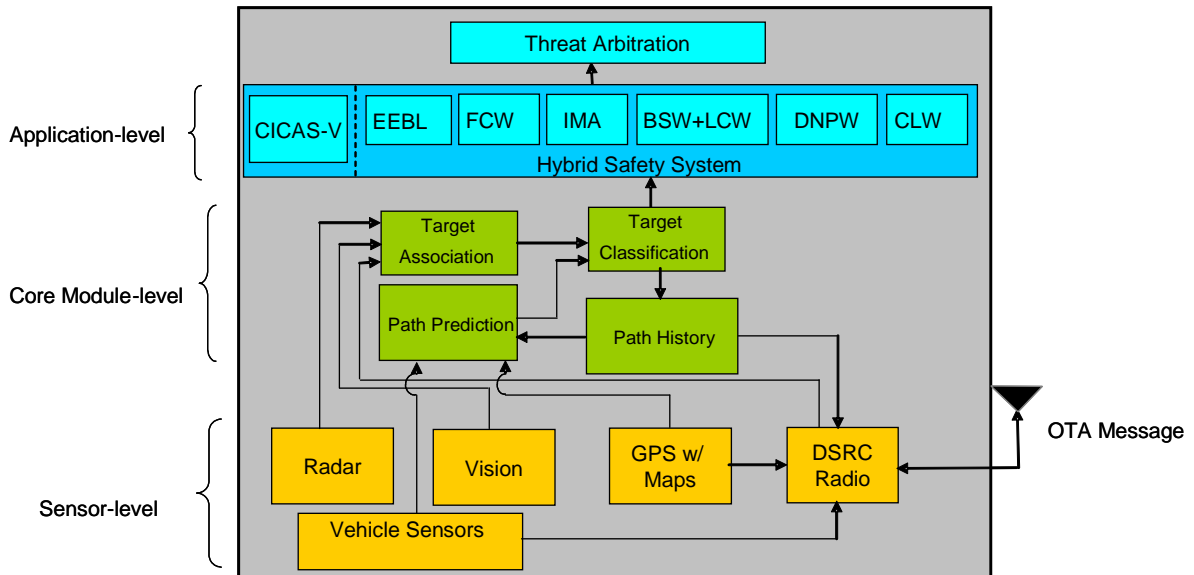
**Figure 5: VSC-A Potential Hybrid Autonomous Sensing with DSRC+Positioning Structure**

The primary module additions and modifications to this hybrid structure over the VSC-A DSRC+Positioning-only structure being developed as part of the VSC-A program include the following:

- Radar Sensor Module

- Vision Sensor Module

- GPS (already assumed in VSC-A DSRC+Positioning-only system) with Maps Module

- Path Prediction Module

- Target Association Module

This framework will not be implemented in the VSC-A Test Bed under the program, rather, it will be used for the system analysis activities to be carried out in Task 6 in 2009.

# 5 Task 5 Summary: DSRC+Positioning-Only Safety System Structure Development

The objective of Task 5 is to define the most efficient system development method to achieve a DSRC+Positioning-based "single vehicle safety communication system" by addressing the following:

- System concepts of operation, requirements, and minimum performance specifications

- An interoperable, scalable Vehicle Safety Communications (VSC) architecture that can support a large number of vehicles

- Affordable and reliable vehicle relative positioning needed for VSC system features

- The benefits of exchanging vision-based sensor information between vehicles, over DSRC, for improving the overall performance of the VSC-A applications

## 5.1 System Concepts of Operation, Requirements, and Minimum Performance Specifications

In the First Quarter the minimum performance specifications for each of the safety applications were developed based on their corresponding requirements defined in the previous year. Multiple reviews of the minimum performance specifications were held both internally with the VSC-A Team and externally with VOLPE. Comments and suggestions were collected with the draft specifications completed and internally documented in the Third Quarter.

Following the completion of the individual application specifications, a consolidated VSC-A system minimum performance specification was developed and documented in the Fourth Quarter and included the following items:

- The targeted crash types addressed in Task 3 (see Task 3 summary in [1])

- A common domain that applies to all the VSC-A safety applications' minimum performance specification such as the subject and target vehicle types, roadway characteristics, traffic density, Global Navigation Satellite System (GNSS) coverage constraints and weather conditions

- The minimum requirements for the overall correctness of warnings, including both the true positive warnings rate and false positive warnings rate

- The detailed minimum performance requirements for each application, which includes the operating speeds, the detection/warning zone each application shall cover, and both the true positive and false positive aspects of the application performance

The consolidated minimum specifications are currently being reviewed by the VSC-A Team and the USDOT/Volpe. Completion of the minimum specifications and documentation are planned for the First Quarter 2009. The minimum specifications will be used as the basis for the VSC-A Test Bed Objective Test Procedures being developed as part of the Task 8 activities in 2009.

## 5.2 Communication Architecture, Standardized Messages, and Protocols

The overall goal of Task 5.2 is to develop a scalable and interoperable vehicle safety communication systems architecture, including channel considerations, protocols, and security. During the second year of the VSC-A project, notable progress was made in message composition, security, power testing, message dissemination, standard's validation, and multi-channel operation.

Task 5.2 is organized into seven subtasks all of which were active in 2008. The following summary sections are organized by subtask.

## 5.2.1 Standard Message Composition

In 2008 Message Composition had two areas of focus: 1) the VSC-A Test Bed OTA message definition; and 2) the SAE J2735 Data Set Dictionary standard.

### 5.2.1.1 VSC-A Test Bed Over-the-Air Message Definition

The VSC-A Team defined an OTA message for use in the Test Bed being developed as part of the Task 7 activities. The two principal requirements of this message are to ensure that the message defines the following:

- Has enough content flexibility to support the safety applications being developed within the VSC-A project

- Conforms as nearly as possible to the emerging SAE J2735 Message Set Dictionary standard

Accordingly, the OTA message definition was updated as needed in 2008 to meet these requirements and, where appropriate, enhancements to the existing SAE J2735 message format were proposed as discussed in the following section. Figure 6 shows the high-level structure of the VSC-A Level I Test Bed OTA message.
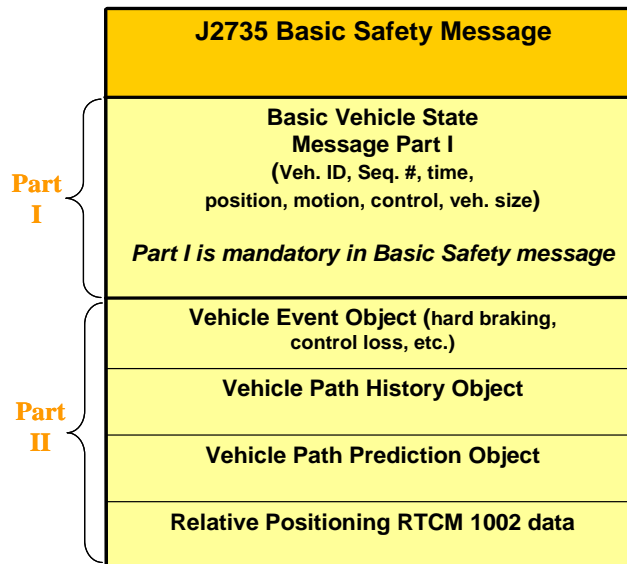


**Figure 6: Level I Test Bed OTA Message Structure**

### 5.2.1.2 SAE J2735 Standard

The VSC-A Team analyzed the content and structure of the Basic Safety Message and prepared a detailed proposal to enhance the message and better align it with VSC-A priorities. The BSM is structured in two parts. Part I has a fixed format and carries basic vehicle state information. Part II allows a sender to supplement the basic state with additional information that it considers required (perhaps at a reduced rate) or optional. The VSC-A proposal for Part I included the:

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- Introduction of new state elements – sequence number, position accuracy, and stability control state

- Elimination of state elements – steering wheel angle, throttle position, and light set

- Modification of existing state elements – the reduction in the size of the elevation and temporary ID elements in order to save bandwidth

Note that elements eliminated from Part I are still eligible for inclusion in Part II. The VSC-A proposal also defined the following three elements for inclusion in Part II:

- Path History

- Differential Position Corrections

- Event Notification Flags

Finally, the VSC-A Team also contributed a seven part informative annex for the J2735 standard illustrating how the periodic exchange of BSMs can facilitate collision avoidance in a variety of situations.

## 5.2.2 Security

The security subtask is focused on message authentication for vehicle-to-vehicle safety communication messages. The objectives are to preserve the sender's privacy and to minimize bandwidth overhead, processing requirements, and latency.

Work was performed in several areas in order to demonstrate the following:

- Design and implement a security solution

- Evaluate and optimize the security solution

- Evaluate privacy mechanisms

- Contribute the results to the Standards Group

### 5.2.2.1 Design and Implementation of Authentication Protocols

The design of three potential authentication protocols, namely Timed Efficient Stream Loss-tolerant Authentication (TESLA) [4], Two-Signature Scheme [2], and Verify-on-Demand [3] that began in 2007, was refined in 2008. The VSC-A Team decided to implement all three protocols as well as the Digital Signature protocol defined in the IEEE 1609.2 security draft standard for comparison reasons. Please refer to Section 6.2.2 for details of the Security SW implementation.

### 5.2.2.2 Evaluation and Optimization

The design and implementation of the authentication protocols provided evidence that the protocols can be efficiently implemented and will provide valuable feedback for improving details of the design and run time parameters of the protocols. However, the actual proof-of-concept implementation will not be able to provide adequate feedback with regard to a large-scale deployment. Therefore, the VSC-A Team made the decision to have network simulations of the potential protocols run in order to optimize the protocols and to establish a relative ranking of the protocols with regard to over-the-air

bandwidth overhead and latency. The relative ranking will compare Digital Signatures as defined by IEEE 1609.2 as well as the three potential VSC-A security protocols.

The VSC-A Team organized a bidding process in order to obtain quotes for the network simulation. A statement of work was prepared and distributed to experts in the field. In the end, three experts were chosen because of their complementary expertise covering security, communication network simulations and safety applications to each run their own network simulation. A kick-off meeting was held in the Fourth Quarter with the work expected to be finished in the Second Quarter 2009.

### 5.2.2.3  Privacy

Privacy of vehicle owners will need to be a primary component of DSRC-based vehicular communication. Therefore, the VSC-A Team both evaluated key management mechanisms that heavily influence the level of privacy and designed the authentication protocols in such a way that they preserve privacy.

In 2008, the VSC-A Team evaluated a variety of key management mechanisms with regard to privacy. The evaluation mainly included mechanisms where: 1) each vehicle is deployed with a group of certificates which are used periodically one after the other; and 2) with a mechanism where a number of vehicles are deployed with the same certificate. While in the first case location privacy is preserved, the mechanism of the second case introduces a considerable burden to identify a vehicle based on a single DSRC transmission.

The Level I Test Bed implementation of the authentication protocols includes an initial mechanism to preserve a vehicle's privacy. It is limited to a change of certificates only and allows for the change to take place at any time. All three implemented security protocols were developed to preserve privacy to the same degree.

At the end of 2008, the strategy for implementing privacy for the Level II Test Bed was defined. It will include a change to all vehicle identifiers in addition to the certificate. The Level II implementation will be completed in the First Quarter 2009.

### 5.2.2.4  Collaborations and Standards Group

A major objective of the VSC-A Team is to share their results, expertise, and recommendations on security to the IEEE 1609.2 Security Standards Group. During 2008, the VSC-A Team worked toward this objective by:

- Holding a technical workshop to align the VSC-A security results with the Vehicle Infrastructure Integration (VII) program security group. The workshop gave the VSC-A Team insight into the VII program privacy and authentication mechanisms and allowed for the discussion to begin on how to jointly shape the IEEE 1609.2 security standard.

- Attending Third and Fourth Quarter 1609 meetings and presenting the three VSC-A potential security protocols, namely TESLA, Two-Signature Scheme, and Verify-on-Demand, which were well received. The IEEE 1609 Group was open to taking VSC-A's input into consideration for extending the existing standard by one of the potential VSC-A protocols by creating a suite of security protocols, each fitted to a specific application. While the existing standard is a proper fit for

most V2I applications, the VSC-A proposal is customized to V2V safety applications where the number of potential messages that require authentication can be elevated, and therefore, optimization of on-board computational resources is an important implementation focus area.

- Agreeing to bring the results of the VSC-A Security Network Simulations back to the 1609 Group in 2009 along with a VSC-A recommendation on which protocol should be included in the standard.

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## 5.2.3 Characterizing DSRC Reception Performance as a Function of Transmission Power

In 2008, the VSC-A Team undertook a power testing study to understand the effect that transmission power, bit rate, fading environment, and obstacles have on packet reception performance. This information is useful in two ways: 1) in determining environments in which the use of high transmission power (greater than 20 dBm) may be warranted in order to achieve acceptable safety application performance; and 2) in determining environments in which the use of low transmission power (less than 20 dBm) may be warranted in order to reduce channel congestion without sacrificing application performance.

The VSC-A Team designed and executed a power test plan using vehicle-based radios. The tests were performed at a variety of venues in the San Francisco Bay area with each test motivated by one or more VSC-A safety applications. Tests were performed in intersection topologies with a building obstruction between the vehicles and in same-direction topologies both with and without an 18-wheel truck obstacle. Venues were selected in urban, suburban-commercial, residential, and rural settings, as well as a "baseline" location at a closed airfield. A total of 17 environments were tested, and at each a variety of transmission powers (from 5 to 33 dBm) and bit rates (3 and 6 Mbps) were used.

The primary metrics were packet error rate and received signal strength indication; these tests did not attempt to assess application performance. The test results were documented in a comprehensive report that was in the final stages of editing at the end of 2008. Test results were also presented at the 2nd International Workshop on Mobile Vehicular Networks (MoVeNet 2008).

The tests indicated that the additional range achieved with high power is most likely to be useful at intersections, to assist the Intersection Movement Assist (IMA) application, and on highways with a truck obstacle between the vehicles, where the Do Not Pass Warning (DNPW), EEBL, Forward Collision Warning (FCW), and Control Loss Warning (CLW) applications are relevant. The tests also indicated that reducing transmission power may be acceptable in line-of-sight scenarios (e.g., a highway with no truck obstacle). In each case a further assessment of application-level performance is warranted.

The prototype DSRC systems used in the testing were capable of producing slightly less than 20 dBm transmission power. VSC-A used an external power amplifier to achieve powers up to 33 dBm.

Figure 7 shows typical results from the Power Testing study, in this case from an urban intersection with buildings on all four corners. Each curve in the graphs represents a fixed transmitter-to-intersection distance as indicated in the legend (i.e., 0 m, 25 m, 50 m, 100 m, and 150 m). The horizontal axis represents the receiver-to-intersection distance and the vertical axis represents the packet error rate (PER). The upper graph corresponds to 20 dBm transmission power while the lower graph shows the results of repeating those tests with 33 dBm transmission power. A comparison of the graphs reveals the extent to which the higher power translates to greater reception range, which could be important for some of the safety applications (e.g., the IMA application).
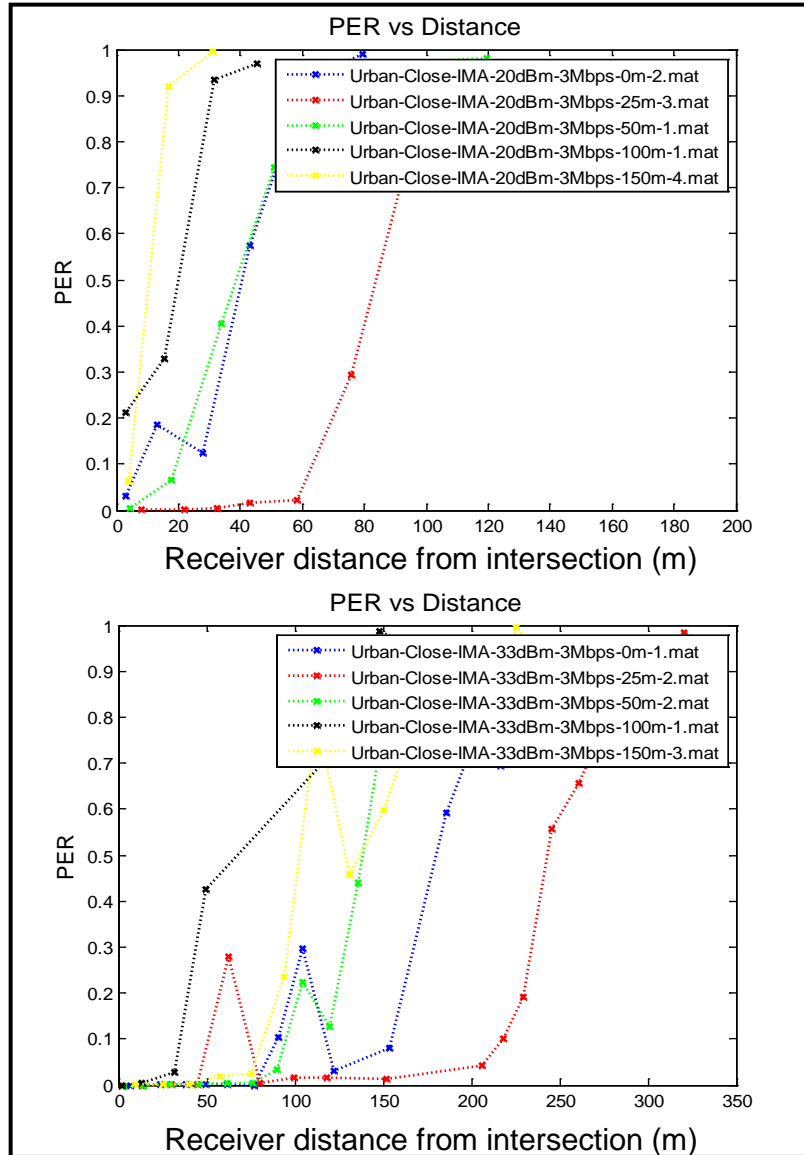


**Figure 7: Communication Range vs. PER at 20 dBm and 33 dBm in Urban Closed Intersection**

## 5.2.4 Message Dissemination Strategies

The objective of Message Dissemination is to study ways to improve message reception, especially the reception of high priority messages, as a function of transmission behavior at the sender. The focus of this work is on controlling network congestion caused by routine traffic so that important safety messages are communicated successfully with high probability.

The nature of this work is best suited for simulation-based study. Thus, the VSC-A Team decided to use the industry standard NS-2 simulation tool to study Message Dissemination. During 2008, improvements to the tool were made to include provisions for an intersecting road topology and for non-uniformly distributed traffic.

A congestion control algorithm operates on some measure of congestion or channel load. The VSC-A Team made a preliminary choice to use a channel load metric called Communication Density for its Message Dissemination work. Simulations validated its utility for that purpose. It was agreed that the congestion control approach should be distributed and cooperative in nature. A solution should be capable of computing a fair share of the channel load based on locally available information and then limiting its contribution to the channel load via local actions (e.g., limits on transmission rate and/or power). A given vehicle should only be concerned with the channel load within its interference range.

In 2009, VSC-A will develop candidate congestion control algorithms that follow the above principles and will evaluate these via simulation. If a preferred approach is identified, VSC-A will communicate that with IEEE 1609 and other interested parties.

## 5.2.5 DSRC WAVE Standards Validation for Safety Applications

VSC-A was very active in standards validation work again in 2008 with the Task 5.2 activities working in conjunction with Task 2 activities. Three standards groups are of direct interest: IEEE 802.11 Task Group p (TGp), IEEE 1609, and SAE DSRC.

### IEEE 802.11 TGp

Task Group p is preparing the Wireless Access in Vehicular Environments (WAVE) amendment to the 802.11 wireless networking standard, which will become 802.11p when published. This standard defines protocols at the Physical (PHY) and Medium Access Control (MAC) layers of the protocol stack.

In 2008 VSC-A validation work on 802.11p focused on the correctness and completeness of the draft amendment. VSC-A representatives submitted roughly 20 percent of the comments on both the May Letter Ballot and the December Recirculation Ballot. Each comment included a suggested improvement to the draft.

### IEEE 1609.x

The IEEE 1609.x series of standards define protocol layers between the MAC and the Application layers. 1609.1 through 1609.4 are designated "trial-use" standards.

In 2008, VSC-A undertook significant validation efforts for both the 1609.2 Security standard and the 1609.4 Multi-channel Operation standard. These standards align respectively with VSC-A subtasks 5.2.2 and 5.2.6.

Security validation involved both an analysis of the performance of the trial-use 1609.2 mechanism and development of alternatives. These alternatives were presented to the 1609 Group in 2008. During 2009, VSC-A will continue analyzing the candidate solutions, select a preferred solution, and work with the IEEE 1609 Group to modify 1609.2 appropriately. Section 5.2.2 of this report includes more information about these activities.

Multi-channel validation also took the form of analysis of the trial-use protocol and development of alternatives. One simulation study was contributed to VSC-A by an OEM member and additional simulations are planned for 2009. During 2009, VSC-A will select a preferred multi-channel approach and communicate that preference to the IEEE 1609 Group. Section 5.2.6 of this report includes more information about these activities.

**SAE DSRC Technical Committee**

The SAE DSRC TC is responsible for the J2735 Message Set Dictionary standard. In 2008, and as discussed in Section 5.2.1, the VSC-A Team performed significant validation work on the content of Part I of the Basic Safety Message and on the definitions of the individual elements that appear in either Part I or Part II. The VSC-A Team has worked with the SAE DSRC Technical Committee to incorporate recommendations into the draft standard. The VSC-A Team has also identified the need for an additional standards activity within SAE related to minimum communication requirements and has requested that SAE initiate work in that area.

## 5.2.6  Channel 172 Usage

The Federal Communications Commission (FCC) has designated DSRC Channel 172 exclusively for V2V safety communication for accident avoidance and mitigation and safety of life and property applications. The trial-use standard IEEE 1609.4, which predates the FCC designation of Channel 172, defines a method of switching among the seven FCC channels that places most safety communication on Channel 178 (the "control channel"). The goal of this subtask is to study how best to organize the multi-channel operations inherent to DSRC, including efficient resource utilization, support of both safety and non-safety applications, the control and service channel concepts defined in IEEE 1609 and the special designation of Channel 172.

The two prongs of this study are an evaluation of the trial-use 1609.4 approach, including its congestion characteristics, and an analysis of potential alternatives. One OEM member of the VSC-A project contributed an initial simulation study of 1609.4 and the VSC-A Team has worked to define a framework for further evaluations, which will be performed in 2009.

The Team also developed a variety of alternative channel switching approaches. An initial phase of development led to a set of 11 alternatives that all conform to the following constraints:

- Single-radio and dual-radio vehicles will co-exist

- No Over-The-Air protocol information is available beyond what is defined in the trial-use 1609 standard set.

- Each vehicle will use its radio(s) to attempt to hear every safety message from neighboring vehicles.

This initial list of alternatives was narrowed to a set of four that will be implemented and tested in the VSC-A Level II Test Bed during 2009. One pair of alternatives conforms to the existing 1609.4 standard in both a single-radio and dual-radio configurations. The other pair utilizes Channel 172 for safety communication, again in both single-radio and dual-radio configurations. Figure 8 shows a classification of the multi-channel operation alternatives investigated during 2008. Those designated "Level II" were selected for implementation in the VSC-A Level II Test Bed.
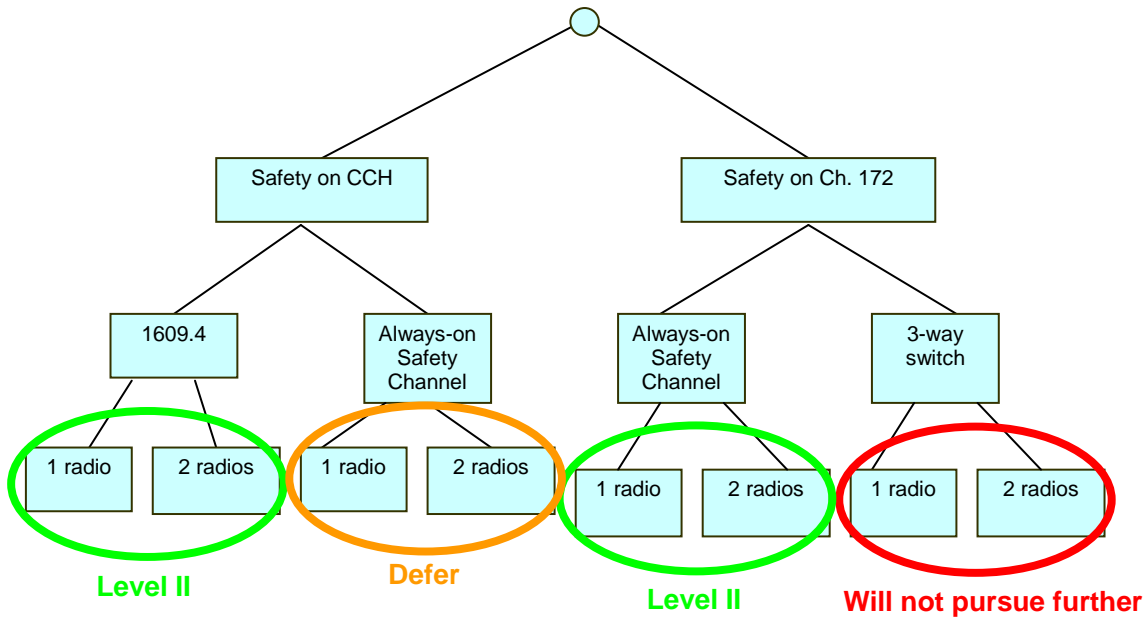


**Figure 8: Taxonomy of Multi-channel Alternatives and Future Focus**

The VSC-A Team will continue to evaluate the strengths and weaknesses of all of the alternatives considered thus far, taking into account both technical and market penetration factors. The Team will select a preferred multi-channel operation approach and will work with the 1609 Standards Group to modify the 1609.4 standard appropriately.

## 5.2.7 International Trends

The goal of this subtask is to engage in dialogues with interested parties outside of the United States (ie., industry consortia in Europe and Japan), standards organizations with a regional focus, or attendees of international conferences. The purpose of this engagement is to track developments in various areas of the world, to disseminate information about the VSC-A project and its work and to facilitate the eventual worldwide deployment of DSRC-based vehicle safety technology.

In 2008, VSC-A participated in a workshop organized to promote harmonization of international standards for wireless vehicle-oriented communication. The workshop was sponsored by the International Organization for Standardization (ISO) TC 204 Working Group 16. The workshop included representatives of European Telecommunications Standards Institute (ETSI), Cooperative Vehicle-Infrastructure Systems (CVIS),

California Partners for Advanced Transit and Highways (PATH), VII-C, Safespot, COMeSafety ITS, IEEE 802, IEEE 1609 and SAE. The workshop also included researchers from Japan, Korea and Australia.

One important outcome of the workshop was a general agreement to use IEEE 1609 as a basis for cooperative, joint work to revise and extend ETSI and ISO standards concerning the middle layers of the protocol stack.

## 5.3  Relative Vehicle Positioning Development

Sub Task 5.3 is focused on designing, developing, implementing, and testing a prototype relative positioning system that can support the VSC-A safety applications. The VSC-A Team identified GPS as the most viable core technology for this development effort.

The GPS Real-Time Kinematic (RTK) positioning technique was identified as a potential technical solution for the VSC-A relative positioning needs. For the RTK method implementation, the VSC-A Team selected a Commercial Off-the-Shelf (COTS) RTK engine from a leading GPS system developer. In the initial evaluations, the VSC-A Team identified customizations required for the RTK software to meet the needs of the VSC-A system with an evaluation version of the customized RTK software received early in 2008. The Team conducted limited preliminary tests using this software and compatible GPS and DSRC hardware to verify that the RTK software was able to meet the VSC-A specifications under the conditions established for Level I implementation. Subsequently, the VSC-A Team received the fully functional RTK software, utilities, and GPS hardware from the GPS supplier. The VSC-A Team subsequently conducted a variety of validation tests of the positioning sub-system. The selected tests covered a wide range of VSC-A operating scenarios. One of the objectives of the validation tests was to investigate the impact of a large number of vehicles on the RTK software and the associated communication links as well as to distribute some of the knowledge and experience gained during the testing and analysis done by individual OEMs.

Early in the Second Quarter, the VSC-A Team held a two-day workshop with the GPS supplier which was focused on finalizing the details of the GPS RTK positioning techniques and software as applicable to the VSC-A RTK relative positioning software solution. Topics ranging from current implementation to its potential evolution were discussed during the workshop as listed below:

- Basic principles of RTK, costs and benefits

- Comparison of alternative approaches of relative positioning such as position differencing (also identified as the Single Point method)

- Setting up VSC-A relative positioning system software

- Use of post-mission tools for accuracy and availability analysis

- Introduction to visualization and online data download tools for post-mission analysis

- Software customization and integration assistance required for VSC-A Test Bed

- Enhancement opportunities with future GPS changes and/or other GNSS systems

The final version of the customized RTK software was delivered to the VSC-A Team in the Second Quarter. This included the support for OTA messages using the Radio Technical Committee for Maritime Services (RTCM) v3.0 and interface modifications for communicating with the VSC-A Level I Test Bed modules. The VSC-A Team subsequently tested this software in laboratory and field test setups to verify that all the basic system requirements are met. No detailed performance evaluation was conducted as a part of these initial tests.

The VSC-A Team designed and executed a limited system level test of RTK software late in the Second Quarter. The primary objective of the tests was to verify that the RTK software solution was able to provide *Which-Lane* accuracy subject to GPS availability. The test was also intended to provide data for a cost/benefit analysis to determine if using RTK software provides sufficient gains, considering the additional OTA data sharing requirements and onboard processing requirements needed for a RTK relative positioning system solution. Two or more vehicles were involved in several test scenarios with the RTK software data output and raw GPS data output both logged during the tests for comparison reasons. Note that no safety applications were running during these tests. The following scenarios were collectively covered by the VSC-A Team:

- Dense vs. free flow traffic (variability of reflection sources/GPS noise)

- Freeway vs. urban streets

- Low speed  vs. high speeds

- Short complete GPS interruptions (i.e., overpasses) vs. longer interruptions

- Tree cover

- Vehicles with different sky visibilities (i.e., one vehicle driving next to a semi-trailer truck)

- Vehicles operating in different GPS modes such as standalone GPS, Wide Area Augmentation System (WAAS)-enabled GPS, and Cooperative Intersection Collision Avoidance System - Violation (CICAS-V) enabled GPS

The analysis of the data collected was completed in the Third Quarter. The VSC-A Team was able to illustrate the benefits of using RTK-based software as compared to using vehicle location differentiation based on vehicle latitude and longitude information only. An illustration is given in Figure 9. In the test scenario, two VSC-A test vehicles were driven in the same lane on a straight road such that the across distance between them was maintained close to zero. Onboard systems were configured to estimate the across distance between vehicles using the RTK software and using standard position differentiation (i.e., identified as Single Point (SP) method). The top plot in Figure 9 shows the comparison of the output using both relative positioning approaches. The Team also investigated the relationship between Across distance output and the GPS satellites each vehicle was using. In the case of this illustration, the output from the SP method was found to be adversely influenced by differences in the satellites visible to each vehicle whereas the RTK method was not influenced to the same extent.
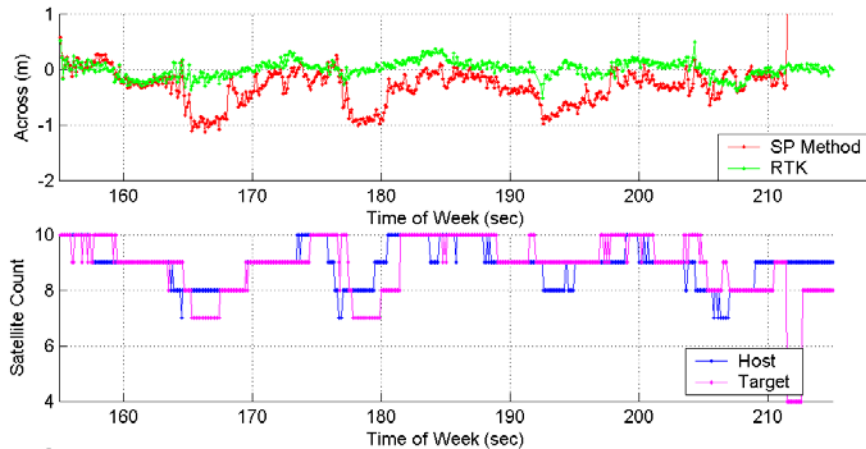
**Figure 9: Comparison of Between-Vehicle Across-Distance**

As a result of the tests, the VSC-A Team was able to characterize both relative positioning methods in detail under various VSC-A operating scenarios. An internal report was generated with a summary of findings. Following were the key conclusions of the analysis:

1. Sharing just the global vehicle coordinates for relative positioning may introduce relative positioning errors in the order of meters solely due to differences in satellite observations used in different vehicles. Such differences are commonly encountered in normal driving even between vehicles that are within several meters of each other.

2. No such errors were observed when using RTK software for relative positioning as expected in the system design.

3. Relative positioning based on global coordinate sharing may introduce errors as high as several meters when vehicle positioning modes are different. Typical example is a case where one vehicle is operating with infrastructural aiding (e.g., CICAS-V support) while the other is not.

4. The method of relative positioning implemented using RTK software is not affected by such positioning mode differences as GPS measurement level information is used in RTK methods and these are not receiver positioning mode dependent.

5. RTK software response to short and complete GPS outages agrees well with the state-of-the-art in terms of reliability and time to recover. It is recommended that Solution Quality reported by the RTK software be used to build system reliability measures and also be used to warn applications when reliability limits are reached.

6. Using relative positioning based on global coordinates may provide misleading information when operating with frequent GPS interruptions or in challenging environments such as urban canyons. It is recommended that RTK method with reliability measures be used under these conditions.

The VSC-A precise RTK relative positioning external platform was fully integrated with the VSC-A Level I Test Bed early in the Fourth Quarter. The module was implemented on an external PC that is connected to the WSU through Ethernet connectivity. Figure 10 shows the GPS data flow within the relative positioning system components in the VSC-A Test Bed. The Car PC-based module receives raw GPS data from the host GPS receiver and the rover raw GPS data from OTA messaging. The PC module outputs precise relative position data back the OBE. The OBE also receives local vehicle GPS information and timing data from the local receiver.
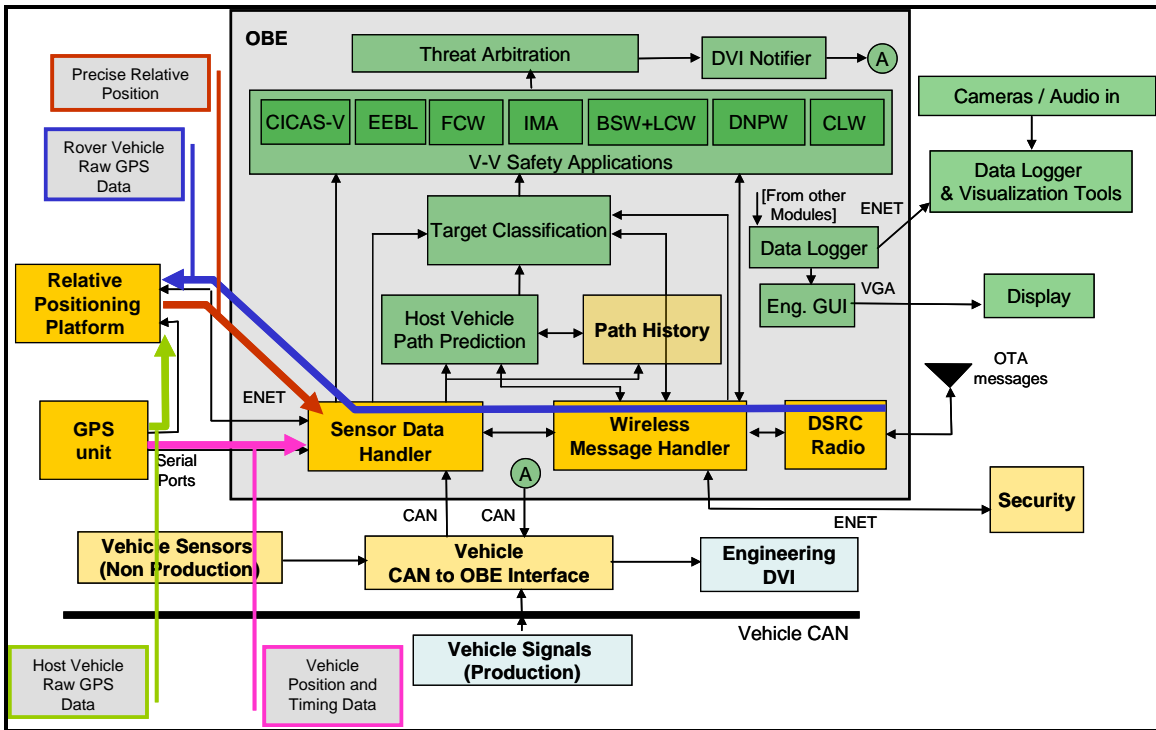


**Figure 10: VSC-A Relative Positioning Test Bed Data Flow**

The VSC-A Team performed multiple field tests with the VSC-A relative positioning module with multiple VSC-A applications running using the system output. Some of these tests were conducted in a controlled environment in a test track with up to four VSC-A vehicles. Similar tests were conducted in normal highways. An illustration of one such multiple vehicle test is provided in the following text and figures. In this test, four VSC-A test vehicles were driven on a three lane roadway. One vehicle was selected as the Host with one of the Target vehicles driven in the same lane and ahead as the Host vehicle. The other two Target vehicles were driven in the adjacent lane of the Host vehicle. This vehicle formation is illustrated in Figure 11.

**Figure 11: Formation of Host Vehicle and Target Vehicles**

The VSC-A system in the Host vehicle was configured to output between vehicle Across (Lateral) distance and Along distance (Longitudinal) using both RTK and Single Point methods. Figure 12 and

Figure 13 show the system output for each Target vehicle using the color codes assigned to each Target vehicle in Figure 11. In each plot RTK output is shown with a solid line and the output from the Single Point method is shown using markers. The VSC-A Team was able to show that the Single Point method may introduce more noise and potential bias into these estimates whereas the RTK method could considerably improve the performance of the VSC-A relative positioning system by minimizing such vulnerabilities.
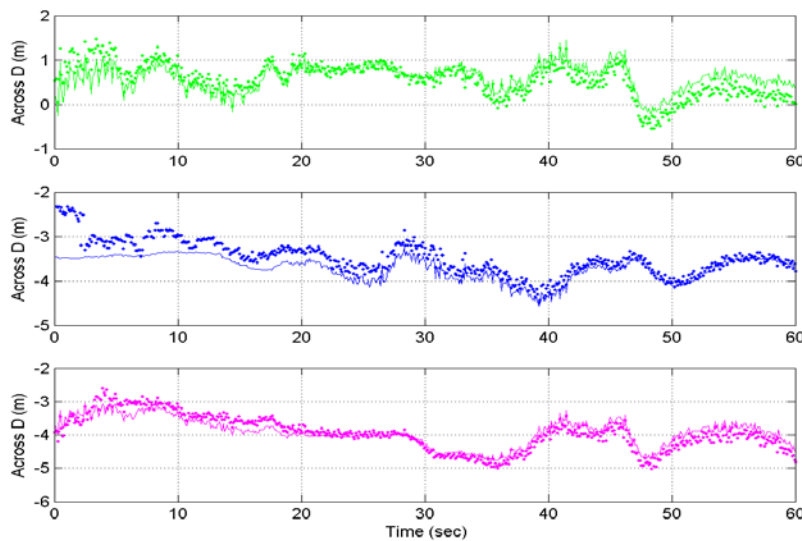


**Figure 12: Between-Vehicle Across Distances in Multiple Vehicle Test Run**
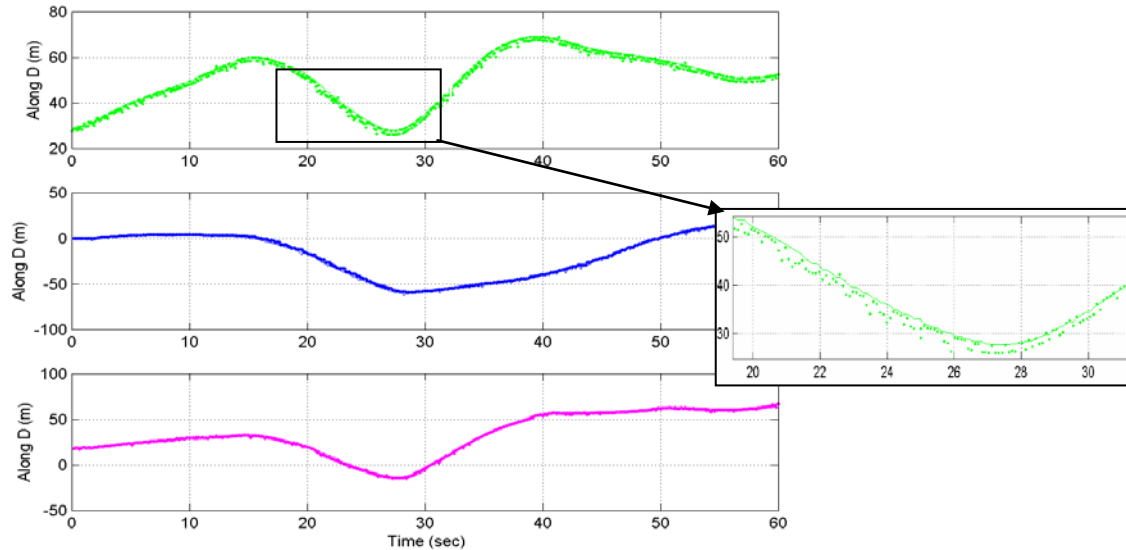**(Solid Line: RTK Method   Other: Single Point Method)**

**Figure 13: Between-Vehicle Along Distances in Multiple Vehicle Test Run
(Solid Line: RTK Method Other: Single Point Method)**

The application performance was monitored in all VSC-A tests to verify that the relative positioning module performed according to the design requirements and needs of the VSC-A applications. Data recorded from these tests were analyzed in post-mission to verify the performance of the VSC-A relative positioning module against reference system performance. Test results from previous positioning module level tests (i.e., tests that investigated between vehicle Across- and Along-distances in same-lane and adjacent lane driving scenarios without applications) were used as the reference system performance.

In the final program year, the benefits of using RTK as well as the additional "costs," such as increased bandwidth utilization will be considered and a recommendation regarding RTK will be included in the project final report.

# 6    Task 7 Summary: Vehicle Safety Communication System Test Bed

The primary achievement of the Team under Task 7 was the completion of the VSC-A milestone Level I Test Bed. This Test Bed consists of one DSRC-equipped test vehicle per OEM with the following V2V safety applications implemented:

- Emergency Electronic Brake Light (EEBL)

- Forward Collision Warning (FCW)

- Intersection Movement Assist (IMA)

- Blind Spot Warning + Lane Change Warning (BSW + LCW)

- Do Not Pass Warning (DNPW)

- Control Loss Warning (CLW)

In 2008, the Task 7 vehicle Test Bed activities included the following:

- The development of the preliminary designs for the core and safety application modules. This effort was based on the system concepts of operation, requirements, and minimum performance specifications developed under Task 5.1.

- The development of a consolidated VSC-A specification, architecture, design, and SW implementation.

- The acquiring and integration of the necessary HW components, including vehicles, into an integrated system.

- The functional testing of the integrated system design.

This Test Bed was ultimately used to verify V2V Over-The-Air interoperability between Ford, General Motors, Honda, Mercedes-Benz, and Toyota vehicles. Public demonstrations of OEM DSRC interoperability were held in NYC at the 2008 ITS WC. Going forward, the Test Bed will serve to validate, via execution of the Objective Test Procedures, the system and minimum performance specifications that are being developed as part of this project.

## 6.1  Test Bed Design

The majority of the VSC-A Level I system Test Bed design activities were completed during 2007. During the First Quarter, the remaining primary activities were completed with the development of the final remaining Level I module designs for the following core modules:

- Target Classification (TC)

- Threat Arbitration (TA)

Like the other designs, these designs were based on a common template that included the incorporation of the requirements developed under Task 5.1.

In addition to the modules listed above, additional specifications and documentation were developed to aid in the implementation of the following:

- Engineering Graphical User Interface (EGUI)

- Log File Format for the Application and Core modules

- Data Logging and Visualization Tool

Throughout the year, based on external reviews of the VSC-A documents, the results of intra-OEM, inter-OEM testing efforts and weekly status meeting discussions updates were made to the relevant applications and core modules designs and documentations for incorporation into the final Level I Test Bed implementation.

## 6.2  Test Bed Development

The VSC-A system Test Bed development activities involved the system software specification, design, implementation, and software release and testing of the OBE.

## 6.2.1  System SW Specification and Design

Figure 14, below, represents the current VSC-A OBE SW Architecture diagram that was developed and refined as part of the system specification and design activities.  It details the interaction and high-level data flow between the safety application modules, system framework modules, the DENSO Wireless Safety Unit (WSU) SW services, and external interface devices.
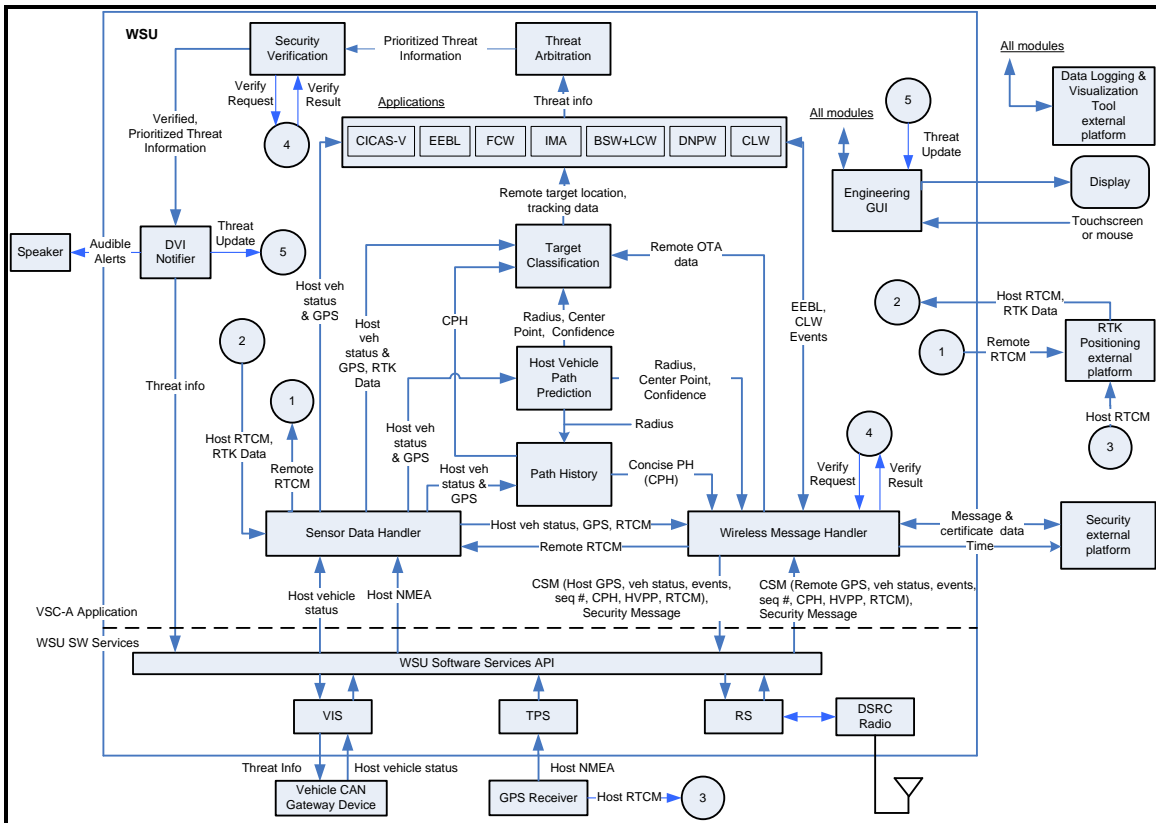


**Figure 14: VSC-A Level I OBE SW Architecture**

The VSC-A modules (above the dotted line) are specific to the VSC-A project.  The WSU Software Services modules (below the dotted line) are generic modules supplied with the WSU that provide services and an Application Programming Interface (API) to enable applications to interface to the CAN buses, GPS receiver and the DSRC Radio. The arrows and text between the modules show the primary data flows.

The VSCA modules are composed of support and application functions.  The support functions interface to external equipment and calculate data to support the VSCA application modules and engineering DVI(s).  The main ones are Threat Arbitration (TA), Driver Vehicle Interface Notifier (DVIN), Target Classification (TC), Host Vehicle Path Prediction (HVPP), Path History (PH), Data Logger (DL), Engineering Graphical User Interface (EGUI), Sensor Data Handler (SDH) and Wireless Message Handler (WMH).

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The application modules evaluate potential categorized safety threats based on the data and inputs from the support modules. These are the warning algorithms used for the six threat scenarios supported by the VSCA program: EEBL, FCW, IMA, BSW+LCW, DNPW and CLW.

The WSU Software Services provides an API to enable applications to obtain data from the GPS receiver or a CAN Bus. The API also enables the application to configure the DSRC radio parameters and to transmit and receive data. The Time/Position Services interfaces to the GPS unit to obtain time and position updates and/or Radio Technical Commission for Maritime Services (RTCM) messages and provides this data to requesting applications. The Time/Position Services also accepts data for output to the GPS through the serial port.

Similarly, the Vehicle Interface Services interface to the CAN bus to obtain vehicle status updates, and provides this data to requesting applications. The Vehicle Interface Services also accepts data from applications for output to the CAN buses. Applications may access other WSU hardware interfaces by using the corresponding device drivers provided by Linux.

The Radio Services is configured to be operated in WAVE mode.

The VSC-A Team decided to use the shared memory interface concept. This allows for data in memory to be accessed by multiple routines for inter-process communication without unnecessary duplication. The need for such a capability may be justified by the following:

- As may be apparent from the software interface block diagram, there are many cases of one module supplying data to many other functional blocks. For example, consecutive Host and Remote GPS Time and Position data points may be used by PP, PH, TC and the warning algorithms at the same time.

- For effective interface to the visualization tool, the architecture needed to be able to provide inter-process data to a consistent location for external retrieval.

The shared memory scheme used in the architecture, therefore, appears to fulfill the requirements for support of the VSC-A functionality and allow for future extensibility.

The SDH and WMH are basic functional blocks necessary for parsing inputs from and appropriately formatting and submitting data to the WSU services and those in use by the other support and application elements.

The SDH interfaces to the CAN Gateway box (through the WSU Software Services) to transmit and receive CAN messages and detect communication errors. It also connects to the GPS receiver through WSU Software Services to obtain National Marine Electronics Association (NMEA) data including Coordinated Universal Time (UTC) time, position, speed and heading as well as RTCM data. The SDH also interfaces to the external computing platform that executes the RTK software to obtain accurate relative positions of the neighboring vehicles.

The WMH interfaces to the DSRC radio through WSU Software Services and to the external computing platform executing the Security Module software. It transmits and receives WAVE Short Messages (WSM) using the Security Module to generate and verify message signatures.

It was understood early on in the program that exact replication of specific V2V test scenarios with multiple vehicles and multiple times for application debug would be problematic. To help alleviate this problem, the VSC-A Team and DENSO collaborated to implement one very important and useful tool referred to as the Scenario Replicator (SR). SR provides the ability to record inputs from the WSU Software Services to applications into a log file. These inputs can then be played back at a later time and different place to aid in application debugging, enhancement and regression testing.

The WSU supports the ability to have the Radio Services (RS), Time Position Services (TPS), Vehicle Interface Services (VIS), RTK SW Interface and the Security external platform record the data they send to applications into a single file in a time-stamped format. This allows different complex scenarios to be executed in the field and to be captured into one or more files, see Figure 15 for an illustration.
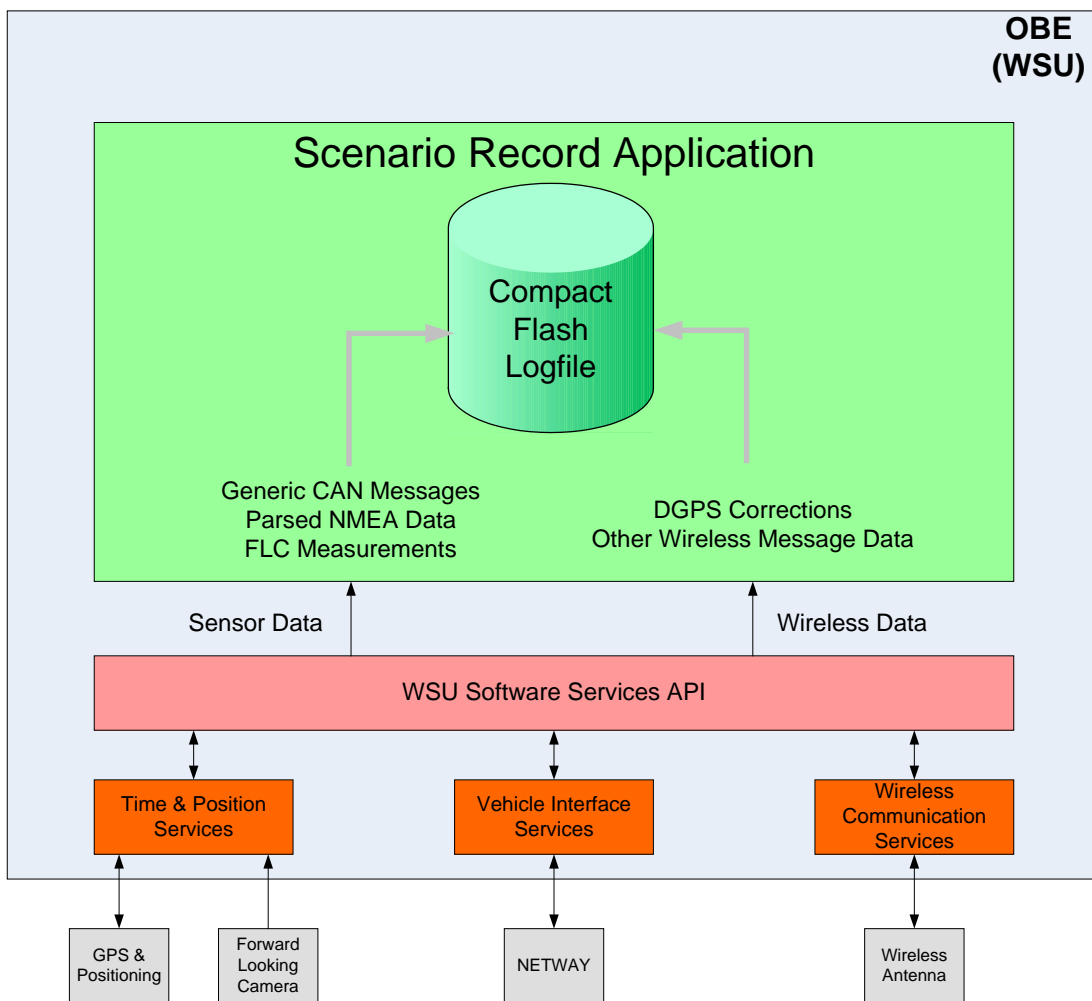


**Figure 15: Scenario Record Mode**

When desired, these scenarios can be played back on the WSU. During playback mode, the applications will receive the identical data that was received at the time the scenario was recorded. In addition, the WSU system time is also set to the time the scenario was recorded, see Figure 16 for an illustration. This capability provides a reliable way to compare and enhance application performance against a complex yet static set of external inputs.
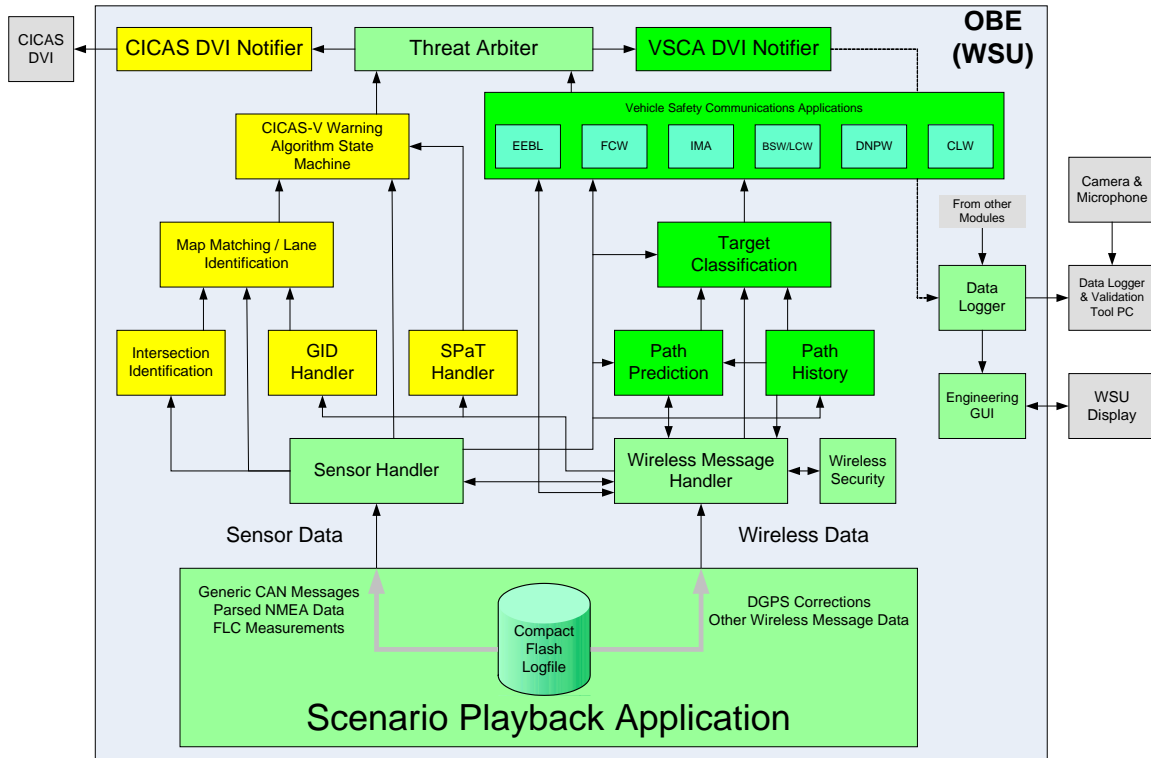


**Figure 16: Scenario Playback Mode**

The scenario record and playback tool provides for increased SW and system debugging efficiency in that specific, real-life scenarios can be accurately and repetitively accessed and system behavior effectively observed and corrected until the desired outcome is reached in the laboratory. Then, re-verification of the solution can be obtained again on the road or track and subsequent related scenarios can be collected.

In the top right hand side of Figure 16 a block termed "EGUI" is seen. This element is the representation of an "engineering type" graphical user interface. Its purpose is to provide a universal HMI to the development community that can be used to understand, evaluate, and configure the VSC-A platform. It is also used to represent visual and auditory vehicle driver warnings as a result of the application module algorithmic processes. Finally, the touch-screen interface allows the user to control parameters associated with the operation of the VSC Applications.

Shown below are examples of the graphical interface as depicted on a VGA touch-screen. Figure 17 shows four examples of the DVIN screen.
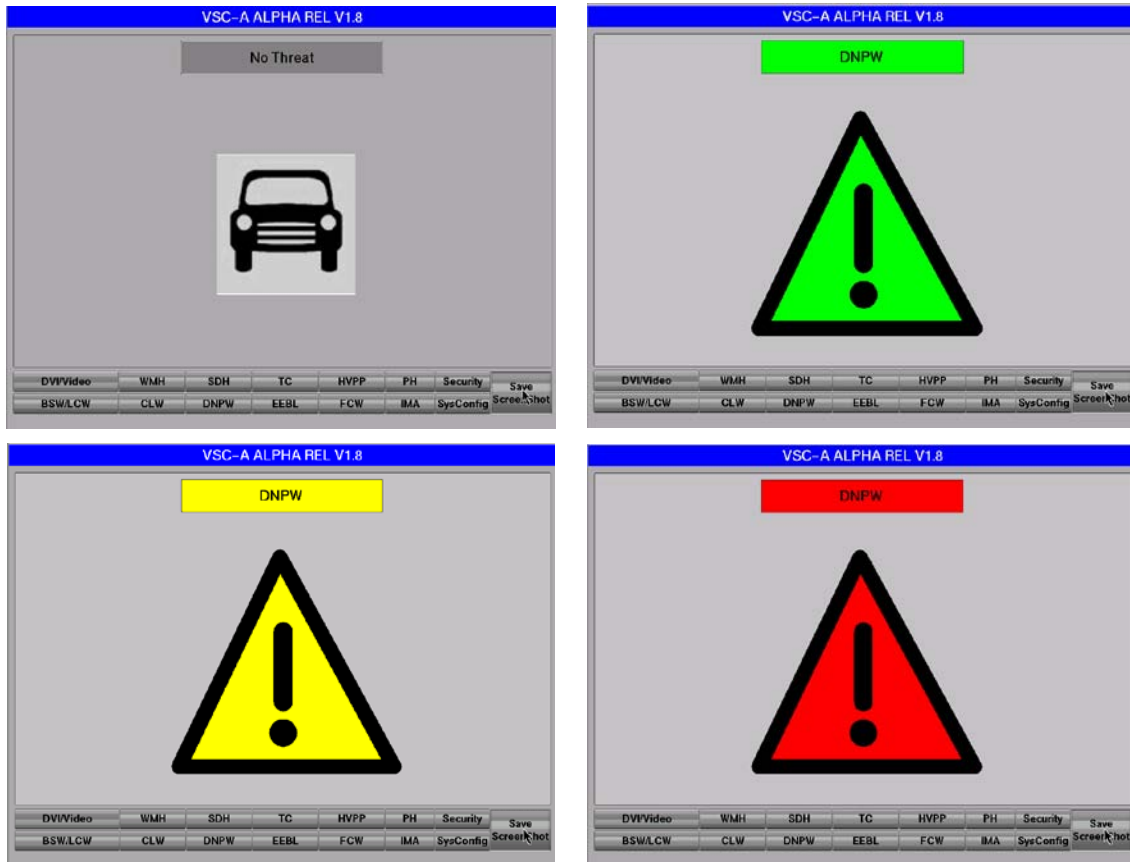
**Figure 17: DVIN Stages: (left → right, top → bottom) No Threat, Threat Detected, Inform Driver, Warn Driver**

This allows the EGUI to display the warning states of a particular threat, and in this case the DNPW is displayed. Only one of the warning screens is visible at any particular time. In order to ensure the most important warning is shown on the DVI screen (and, if appropriate, auditory response) the DVIN uses threat level, relative speed and location of the threat from each of the application modules to assess the severity and determine the highest priority request.

The EGUI can also show the particular operating scenario for an individual warning application. For the DNPW example we used above, Figure 18 shows the screen shot information available in the EGUI. Data such as Lat/Long offset and relative speed are important to monitor as the effectiveness of the warning algorithm is evaluated. The green/yellow colored graphics provide a quick view of the position and status of potential threat vehicles, relative to the host vehicle. The other five VSC-A Applications have similar type data screens available for debug and evaluation.
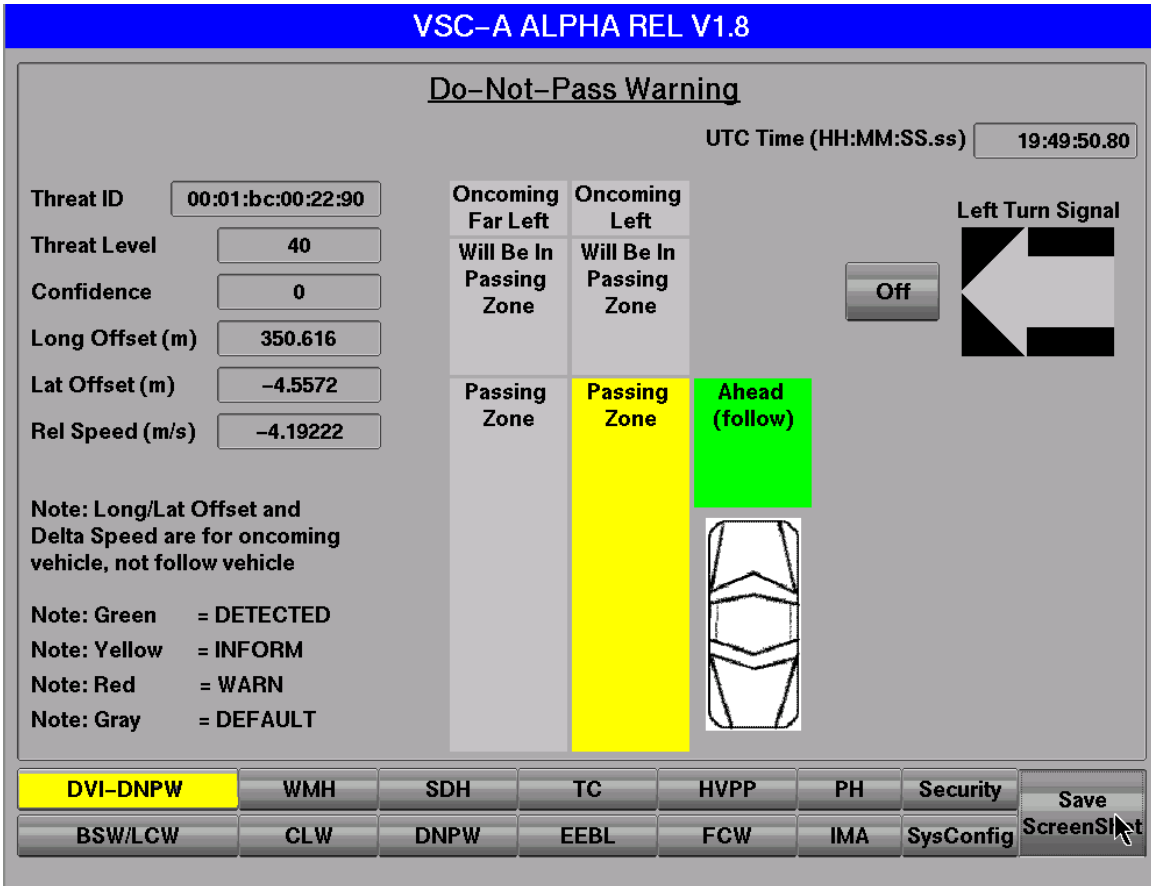
**Figure 18: DNPW EGUI Screen**

Finally, we show an example of support block data presentation in Figure 19. Here, the example of the WMH data for remote (neighboring) vehicle ID #1 is provided. The data presented is gathered from the over-the-air safety message; therefore information such as remote vehicle heading, brake status, lat/long location, yaw rate, etc., is shown on the screen. Such information is extremely valuable in assessing the capability of the support module and determining, along with other data, whether or not the threat detecting applications are correctly processing the sensor information.
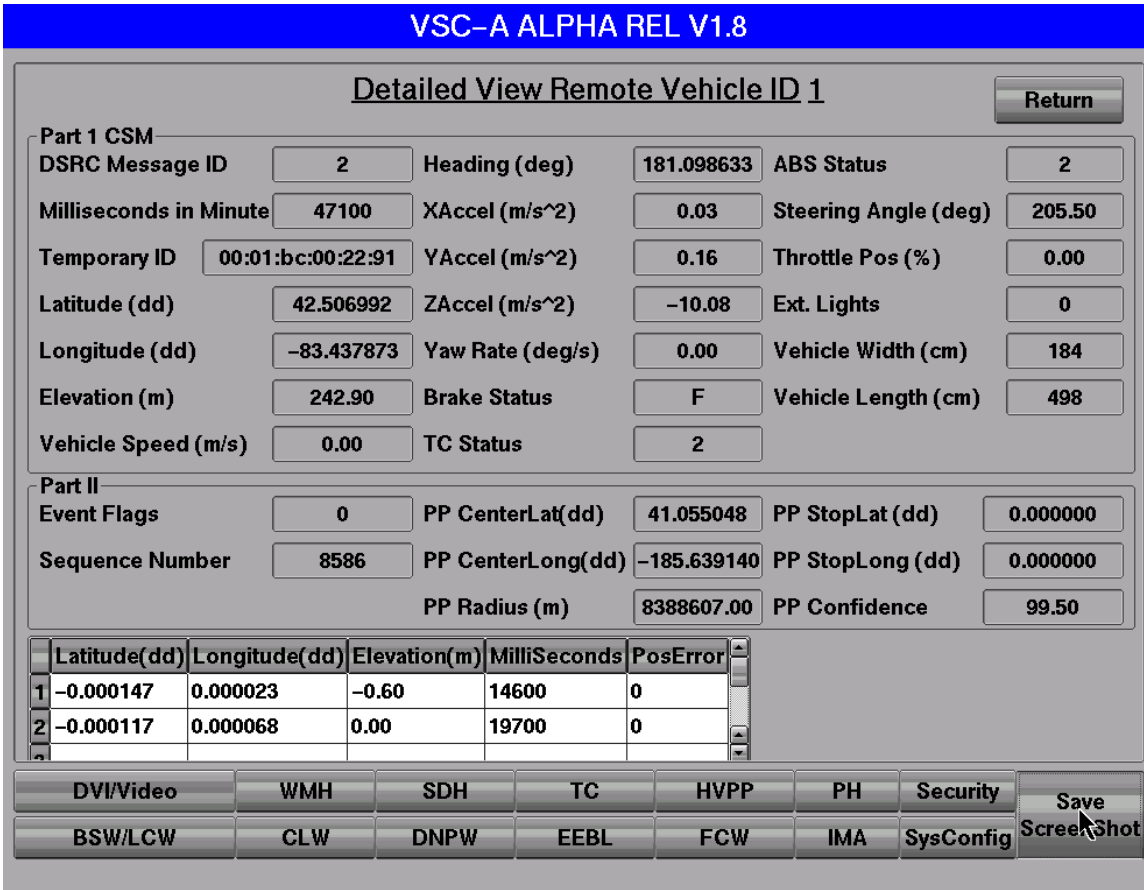
**Figure 19: WMH – Remote Vehicle Screen Shot**

## 6.2.2  Software Implementation and Release

The SW implementation for the core and application modules was accomplished in several stages where increased functionality was added and tested at each stage. Prior to final integration into the WSU the SW implementation for each of the modules was provided to the VSC-A Team for review.   The following SW release types were developed during 2008:

- Interface – Supported the external interface requirements to the WSU. This release of the software allowed issues with the interfaces to be worked out prior to receiving application level software.

- Alpha – Supported the primary functionality of the core and safety application modules. Multiple Alpha releases were received with the content of the releases prioritized to aid in the testing/debugging activities. As much as possible, required changes identified in an Alpha release were incorporated into subsequent Alpha releases rather than waiting until the Baseline release (discussed below) to incorporate the changes.

- Baseline – Supported the full functionality of the of the core and safety application modules and is referred to as the Level I Test Bed. This release of the software incorporated the remaining items that were not present in the final Alpha release as well as the required remaining changes identified through the Alpha release testing efforts.

Each of the release types identified above had multiple releases packages with each package containing a WSU SW Services release and a VSC-A Application release. During the first three quarters of the year the VSC-A Team conducted testing on the Interface and Alpha SW releases of the Level I Test Bed which focused on refining the core modules as well as the safety applications. Table 2 below lists the key SW releases that were made available during the year.

**Table 2: VSC-A Level I SW Release Details**

| Release Type | Release Date | Release Revision | | Release Content Summary |
| --- | --- | --- | --- | --- |
| | | WSU SW Services | VSC-A Application | |
| Interface | 02-18-2008 | 1.5 | 1.0 | Controller Area Network (CAN), GPS and OTA Interfaces, EGUI, Standalone Security solution, Scenario Record and Playback Tool and Data Logger |
| Alpha | 05-30-2008 | 1.12 | 1.0 | Core Modules, EEBL Application |
| Alpha | 06-29-2008 | 1.14 | 1.4 | Blind Spot Warning (BSW)+Lane Change Warning (LCW) and IMA Applications |
| Alpha | 07-09-2008 | 1.15 | 1.4b | DNPW and FCW Applications |
| Alpha | 07-17-2008 | 1.16 | 1.5 | CLW Application |
| Alpha | 08-14-2008 | 1.18 | 1.7 | Preliminary TA and Driver-Vehicle Interface Notifier (DVIN) |
| Alpha | 08-21-2008 | 1.19 | 1.8 | Applications and core modules enhancements |
| Alpha | 09-18-2008 | 1.20 | 1.9 | Relative Positioning support and Applications and core modules enhancements |
| Baseline | 10-16-2008 | 1.21 | 1.0 | Data Logging and Visualization Tool support, Security support, and Applications and core modules enhancements |
| Baseline | 12-16-2008 | 1.22 | 1.1 | Applications and core modules enhancements |

Along with each SW release, engineering debugging utilities (Scenario Record and Playback) and enhanced engineering monitoring tools (EGUI and Data Logging) were developed to accelerate the iteration cycle between design refinement, testing and verification.

Multiple testing sessions took place in the Second and Third Quarters involving all five OEMs. These sessions focused on testing the integrated set of the six safety applications in addition to validating the enhancements made to the applications identified from previous testing sessions.

In addition to the SW implementation for the core and safety application modules the following Security implementation work took place during the year:

- Implementation, integration, and release of the security module incorporating all three security schemes (TESLA, Two-Signature, and Digital Signature) running on an external PC platform

- Testing of the security module using SW running on the WSU was performed which provided performance estimations for the security module running on an external PC platform.

- Selection of the hardware for the Level II security module was finalized during the Fourth Quarter

- Integration of the security module on-board the WSU was initiated and planned for completion in the First Quarter 2009

## 6.3  Test Bed In-Vehicle Hardware Integration

This in-vehicle hardware (HW) integration activities involved the identification, acquisition, installation, and integration of all the HW and SW required for completion of the Test Bed to allow for testing to proceed under this and subsequent tasks. Note that some aspects of the HW and SW identification were handled through the activities of other tasks/sub-tasks. All vehicle builds were completed to support the Level I Alpha and Baseline SW releases.

The CAMP—VSC2 Consortium member OEMs purchased the following vehicles during the first year of the project to be used in the VSC-A system Test Bed. They are listed here in order to provide a complete list of the equipment used for the VSC-A Test Bed.

| | |
|---|---|
| Ford: | 2007 Volvo S80 |
| General Motors: | 2007 Cadillac STS Sedan |
| Honda: | 2006 Honda Acura RL |
| Mercedes-Benz: | 2007 Mercedes ML 350 |
| Toyota: | 2006 Toyota Prius |

Table 3 identifies the model and manufacturer of the equipment installed on the VSC-A test vehicles comprising the Level I Test Bed.

**Table 3: VSC-A Test Bed Hardware List**

| Item Description | Manufacturer | Model |
|---|---|---|
| GPS Receiver | Novatel | OEMV Flexpak V1-RT20A |
| GPS Antenna | Novatel | GPS-701-GG |
| LCD VGA Monitor | Xenarc | 700TSV-B |
| Monochrome Camera | Sony | BW-5LL |
| Video Quad Splitter | SuperCircuits, Inc | QS25 |
| Frame Grabber | Sensoray | 2255S |
| Car PC | Logic Supply | Voom PC-2 |
| Inertial Measurement Unit | Silicon Sensing | DMU |
| OBE Vehicle CAN interface | Smart Engineering Tools | Netway 6 |
| DSRC Antenna | Nippon Antenna | DEN-HA001-001 |
| Ethernet Switch | Netgear | GS105 |

Figure 20 below illustrates the current hardware layout of the Test Bed.
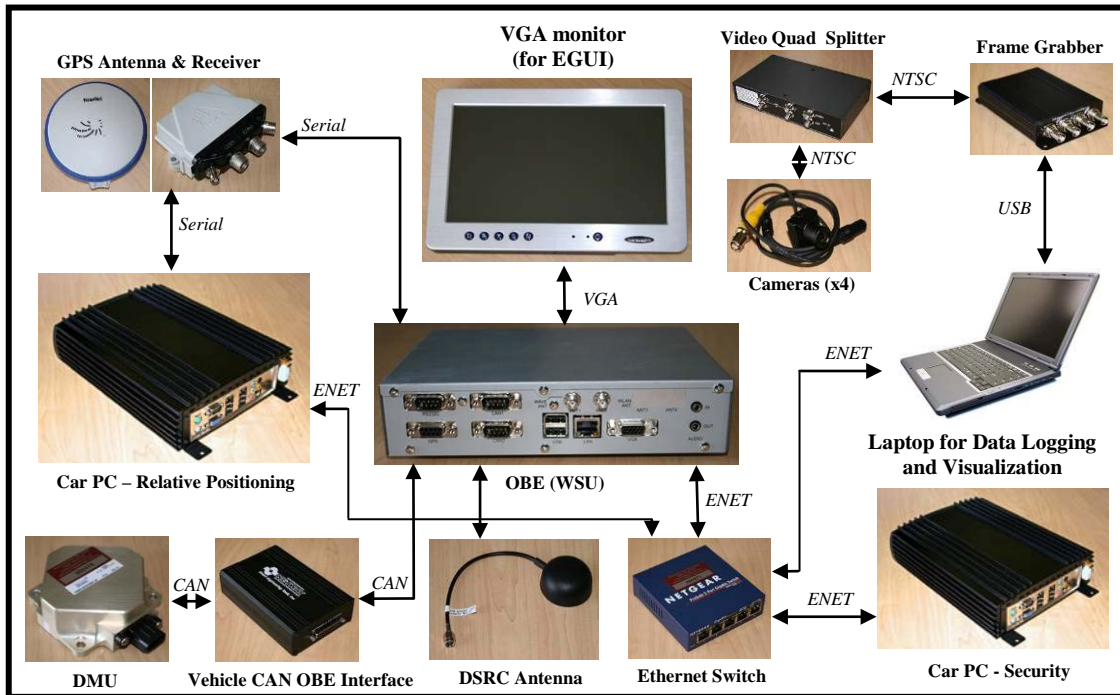


**Figure 20: VSC-A System Test Bed HW Layout**

Integration of some of the items identified in the figure above, such as the video equipment, is still an on-going effort expected to complete early in the First Quarter of 2009.

# 7    Task 8 Summary: Objective Test Procedures

The purpose of the task is to define the Objective Test Procedures (OTP) for the VSC-A system in order to verify that the system implementation performs as described in the minimum performance specifications document. The activities of this task tracked closely with the ones for the Task 5.1 Minimum Performance Specifications with individual test procedure documents being developed based on a common template, reviewed, updated and consolidated into single VSC-A OTP document.

The consolidated OTP document was developed in the Fourth Quarter and contains the following information:

General Information

- The general procedures which must be followed for each of the test cases such as where to test, the number of people required for a test, etc.

- Assumptions being made as they relate to the test observers and/or test drivers familiarity with the system

- Test scenarios overview which lists the test scenarios for all the VSC-A applications

- The minimum criteria that must be met for a test to be considered valid such as vehicle speed deviation, acceptable packet error rate, GPS coverage, etc.

- The minimum criteria that must be met for a test to be considered successful such as test validity, warning issuance and timing

- The general requirements for conducting the tests which includes data exchange, collection, logging and necessary environmental and roadway conditions

Test Specific Information

- Background describing the objective of and reasoning behind the test

- Any test assumptions that may exist

- Test setup required prior to execution of the test which includes initial position of vehicles and if necessary position markers

- Driving instructions necessary for properly executing the test

- Criteria which must be met for the test to be considered successful

- Criteria which cause the test to be considered unsuccessful

- Criteria for evaluating the test results

Reviews of test procedures were held both internally and externally with VOLPE with a plan for completing the document in the First Quarter 2009. This document is the basis for the VSC-A System Testing and Objective Test Procedures Validation activities taking place as part of the Task 9 activities.

# 8  Task 9 Summary: System Testing and Objective Test Procedures Validation

A high level timeline of the Task was developed to help support the USDOT planning activities for the benefits estimation efforts. The timeline will be finalized in the First Quarter 2009 based on a joint review between the VSC-A Team and NHTSA.

# 9  Task 11 Summary: Project Administration

CAMP administered and coordinated the overall activities of the Cooperative Agreement and the VSC-A project and served as the single interface between all Participants and the Government in the performance of the Agreement. These activities included the following:

- Overall program management and coordination activities with NHTSA Program Office and Office of Acquisition Management

- Coordinated the submission of program milestones, deliverables and reporting requirements

- Coordinated activities related to Government requests for subsequent Work Order Proposals

- Ensured the coordination of CAMP project work order activities with other USDOT Programs and contractors in coordination with the NHTSA Contracting Officer's Technical Representative (COTR)

- Ensured proper communication and coordination amongst project work order Participants

- Conducted financial and administrative reviews of subcontract and sub-recipient proposals

- Issued and managed subcontracts and sub-awards

- Ensured the proper documentation, recording and tracking of project equipment

- Coordinated submission of invoices and cost reports

- Executed Agreement modifications and Project Order Amendments

# 10  Task 3, Task 6, Task 10 Summaries – No Major Activities

The Task 3 activities were completed in calendar year 2007.  There were no major activities to report under Tasks 6 and 10. The majority of the work for these tasks is scheduled for 2009.

# 11   References

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[2] Bhargav Bellur, Anitha Varghese, *"TESLA Authentication and Digital Signatures for V2X Messages,"* www.ip.com, IP.com number: IPCOM000175320D, IP.com Electronic Publication: October 9, 2008.

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