

USING DEDICATED SHORT RANGE COMMUNICATIONS FOR VEHICLE SAFETY APPLICATIONS – THE NEXT GENERATION OF COLLISION AVOIDANCE

Arthur A. Carter
National Highway Traffic Safety Administration
United States of America

James Chang
Noblis
United States of America

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ABSTRACT

This paper provides the status of the Vehicle Safety Communications-Applications (VSC-A) research project, which was designed to determine if dedicated short range communications (DSRC) paired with accurate vehicle positioning can improve upon autonomous vehicle-based safety systems or enable new communication-based safety applications. This three-year project is a collaborative effort between government and industry to develop the underlying pre-competitive elements needed to enable the deployment of vehicle-to-vehicle (V2V) communication-based crash avoidance applications. The effort includes the development of core software and hardware modules and prototype applications. These use DSRC in conjunction with enhancements to vehicle positioning systems to demonstrate crash avoidance capabilities, which are interoperable between different vehicle manufacturers. To support the development of interoperable systems, the partners have participated in standards and security protocol development activities. The core modules and prototype applications are implemented on a five-vehicle testbed fleet, which will be used to conduct objective tests that are then used to validate minimum performance specifications established as part of this project. These tests will in turn support a safety benefits estimation process to determine the potential for preventing or mitigating crashes and associated fatalities, injuries, and property damage.

BACKGROUND

In 1999¹, the US Federal Communications Commission (FCC) allocated wireless spectrum in the 5.9 GHz frequency range for use by DSRC systems supporting Intelligent Transportation Systems. One of the goals in establishing this DSRC capability was to improve traveler safety by

supporting the development of vehicle safety applications. In 2006², the FCC further refined the rules for DSRC to explicitly consider "vehicle-to-vehicle collision avoidance and mitigation," reflecting the results of research experience. As a result, DSRC is enabling the development of these next-generation communications-based vehicle safety systems in the VSC-A initiative.

The VSC-A project builds upon the results of the first Vehicle Safety Communications (VSC) project(1), conducted from 2002 to 2005 through collaboration between the National Highway Traffic Safety Administration (NHTSA) and automakers in the Crash Avoidance Metrics Partnership³ (CAMP) Vehicle Safety Communications Consortium consisting of seven automotive original equipment manufacturers (OEMs). Working together, they investigated the potential of V2V and vehicle-to-infrastructure communications as a means of improving crash prevention performance.

Building upon the success of the VSC project, the CAMP Vehicle Safety Communications 2 Consortium (Ford, General Motors, Honda, Mercedes-Benz, and Toyota) and NHTSA are now engaged in the final year of a 3-year cooperative agreement to conduct enabling research to support

² FCC Memorandum Opinion and Order 06-100, adopted July 20, 2006.

³ The Ford Motor Company and General Motors Corporation formed the Crash Avoidance Metrics Partnership (CAMP) in 1995. The objective of the partnership is to accelerate the implementation of crash avoidance countermeasures to improve traffic safety by defining and developing necessary pre-competitive enabling elements of future systems. CAMP provides a flexible mechanism to facilitate interaction among additional participants as well, such as the US DOT and other OEMs, in order to execute cooperative research projects.

¹ FCC Report and Order 99-305, adopted October 21, 1999.

pre-competitive system development and demonstrate the performance of V2V communications-based safety applications. The VSC-A project aims to develop and test the system components that are required before automotive OEMs can develop and deploy production systems.

CRASH SCENARIO IDENTIFICATION

Figure 1 gives the distribution of the 6.2 million crashes reported in 2004 via NHTSA’s General Estimate System (GES) (2). Classification of crashes is by the GES variable “Manner of Collision.” While radars have a limited FOV (field of view) for detecting potential collisions, V2V communications and GPS receivers enable a 360 degree FOV. Thus, rear-end, head-on, angle, and sideswipe crashes are all relevant to V2V applications. Angle and sideswipe crashes would also include intersection related crashes. Crashes classified as “not collision with motor vehicle in transport” represents road departure crashes that are not relevant to the VSC applications. Based on this classification, the V2V applications discussed above are applicable to approximately 66% or 4 million crashes annually.

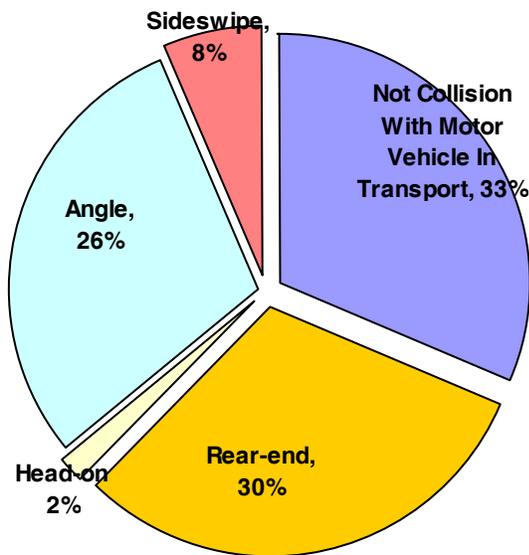


Figure 1, Crash problem classified by manner of collision, 2004 GES.

To focus the development efforts, the U.S. DOT provided the VSC-A team with crash scenarios to serve as a starting point for analysis and as a reference for the selection of the set of safety applications for study under the VSC-A project. The U.S. DOT, with support from the U.S. DOT’s Volpe

national transportation Systems Center and Noblis, evaluated eight pre-crash scenarios in order to provide high potential benefit crash imminent safety scenarios for study. The crash scenarios chosen were based on:

- Crash rankings by frequency;
- Crash rankings by cost;
- Crash rankings by functional years lost⁴; and
- A composite crash rankings (based on the above three ranks)

The 2004 GES crash database is the basis for the set of crash scenarios. The evaluation also indicated which system type (autonomous, V2V, or both) addresses, or could address, the different crash scenarios presented.

From the composite ranking of crash imminent scenarios, the top five crash scenarios, ranked based on crash frequency, crash cost, and functional years lost, that could be addressed by V2V safety applications, were selected. This ranking allowed the team to focus on the most frequent, highest cost, and most damaging crashes, while keeping the program scope to a manageable level. Table 1 contains the final set of crash imminent scenarios, as agreed between the VSC-A team and U.S. DOT, to be targeted under the VSC-A project

	Crash Imminent Scenario	High Freq	High Cost	High Years
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⁴ Functional Years Lost is a non-monetary measure that sums the years of life lost to fatal injury and the years of functional capacity lost to nonfatal injury (3)

1	Lead Vehicle Stopped	✓	✓	✓
2	Control Loss Without Prior Vehicle Action ⁵	✓	✓	✓
3	Vehicle(s) Turning at Non-Signalized Junctions	✓	✓	
4	Straight Crossing Paths at Non-Signalized Junctions			✓
5	Lead Vehicle Decelerating	✓	✓	
6	Vehicle(s) Not Making a Maneuver – Opposite Direction			✓
7	Vehicle(s) Changing Lanes – Same Direction	✓		
8	LTAP/OD at Non-Signalized Junctions			

A “✓” Denotes a Top Five Ranking in each category

Table 1 Crash Imminent Scenarios

VSC-A OBJECTIVES

To address the goal of the VSC-A program, the program has the following objectives, broken out into two parts: 1) Technology development and 2) Benefits assessment activities:

Technology development objectives:

1. 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.
2. 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.

⁵ The control loss cases being addressed by vehicle to vehicle communications are those in which a vehicle that begins to experience control loss (e.g. slippery conditions- detected using ABS or stability control) broadcasts a message to other vehicles. The first (transmitting) vehicle does not need to crash for this warning to be transmitted.

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

Benefit assessment activities objectives:

1. Assess how previously identified crash-imminent safety scenarios in autonomous systems could be addressed and improved by DSRC + Positioning systems.
2. Develop a well understood and agreed upon benefits, with respect to market penetration, analysis, and potential deployment models, and crash reduction and mitigation for a selected set of communication-based vehicle safety applications.
3. Develop and verify a set of objective test procedures for the vehicle safety communications applications.

VSC-A PROGRAM

To achieve the goals outlined in the introduction, the VSC-A program is organized as follows:

- Technology Development
- Performance Specifications Development
- Safety Benefits Estimation

Technology Development

The U.S. DOT has conducted extensive research on the effectiveness of autonomous vehicle-based collision countermeasures for rear-end, road departure, and lane change crashes(4, 5, 6, 7, 8). Field operational tests 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 vehicles and other in-path obstacles for rear-end collision warning systems, as well as map errors , misidentified lane markings, and limited availability for road departure crash warning systems.

A VSC-A equipped vehicle uses DSRC, in conjunction with vehicle positioning information, to broadcast its location, travel path, and status (e.g. braking, etc.). By using wireless communications, VSC-A has the potential to prevent vehicle crashes in

situations where an autonomous vehicle safety system may have difficulties. For example, if a braking vehicle on a curve falls outside the coverage area of an autonomous radar-based system, a wireless message could still relay information to a following vehicle so that it would recognize the need to stop. As part of this project, CAMP has investigated specific scenarios in which communications-based safety systems may be more effective than autonomous systems.

V2V wireless communications, paired with accurate vehicle positioning, may truly overcome these shortcomings and thus enable improved safety system effectiveness by complementing or, in some instances, providing alternative approaches to autonomous safety equipment.

To access the performance of the scenarios identified above a test program was proposed. Implementing this test program requires that CAMP build a fleet of test vehicles. The testbed fleet consists of five different vehicles (a 2007 Ford Flex, a 2005 GM Cadillac STS Sedan, a 2006 Honda Acura RL, a 2006 Mercedes-Benz ML 350, and a 2006 Toyota Prius). Each participating OEM will build a vehicle, and each is equipped with identical VSC-A system components. The major technology components developed and installed in each vehicle include:

- A DSRC Radio – the DSRC radio transmits and receives messages to/from other vehicles
- A Global Positioning Satellite (GPS) Receiver – the GPS receiver provides real-time location information for the host vehicle
- An Interface for each Specific Vehicle – the interface provides a common connection to permit access to information on the internal vehicle bus of the host vehicle
- On-Board Equipment – this hosts the system core software modules and the prototype applications

The system core modules provide the supporting capabilities that enable the applications to function. They include path history, host vehicle path prediction, target classification, wireless message handler, and threat arbitration. These modules receive messages from other vehicles, store and process relevant information to determine threats, and monitor host-vehicle location and actions and

transmit messages to other vehicles, enabling them to do the same.

DSRC + Positioning

This stage of the program is concerned with the development of accurate, and affordable, vehicle positioning. DSRC provides the wireless communications system supporting V2V communications for the safety applications. Under VSC-A, an equipped vehicle will be able to keep track of surrounding vehicles and the potential threat they pose by receiving periodic wireless messages. For a vehicle to determine the potential threats posed by other vehicles, it needs to know the relative position of surrounding vehicles and other relevant information such as braking status from those vehicles. The relative position can be determined using knowledge of a vehicle's own position in conjunction with the other vehicle's broadcasted position information. The core modules developed for the VSC-A testbed support the necessary processing and tracking for both transmission of messages to other vehicles and receipt and processing of other vehicles' messages.

The positioning information necessary to support the applications requires sufficient precision to support lane-level positioning so that other vehicles posing a potential threat could be classified by lane.

The VSC-A team investigated existing GPS-based systems used in high accuracy relative-positioning applications. Based on results from the CICAS-V⁶(9) lane-level positioning system implementation, and results from an expert workshop on existing technologies, appropriate relative positioning methods were identified for further evaluation(10). The interface definition of the relative positioning system was defined so that different relative positioning implementations can be used in the testbed without changing the over-the-air message format.

Interoperability / Standards

Without standardization, different vehicles cannot communicate properly with other vehicles, and an interoperable solution involving different manufacturers would be impossible. To this end, CAMP is focused on the development of scalable, common communications architecture. Thus, an important goal of the VSC-A project is the standardization of the message sets, message composition approach, and communication protocols

⁶ CICAS-V stands for Cooperative Intersection Collision Avoidance System - Violation

for DSRC-based vehicle safety. To achieve this goal, the VSC-A standards working group developed a standards support plan in February 2007 (10). This plan outlines the current standards landscape. The plan also provides a guideline by which the VSC-A standards working group will coordinate their interactions between the various task activities and results and the identified relevant Standard Development Organizations activities.

As part of the short-term standards support activities highlighted in the plan, the VSC-A team has substantially increased OEM participation under the Society of Automotive Engineers (SAE) DSRC Technical Committee. The following standards were impacted as a result:

- SAE J2735, which specifies message sets, data frames and elements to permit interoperability at the application layer. This supports development of different applications that can rely upon the same standard message set elements.
- Institute of Electrical and Electronic Engineers (IEEE) 802.11p standard, which is similar to 802.11g used for home wireless networks, covers the lower layer communications standards that enable low-latency wireless communications critical for vehicle-based safety communications.
- The IEEE 1609.x Family of Standards for Wireless Access in Vehicular Environments (WAVE) defines the architecture, communications model, management structure, security mechanisms, and physical access for wireless communications in the vehicular environment. WAVE is a mode of operations for use by 802.11p compliant devices that enable low latency communication exchanges.

The VSC-A team will continue active participation to guide these developing standards based on the output of the work being performed under the VSC-A project.

Security

In order for communications-based vehicle safety systems to be deployed, the systems must implement security protocols and capabilities ensuring that drivers are given warnings based only on authentic threats, and that drivers' privacy is protected. Within the VSC-A project, the security task is focused primarily on message authentication while preserving

driver/owner privacy, controlling bandwidth overhead, processing requirements, and latency.

Working with a consulting security expert, a VSC-A threat model document was developed which considers privacy vs. revocation, certificate distribution and revocation, and computational and bandwidth requirements. Threats to privacy were identified as a major priority. Several candidate security protocols for broadcast authentication and privacy protection were also developed and subjected to a preliminary evaluation. In addition, development includes the definition of over-the-air security message formats and initial efforts to interface the security module with the rest of the testbed system.

Prototype Applications

The VSC-A project is prototyping six distinct applications intended to address different crash scenarios (see Table 1). However, the project does not focus on production-ready applications, only prototype applications to demonstrate and evaluate system capabilities. The applications, and a brief description of each, follow:

- A. Emergency Electronic Brake Light (EEBL) - The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and, if necessary, warns the driver. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions - fog, heavy rain, for example.
- B. Forward-collision warning (FCW) - The FCW application warns the driver of the host vehicle of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help drivers avoid or mitigate rear-end vehicle collisions in the forward path of travel.
- C. Intersection-Movement Assist (IMA) - The IMA application is intended to warn the driver of a host vehicle when it is not safe to enter an intersection due to high collision probability with other remote vehicles.
- D. Blind-Spot Warning (BSW) + Lane-Change Warning (LCW) - During a lane-change attempt, the BSW + LCW application warns the driver of the host vehicle if the zone into

which the host vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction. Moreover, when a lane change is not being attempted, the application informs the driver of the host vehicle when a vehicle in an adjacent lane is positioned in a host vehicle’s blind-spot zone.

- E. Do-not-pass warning (DNPW) - When the host-vehicle driver attempts to pass a slower vehicle, the DNPW application issues a warning when the passing zone is occupied by a vehicle traveling in the opposite direction. In addition, even when a passing maneuver is not being attempted, the application informs the host-vehicle driver of the host vehicle that the passing zone is occupied .
- F. Control-loss warning (CLW) - The CLW application enables a host vehicle to broadcast a self-generated control loss event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and, if necessary, provides a warning to the driver.

These applications have been prototyped in the testbed and the OEMs have begun testing their performance under a variety of controlled conditions. Table 2 shows the relationship between the crash types and applications.

		SAFETY APPLICATIONS					
		A	B	C	D	E	F
CRASH TYPES	Lead Vehicle Stopped	✓	✓				
	Lead Vehicle Decelerating	✓	✓				
	Vehicle(s) Turning at Non-Signalized Junctions			✓			
	Straight Crossing Paths at Non-Signalized Junctions			✓			
	Vehicle(s) changing lanes – same direction				✓		
	Vehicle(s) Not Making a Maneuver – Opposite Direction					✓	
	Control Loss Without Prior Vehicle Action						✓

Table 2: Crash Types vs. Safety Applications

Performance Specifications Development

The VSC-A project also includes the development of performance specifications for each of the prototype applications. These specifications represent the minimum performance that an application must satisfy in order to achieve basic crash avoidance capability. It is expected that application developers will go beyond these minimum specifications when production systems are developed. However, a common basis established by minimum performance criteria can be used to test application performance across different vehicles and application developers.

The project also includes the development and execution of objective tests. These tests will verify system performance at the prototype stage. The tests will include specific procedures based on the minimum performance specifications developed and will result in objective measures of how well the prototype satisfies the criteria under specific test conditions. Since the VSC-A system is not yet at the stage of a field operational test, the objective test plan will attempt to capture how well the prototype applications and underlying core modules developed in this project achieve the crash avoidance capabilities in a variety of scenarios. These scenarios are selected based on the particular application, and since the tests are intended to capture prototype performance, they will not include evaluation of the driver-vehicle interface performance.

Safety Benefits Estimation

The Volpe Center is leading the effort to estimate safety benefits associated with deployment of safety applications within the VSC-A project. To determine the safety benefits of this new technology the Center will implement a benefits equation for the estimation of number of crashes prevented by the V2V countermeasure, and provide extensions for estimation of impact on level of injury. Although there are many formulations, they all are based on the fundamental definition of benefits (11):

$$B = N_{wo} - N_w \tag{1}$$

Where,

B = benefits, (which can be the number of crashes, number of fatalities, “harm,” or other such measures).

N_{wo} = value of this measure, (for example, number of crashes) that occurs *without* the system.

N_w = value of the measure *with* the system fully deployed.

The value of N_{wo} is usually known from crash data files, but N_w is not known for pre-production. Thus, it is necessary to estimate the effectiveness of a countermeasure and combine it with the known value of N_{wo} , as shown in the following equation:

$$B = N_{wo} \times SE \quad (2)$$

Where,

SE = effectiveness of the system, and

N_{wo} = baseline number of crashes.

An extension of this idea is that the overall benefits consist of the sum of benefits across a number of specific scenarios:

$$B = \sum_i N_{wo_i} \times E_i \quad (3)$$

Where,

“i” = individual scenarios.

E_i = effectiveness of the system in reducing the number of crashes in a specific crash-related scenario

N_{wo_i} = baseline number of crashes in individual scenario “i”

B_i = the benefits in each of the individual scenarios.

This safety benefits estimation effort will incorporate the results from objective tests conducted in the coming year and use NHTSA crash databases to determine the crashes scenarios likely to be avoided by each VSC-A application. In support of this process, Noblis is developing a market penetration model to capture the impact of deployment of the system over time. The results of the safety benefits estimation will utilize the best available information to guide further development and deployment.

FUTURE ACTIVITIES

During the final year of the project, objective tests will be run to evaluate the prototype’s performance, support estimation of safety benefits, and guide future development.

SUMMARY

This paper provided the status of research on the use of V2V communications and relative positioning for crash avoidance applications. The VSC-A project has made considerable progress in developing the key components necessary for interoperable crash avoidance applications. Project activities have focused on two major areas:

Technology development objectives:

1. Develop scalable, common vehicle safety communication architecture, protocols, and messaging framework (interfaces) necessary to achieve interoperability and cohesiveness among different vehicle manufacturers.
2. Develop accurate and affordable vehicle-positioning technology
3. Define set of DSRC + Positioning-based vehicle safety applications and application specifications.

Benefit assessment objectives:

1. Assess how previously identified crash-imminent safety scenarios in autonomous systems could be addressed and improved by DSRC + Positioning systems.
2. Develop a well understood and agreed upon benefits, with respect to market penetration, analysis, for a selected set of communication-based vehicle safety applications.
3. Develop and verify a set of objective test procedures.

Coordination and support with other programs / organizations has also taken place.

The system concept and prototype described in this paper has already experienced substantial development in the form of testbed fleet with functioning system core modules and six prototype applications.

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REFERENCES

1. Vehicle Safety Communications Project - FINAL REPORT - CAMP IVI Light Vehicle Enabling Research Program, NHTSA, Washington, D.C., DOT HS 810 591, April 2006.
2. GES, "General Estimates System Coding And Editing Manual," 2006; <http://www-nrd.nhtsa.dot.gov/Pubs/GES06.PDF>
3. T. Miller, J. Viner, S. Rossman, N. Pindus, W. Gellert, J. Douglass, A. Dillingham, and G. Blomquist, "The Costs of Highway Crashes". FHWA-RD-91-055, October 1991.
4. Wassim G. Najm, Mary D. Stearns, Heidi Howarth, Jonathan Koopmann, John Hitz, "Evaluation of an Automotive Rear-End Collision Avoidance System," Sponsored by NHTSA, Washington, D.C., DOT VNTSC-NHTSA-06-01, DOT HS 810 569, March 2006.
5. Bruce H. Wilson, Mary D. Stearns, Jonathan Koopmann, C.Y. David Yang, "Evaluation of a Road-Departure Crash Warning System," Sponsored by NHTSA, Washington D.C., DOT HS 810 854, December 2007.
6. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J. Mefford, M., Hagan, M., Bareket, Z., Goodsell, R., and Gordon, T.; "Road Departure Crash Warning System Field Operational Test: Methodology and Results - Technical Report", Performed by University of Michigan Transportation Research Institute (UMTRI) - Contract DTFH61-01-X-00053, Washington, DC, June 2006.
7. S. Talmadge, R. Chu, C. Eberhard, K. Jordan, P. Moffa, "Development of Performance Specifications for Collisions Avoidance Systems for Lane Change Crashes", Sponsored by NHTSA, Washington, D.C., DOT HS 809 414, August 2000.
8. P. L. Zador; S. A. Krawchuk; R. B. Voas, "Final Report -- Automotive Collision Avoidance System (ACAS) Program," Performed by Delphi-Delco Electronic Systems, Contract No: DTNH22-95-H-07162, DOT HS 809 080 Washington, DC, August 2000
9. Michael Maile, Farid Ahmed-Zaid, Lorenzo Caminiti, John Lundberg, Priyantha Mudalige, Chuck Pall, Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations Midterm Phase I Report May 2006 – April 2007, NHTSA, Washington, D.C., DOT HS 811 048, October, 2008.
10. Vehicle Safety Communications – Applications – VSC-A First Annual Report December 7, 2006 through December 31, 2007, Available at <http://www.vehicle-infrastructure.org/applications/cicas/09042008-vsc-a-report.pdf> , September 2008.
11. Burgett, A., Srinivasan, G., and Ranganathan, R.; "A Methodology for Estimating Potential Safety Benefits for Pre-Production Driver Assistance Systems," DOT HS 810 945., National Highway Traffic Safety Administration, Washington D.C., May 2008