VEHICLE SAFETY COMMUNICATIONS IN THE UNITED STATES

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ABSTRACT

In the United States, passenger vehicle manufacturers have been working together, along with the U. S. government, to study wireless communications for vehicle safety applications.

From 2002-4, seven automotive manufacturers—BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW— worked with the United States Department of Transportation (USDOT) to evaluate vehicle safety applications enabled or enhanced by communications. This project determined initial communication requirements for identified applications, performed some Dedicated Short Range Communications (DSRC) vehicle testing and helped develop the DSRC standards to support the requirements of safety applications. The project identified eight scenarios as high-priority for further research based on their estimated potential safety benefits. Of these eight application scenarios, four involved vehicle-to-vehicle (V-V) communications and four involved communications between vehicles and the infrastructure. Three of the vehicle-infrastructure communication applications involved intersections.

From 2005-6, BMW, DaimlerChrysler, Ford, GM, Nissan and Toyota worked together to develop and evaluate the Emergency Electronic Brake Light application (EEBL) as the first vehicle-to-vehicle cooperative active safety application in order to:

  o   Develop concepts of operation, system and
      communication requirements
  o   Establish a common V-V EEBL message set
      and demonstrate interoperability
  o   Perform common engineering tests
  o   Report to the industry on results
  o   Guide future V-V safety applications
      development

In 2006, DaimlerChrysler, Ford, GM, Honda and Toyota initiated two major vehicle safety communications projects with the USDOT. The first project is developing and field testing a Cooperative Intersection Collision Avoidance System using infrastructure-to-vehicle communications to address intersection crashes that result from signal Violations (CICAS-V). The second project, Vehicle Safety Communications Applications (VSC-A), is developing a common vehicle safety communication architecture, protocols and messaging framework necessary to achieve interoperability among different vehicle manufacturers' applications and an analysis of potential benefits versus market penetration for vehicle safety communications applications.

INTRODUCTION

Vehicle communications, both between vehicles and between vehicles and the infrastructure, offer the possibility to significantly improve crash avoidance and crash mitigation systems. Information could be exchanged over a wireless network that is difficult, if not impossible, to measure remotely with sensors such as radars, lidars or cameras. In addition, the cost of a vehicle communication system (transceiver and GPS receiver) is significantly less than, for instance, an ACC radar, making it feasible to widely deploy such a system.

DEDICATED SHORT RANGE COMMUNICATION (DSRC)

FCC DSRC Frequency Allocation

In the United States in 1997, ITS America petitioned the Federal Communications Commission to allocate seventy-five megahertz of spectrum in the 5.9 GHz band for ITS, in particular for DSRC. The following year, in 1998, Congress passed and the President signed into law the Transportation Equity Act for the 21st Century ("TEA-21"), which directed the Commission, in consultation with the USDOT, to consider the spectrum needs "for the operation of intelligent transportation systems, including spectrum for the dedicated short-range vehicle-to-wayside wireless standard," DSRC. In October 1999, the Commission allocated the 5.9 GHz band for DSRC-based ITS applications and adopted basic technical rules for DSRC operations.

On December 17, 2003 the Commission adopted a Report and Order establishing licensing and service rules for the DSRC Service in the Intelligent Transportation Systems (ITS) Radio Service in the 5.850-5.925 GHz band (5.9 GHz band). Equipment in the DSRC Service comprises On-Board Units (OBUs) and Roadside Units (RSUs). An OBU is a transceiver

that is normally mounted in or on a vehicle, or in some instances may be a portable unit. An RSU is a transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or hand carried, but it may only operate when the vehicle or hand-carried unit is stationary. An RSU broadcasts data to OBUs or exchanges data with OBUs in its communications zone.[1]

The ASTM DSRC Standard

Subsequent to the Commission's allocation of the 5.9 GHz band to the mobile service for use by DSRC systems, ITS America began to hold stakeholder workshops, panel discussions, and other industry meetings to develop a consensus on how to achieve national interoperability in the deployment of DSRC-based ITS user services. The Federal Highway Administration (FHWA), an agency of the USDOT, entered into a cooperative agreement with the American Society for Testing and Materials (ASTM) to develop a national, interoperable standard for DSRC equipment operating in the 5.9 GHz band.

On August 24, 2001, the Standards Writing Group selected a version of the Institute of Electrical and Electronic Engineers, Inc.'s (IEEE) 802.11 and 802.11a standard as the preferred technology to provide national interoperability for DSRC operations. IEEE 802.11, the Wi-Fi standard, denotes a set of Wireless LAN/WLAN standards developed by working group 11 of the IEEE LAN/MAN Standards Committee. IEEE 802.11p was adopted as the specification for the lower-layer DSRC standard, specifically for the Medium Access Control (MAC) and Physical Layer (PHY).

Band Plan

The Commission also decided that "some channelization of the DSRC spectrum may be essential to promote spectrum efficiency and to facilitate interoperability."[1] The DSRC spectrum was divided into 8 channels – one 5 MHz channel kept in reserve and 7 10MHz channels, channels 172, 174, 176, 178, 180, 182 and 184. In addition, channels 174 and 176 and also channels 180 and 182 may be aggregated into 20 MHz channels, designated as Channels 175 and 181 respectively. The ASTM-DSRC standard allows for a 10 MHz channel to support a data exchange rate of 27 Mbps and a 20 MHz channel to support a data exchange rate of 54 Mbps. In the center of the band, channel 178 was designated the "control channel". The basic concept is that a Road- Side Unit announces to OBUs 10 times per second the applications it supports

on which channel. The On-Board Unit listens on Channel 178, authenticates the RSU digital signature, executes safety applications first, then switches channels and executes non-safety applications, then returns to Channel 178 and listens.
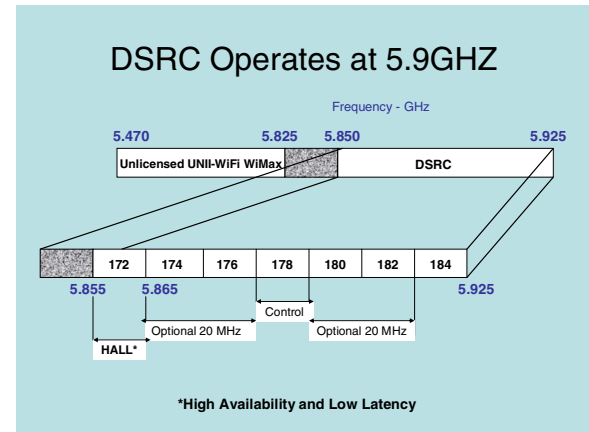

Figure 1. The DSRC band plan

Further, in a Memorandum Opinion and Order adopted on July 20, 2006[2], the Commission designated Channel 172 (frequencies 5.855-5.865 GHz) exclusively for vehicle-to-vehicle safety communications for accident avoidance and mitigation, and safety of life and property applications, and designated Channel 184 (frequencies 5.915-5.925 GHz) exclusively for high-power, longer distance communications to be used for public safety applications involving safety of life and property, including road intersection collision mitigation. The Commission recognized that vehicle-to-vehicle collision avoidance and mitigation applications are exceptionally time-sensitive and should not be conducted on potentially congested channels. By dedicating Channel 172 for public safety applications, the Commission significantly reduced the potential for interference that would otherwise be expected were the channel shared with non-public safety applications.

CRASH AVOIDANCE METRICS PARTNERSHIP

The Role of CAMP

In 1995, Ford Motor Company and General Motors Corporation formed the Crash Avoidance Metrics Partnership (CAMP). The goal of CAMP is to accelerate the deployment of Active Safety features in the United States by developing the pre-competitive enabling elements. CAMP is a mechanism for OEMs to work together, along with the US DOT and suppliers, on specific research projects. Since 1995, CAMP consortia have successfully completed projects on Forward Collision Warning Human Factors (Ford

and GM), Driver Workload Metrics (Ford, GM, Nissan and Toyota) and Enhanced Digital Maps (DCX, Ford, GM, Toyota and Navteq) as well as several initiatives involving vehicle to vehicle / infrastructure communications to be discussed below.

The VSC Project

In 2002, the Vehicle Safety Communications (VSC) project was established using the CAMP mechanism to evaluate vehicle safety applications enabled or enhanced by communications. Seven automotive manufacturers—BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW—formed the VSC Consortium (VSCC) to participate in this project with the USDOT. The following questions illustrate the focus and organization of the VSC project:

- What vehicle safety applications have the potential to be enabled or enhanced using external vehicle communications?
- Which communication-based vehicle safety applications have the highest potential safety benefits?
- What are the preliminary communication requirements for communications-based vehicle safety applications?
- Does initial testing confirm the technical feasibility of using DSRC for vehicle-safety applications?
- What are the elements of a security system for vehicle safety communications?

What Vehicle Safety Applications Have The Potential To Be Improved Or Made Possible With External Vehicle Communications? - The VSC project compiled and evaluated a comprehensive list of potential vehicle safety applications. This list represented the best efforts of the participants at the time of publication. It does not contain all vehicle safety applications (due to similarity) but does contain, at a minimum, examples and brief descriptions of representative safety applications. More than 75 applications were identified and analyzed resulting in 34 potential safety and 11 non-safety application descriptions. Details of this study are presented in the VSC project Task 3 Final Report[3]. It is likely that additional vehicle safety applications enabled or enhanced by wireless communications will be identified in the future, as advances in wireless technology become available.

Table 1.

Safety-Related Vehicle Communication Applications[3]

Category	Application
Intersection Collision Avoidance	Traffic Signal Violation Warning Stop Sign Violation Warning Left Turn Assistant Stop Sign Movement Assistant Intersection Collision Warning Blind Merge Warning Pedestrian Crossing Information Warning
Public Safety	Approaching Emergency Vehicle Warning Emergency Vehicle Signal Preemption SOS Services Post-Crash Warning
Sign Extension	In-Vehicle Signage Warning Curve Speed Warning Low Parking Structure Warning Wrong Way Driver Warning Low Bridge Warning Work Zone Warning In-Vehicle Amber Alert Warning
Information from Other Vehicles	Cooperative Forward Collision Warning Road Condition Warning Emergency Electronic Brake Lights Lane Change Warning Blind Spot Warning Highway Merge Assistant Visibility Enhancer Cooperative Collision Warning Cooperative Vehicle-Highway Automation System (Platoon) Cooperative Adaptive Cruise Control Road Condition Warning Pre-Crash Sensing Highway/Railroad Collision Warning Vehicle-to-Vehicle Road Feature Notification Cooperative Glare Reduction Adaptive Headlamp Aiming

Which Communications-Based Safety Applications Have The Highest Potential Safety Benefits? - For each vehicle safety application scenario, initial estimates of potential safety benefits were derived. These estimates were based on the accident analysis from the General Motors 44 Crashes report.[4] The VSC project team and the US DOT defined a set of analysis categories by which the potential safety benefits of application scenarios could be compared. The team used a methodology for analysis and ranking that included consideration of:

- Estimated Deployment Time Frame
  Near-term application systems were considered to be potentially deployable in the U.S. market between the years 2007 and 2011; mid-term applications deployable between 2012 and 2016; and long-term applications deployable beyond 2016.

- Estimated Effectiveness
  Defines the effectiveness of an application in

terms of the reduction of three crash-related factors: (i) functional years lost (number of years lost to fatal injury plus years lost of functional capacity to nonfatal injury), (ii) vehicles crashed (number of vehicles involved in various crash types in the U.S.), and (iii) direct costs (dollar expenditures related to the damage and injury caused by a crash),.

- Estimated Market Penetration
  Estimates the number of light-duty vehicles in the U.S. market that would be equipped with each vehicle safety application in each year after initial deployment.

- Estimated Cooperation from Infrastructure and/or Other Vehicles
  Estimates the probability of securing infrastructure cooperation and/or other vehicle cooperation. Cooperation required by the applications is in the form of relevant safety-related data exchange using infrastructure-to/from-vehicle communication and vehicle-to-vehicle communication.

For each application system, the VSC team used engineering judgment in estimating the application ranking attributes. The methodology used to estimate of the safety benefits and the relative ranking of the application scenarios is presented in the VSC project Task 3 Report[3]

The safety applications enabled or enhanced by communications that were estimated to have the greatest potential safety opportunity in each time period are listed in Table 2.

Table 2.
Vehicle Safety Communications Applications with Highest Potential Benefit[3]

Near-term	Mid-term	Long-Term
Traffic Signal Violation Warning (V-I)	Pre-Crash Sensing (V-V)	Cooperative Collision Warning (V-V)
Curve Speed Warning (V-I)	Cooperative Forward Collision Warning (V-V)	Intersection Collision Warning (V-I)
Emergency Electronic Brake Lights (V-V)	Left Turn Assistant (V-I)	
	Lane Change Warning (V-V)	
	Stop Sign Movement Assistance (V-I)	

V-I denotes communication required between vehicles and the infrastructure and V-V indicates communication between equipped vehicles is required.

This analysis was completed based on the assumptions available in late 2002 and early 2003. Subsequently, there has been considerable effort in the United States on Vehicle Infrastructure Integration (VII), which would significantly affect the estimates for cooperative infrastructure and vehicle deployment. VII will be discussed later.

What Are The Communication Requirements For Communications-Based Vehicle Safety Applications? - The eight near-term and mid-term safety applications enabled or enhanced by communications that were estimated to have the greatest safety opportunity were evaluated to establish preliminary communication requirements.[5] The proposed operational characteristics and preliminary communication requirements for the eight vehicle safety applications were described in terms of the following parameters:

Type of Communication: Considers the (i) source-destination of the transmission (infrastructure-to-vehicle, vehicle-to-infrastructure, or vehicle-to-vehicle communications), (ii) direction of the transmission (one-way or two-way), and (iii) source-reception of the communication (point-to-point or point-to-multipoint).

Transmission Mode: Describes whether the transmission is triggered by an event (event-driven) or sent automatically at regular intervals (periodic).

Update Rate: Defines the minimum rate at which a transmission should be repeated (e.g., 1 Hz).

Allowable Latency: Defines the maximum duration of time allowable between when information is available for transmission and when it is received (e.g., 100 msec).

Data to be Transmitted and/or Received: Describes the contents of the communication (e.g., vehicle location, speed, heading, etc.).

Maximum Required Range of Communication: Defines the communication distance between two units that is required to effectively support a particular application (e.g., 100 m).

The results of this analysis are shown in Table 3.

Table 3.

Preliminary Application Communication Scenario Requirements[3]

	Comm. Type	Trans. Mode	Min. Freq (Hz)	Latency (msec)	Primary data to be transmitted and/or received		Max. Req'd Comm Range (m)
Traffic Signal Violation Warning	Infrastructure-to-vehicle One-way Point-to-multipoint	Periodic	~10	~100	Traffic signal status Timing Directionality Position of the traffic signal	Stopping location Weather condition (if available) Road surface type	~250
Curve Speed Warning	Infrastructure-to-vehicle One-way Point-to-multipoint	Periodic	~1	~1000	Curve location Curve speed limits Curvature	Bank Road surface condition	~200
Emergency Electronic Brake Lights	Vehicle-to vehicle One-way Point-to-multipoint	Event-driven	~10	~100	Position Heading Velocity Deceleration	Bank Road surface condition	~300
Pre-Crash Sensing	Vehicle-to-vehicle Two-way Point-to-point	Event-driven	~50	~20	Vehicle type Position Velocity	Acceleration Heading Yaw-rate	~50
Cooperative Forward Collision Warning	Vehicle-to-vehicle One-way Point-to-multipoint	Periodic	~10	~100	Position Velocity Acceleration	Heading Yaw-rate	~150
Left Turn Assistant	Vehicle-to-infrastructure and infrastructure-to-vehicle One-way Point-to-multipoint	Periodic	~10	~100	Traffic signal status Timing Directionality; Road shape and intersection information;	Vehicle position Velocity Heading	~300
Lane Change Warning	Vehicle-to-vehicle One-way Point-to-multipoint	Periodic	~10	~100	Position Heading Velocity	Acceleration Turn signal status	~150
Stop Sign Movement Assistance	Vehicle-to-infrastructure and infrastructure-to-vehicle One-way Point-to-multipoint	Periodic	~10	~100	Vehicle position Velocity Heading;	Warning Turn signal status	~300

This preliminary analysis showed that:

- Message packet size is small, approximately 200 to 500 bytes (all 8 scenarios), not including the security overhead, which is approximately 200 bytes.
- Maximum required range of communications is short, about 50 to 300 meters (all 8 scenarios)
- Most applications are one-way, point-to-multipoint broadcast messages (7 of 8 scenarios)
- One application is two-way, point-to-point messages (pre-crash)
- Most applications can utilize periodic transmissions (6 or 7 of 8 scenarios)
- Most applications have allowable latency of 100 milliseconds (6 of 8 scenarios)
- One application has an allowable latency of 20 milliseconds (pre-crash)

It was therefore identified that a periodic common message broadcast at 10 Hz would enable most applications identified (both vehicle-to-vehicle and vehicle-to-infrastructure), and that the pre-crash sensing application has unique requirements. The contents of the preliminary common periodic message were elements such as latitude, longitude, time, heading angle, speed, lateral acceleration, longitudinal acceleration, yaw rate, throttle position, brake status, steering angle, headlight status, turn signal status and vehicle length/width. These preliminary communications requirements will need further refinement as prototype vehicle safety applications are developed and the need for bandwidth conservation (if any) becomes apparent.

Comparison of Alternative Wireless Communication Technologies: A wide variety of wireless communications technologies were examined for their ability to meet these communication requirements. These technologies included 5.9 GHz DSRC, 2.5-3G PCS and Digital Cellular, Bluetooth, Digital Television (DTV), High Altitude Platforms, IEEE 802.11 Wireless LAN, Nationwide Differential Global Positioning System (NDGPS), Radar, Remote Keyless Entry (RKE), Satellite Digital Audio Radio Systems (SDARS), Terrestrial Digital Radio, Two-Way Satellite and Ultra-wideband (UWB). It was concluded that DSRC is the only technology at this time that meets all of the application requirements, especially the ability to support low-latency wireless data communications between vehicles and between vehicles and infrastructure. This was primarily due to the short range nature of the communications - a few hundred meters supports most safety applications while not overloading the spectrum with messages from vehicles and infrastructure.

Does preliminary testing confirm the technical feasibility of using DSRC for vehicle-safety applications? - To answer this, both Field Testing and Evaluation and Simulation Testing and Evaluation were performed.[5]

Field Testing and Evaluation

The VSC project assessed the DSRC characteristics relevant to potential safety applications in real-world environments through field testing on test tracks and public roadways, using both vehicle-vehicle and vehicle-infrastructure wireless data transfer. The anticipated communications parameters for two potential vehicle-safety application scenarios were tested in detail: Traffic Signal Violation Warning and Emergency Electronic Brake Lights. The communication equipment used for this testing was developed by Denso.[6]

Testing focused on:
- Collecting and analyzing data in real-world intersection environments to determine communications characteristics.
- Vehicle-to-vehicle testing using test track and public roadway environments to send actual common message set data between vehicles.

Intersection Testing

At intersections, testing focused on the capability of a DSRC on-board unit (OBU) to receive packets sent from a dedicated roadside unit (RSU) stationed near an intersection. A key issue investigated was the degree to which a test vehicle could move through different types of intersections while maintaining communications with the RSU when variables such as buildings, terrain, roadway geometry and traffic conditions were presented. The findings from tests conducted at a representative intersection demonstrated an 85% successful transmission ratio while the test vehicle was approaching the RSU from 250 m, and a 99% success ratio while approaching from 100 m. The results were derived with an inverted OBU roof-mount antenna serving as the RSU antenna (clearly not optimized for RSU conditions), and with the antenna situated at a less-than-optimal position (intersection corner, 10 feet high above the ground).

Figure 2 shows the signal phase (red, yellow or green) as broadcast by an RSU interfaced to a synchronized signal controller and received by an OBU traveling through the intersection. For a safety application such as Traffic Signal Violation Warning, no major communications issues were uncovered in testing that conflicted with the preliminary requirements. These results show that the
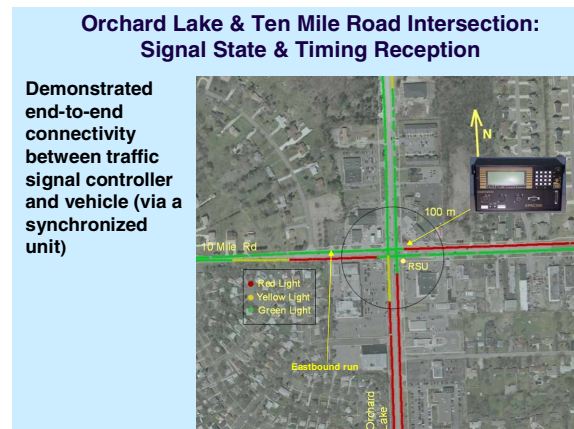

Figure 2.   Signal phase broadcast from an RSU and received by an OBU

test equipment used, which is representative of the currently approved lower layer DSRC standard, can support communications for application scenarios like Traffic Signal Violation Warning.

Vehicle Data Exchange

For message sizes of 200 bytes, results showed 100% reception and no packet loss between two vehicles up to ranges that exceed 200 m in a vehicle following scenario, and ranges exceeding 600 m in both directions of travel. Reducing the transmit power from 20 dBm to 5 dBm reduced the maximum range to approximately 250 m in both directions of travel. Increasing the data rate from 6 Mbps to 27 Mbps resulted in higher packet losses and a reduction in communication range. Testing was conducted on an interstate freeway and a state highway. Seven test vehicles formed a caravan with information shared among all. In general, the results showed that in a freeway environment, there was communication between vehicles to 180 m range with transmission power of 20 dBm. In a freeway ramp environment, there was communication between vehicles to a 100-meter range with a reduced transmit power of 16 dBm. It should be noted that none of the test scenarios used the maximum transmit power allowed by the FCC. Based on the vehicle-to-vehicle testing, the performance of DSRC appears adequate for future vehicle-safety application development.

Simulation Testing and Evaluation

In order to study channel loading issues, VSCC simulated and evaluated DSRC performance in an urban intersection environment densely populated with DSRC-equipped vehicles and infrastructure. This was done to assess simulation test scenarios of high volume, signalized intersections. A simulation test environment was configured, containing both a high traffic volume intersection with a freeway nearby. Both environments were filled with dense vehicle traffic. Great care was taken so that both the environment and the vehicle traffic patterns reflected realistic, though stressing conditions.

The simulation testing completed during the VSC project indicated a requirement for a dedicated high-availability, low-latency channel for latency-critical safety applications. The simulation testing also showed that emergency message prioritization consistently improved the reception probability over routine messages by 5% to 40%, and reduced the safety communications latency across a wide range of simulation scenarios. The simulation results further illustrated that channel capacity is an issue that will need to be adequately addressed for large-scale deployment in stressing traffic environments. The FCC subsequently allocated DSRC Channel 172 as the high-availability, low-latency channel for collision avoidance systems.

What are the elements of a security system for vehicle safety communications? - Security is an important consideration for DSRC vehicle safety applications. For the system to be secure, the applications must be able to trust that the communication has been received unaltered and from a trusted source. In addition, the communication should be anonymous, at least to passive listeners. It should require a low amount of computational and communications overhead and be robust in the event of individual units being compromised. After preparing a threat model, the following defense was proposed:

- All on-board units (OBUs) and roadside units (RSUs) are issued certificates (OBUs are issued multiple) in a special, compact format.
- The certificates for RSUs contain authorization information such as the area in which the unit is permitted to operate and the type of information it is allowed to broadcast.
- OBU certificates do not contain the permanent vehicle-identity information.

- All messages are digitally signed. Any units suspected of being compromised are put on a revocation list that is flooded to all other units.

However, this security solution would come at a price. Each message transmitted would include significant overhead, and the message signatures would take time to process once they are received. Management of a public key infrastructure for RSUs would be necessary, according to the proposed scheme. In addition, there are piece costs, administrative costs, maintenance costs, and enforcement costs. Current efforts regarding DSRC security are being conducted in the VII program and the VSC-A project, discussed below.

THE EMERGENCY ELECTRONIC BRAKE LIGHTS PROJECT

During 2005 and 2006, six of the VSCC members (BMW, DCX, Ford, GM, Nissan and Toyota) decided to build and evaluate a safety application based on communications. The application chosen was Emergency Electronic Brake Lights (EEBL) because this is a near-term, vehicle-to-vehicle (V2V) application. The goal was to gain experience with the message protocol (when to send a message) and message content (necessary information in a message) required to successfully implement such an application. Three message protocols were implemented for evaluation – a periodic (10 Hz message), based on the "Common Message", an event-based message when hard-braking occurred and a "hybrid protocol" which used a combination of a lower-frequency periodic message with an event-based message.

A key to the successful implementation of an application of this type is path prediction – the ability to determine if the transmitting vehicle is in the path of the receiving vehicle. This is similar to the path prediction necessary for features such as Adaptive Cruise Control (ACC). However, because of the communication link between the vehicles, information can be added to the message which greatly facilitates this path prediction. Specifically, the last ten GPS positions, at 1 sec intervals, called "breadcrumbs", were added to the transmitted message for evaluation, as shown in Figure 3.

The OEMs involved in this project successfully developed and implemented an EEBL application as the first V2V communication-based safety application and demonstrated interoperability of the application between the vehicles of all the OEMs. All of the concepts of operation were implemented

and resulted in correct warnings. Message sets for the three concepts of operation were defined. The systems implementation and the warning algorithm were OEM-specific but interoperability was established on the basis of the message set. As seen in Figure 4, the EEBL warning was received by the fourth (Ford) vehicle about 4 sec before that vehicle would have otherwise began braking in response to the hard braking of the lead (Toyota 2) vehicle. The experience gained in developing EEBL will be utilized in the VSC-A project (discussed later), where the final recommendations on message protocol and message content will be reached. In addition, the information from this project was transferred to the SAE for use in the development of the DSRC Message Set Dictionary (J2735).

CURRENT ACTIVITIES

In the United States, there are major activities underway related to communications-based vehicle safety applications.

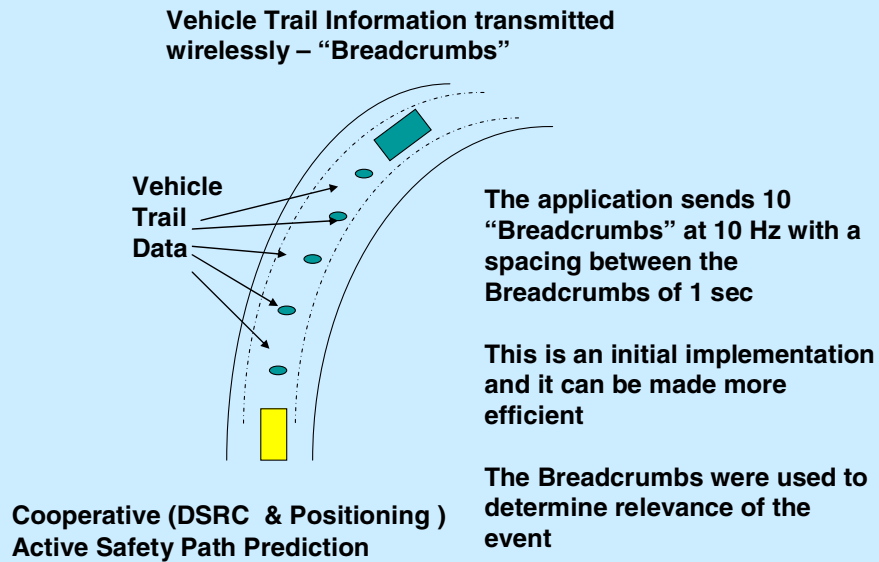### Vehicle Infrastructure Initiative (VII)

The VII vision is that every car manufactured in the U.S. would be equipped with a communications device and a GPS unit so that data could be exchanged between vehicles and with a nationwide, instrumented roadway system. Realization of this vision could mean a significant reduction in highway fatalities, while at the same time offering dramatic improvements in transportation efficiency and mobility. Besides safety applications, such a system would enable features such as probe vehicle data, weather/road surface data, traveler information, electronic tolls, electronic payment, auto manufacturers' customer relations, etc. The US DOT, vehicle manufacturers, state and local DOTs and suppliers are developing the VII system. Proof-of-Concept testing is scheduled for 2007 and a deployment decision is scheduled for 2008.[7]

The Vehicle Safety Communications 2 Consortium (VSC 2) formed using the CAMP mechanism in 2006 to develop and test the VII safety applications. The five OEMs involved in this consortium (DCX, Ford, GM, Honda and Toyota) are engaged in two major projects, CICAS-V and VSC-A, in coordination with the rest of the VII Program.

CICAS

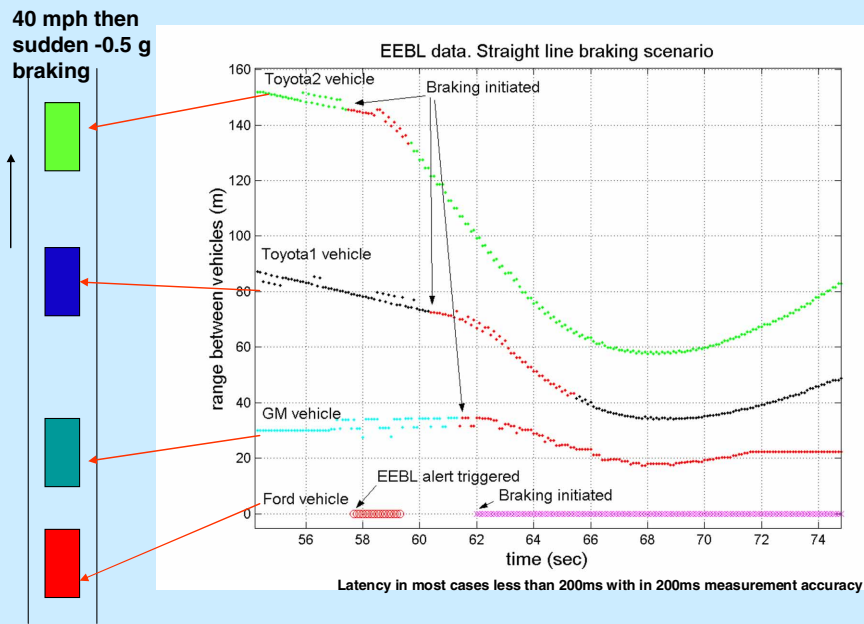The Cooperative Intersection Collision Avoidance System (CICAS) program is a major government-

Figure 3. Vehicle path history sent over the communications link.

Figure 4. EEBL Test Results

industry initiative in the United States to develop and deploy a cooperative vehicle-infrastructure system to improve intersection safety. There are three operational concepts for CICAS being researched:

- CICAS-Violation (CICAS-V): a system that warns the driver via an in-vehicle device when it appears likely that the driver will violate a traffic signal or stop sign.

- CICAS-Stop Sign Assist (CICAS-SSA): a system that uses a Dynamic Message Sign to tell drivers on the minor road when it is unsafe to enter the intersection due to insufficient gaps in traffic on the main road.

- CICAS-Signalized Left Turn Assist (CICAS-SLTA): a system that uses a Dynamic Message Sign or an in-vehicle sign to tell drivers when it is unsafe to make an unprotected left turn at a signalized intersection.

The CICAS-V system is being developed by the VSC 2 Consortium, and the primary objective is to develop an effective prototype that is suitable for deployment. The CICAS-SSA project is being conducted under a partnership agreement with Minnesota DOT and its research partner, University of Minnesota. CICAS-SLTA is being conducted under a partnership agreement with California DOT and its research partner University of California Partners for Advanced Transit and Highways (PATH) Program. The primary objectives of these last two projects are to develop system designs for prototyping and field operational testing.

CICAS-V

CICAS-V is a warning system to reduce crashes at intersections resulting from unintended violations of traffic control devices (i.e., traffic signals and stop signs). The CICAS-V system is intended to mitigate potential causal factors that include driver distraction, obstructed/limited visibility due to weather or intersection geometry or other vehicles, the presence of a new control device not previously known to the driver and driver judgment errors.

The basic CICAS-V concept is that both the vehicle and the intersection would be equipped with DSRC radios. As the vehicle approaches, for example a signalized intersection, it would be informed that the intersection is CICAS-V equipped and that a map of the intersection is available on a service channel, along with positioning corrections and possibly road surface condition. After receiving this information,

the vehicle would then download the map (if necessary) and position itself on this map, at the lane-level if necessary for complex intersections. Then the vehicle would receive information on signal phase (red, yellow or green) and, if yellow, the timing until the red phase. Based on this information, the vehicle would issue a warning to the driver, if necessary, and possibly send a message to the intersection of an impending violation. The intersection could potentially use that information for a countermeasure, such as warning other approaching vehicles or going to an all-red phase until the violator has cleared.
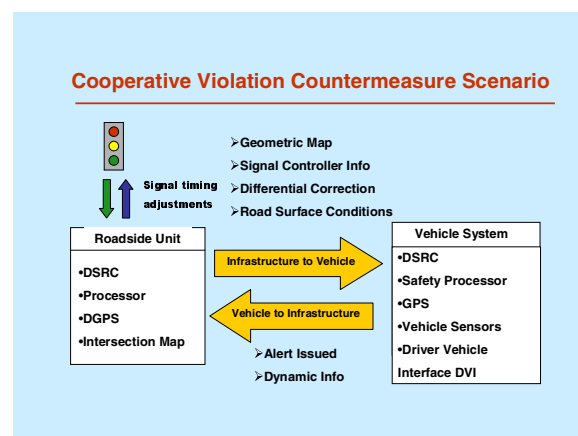

Figure 5. CICAS-V Communications

The CICAS-V project started in May, 2006. The first phase, which will last for two years, will develop and test a prototype design suitable for a Field Operational Test (FOT). Then, a second FOT phase is planned, with approximately nine months of data collection with naive drivers using fifty equipped vehicles and 25 equipped intersections. The collected data would be used to study safety benefits, unintended consequences and driver acceptance.

Vehicle Safety Communications – Applications (VSC-A)

In December, 2006, the VSC2 Consortium (DCX, Ford, GM, Honda and Toyota) also initiated the three-year VSC-A project with the US DOT. This project builds upon the previous work done in the first CAMP VSC project as well as previous NHTSA Active Safety projects. The scope of this project includes all safety applications that use communications, except for the intersection safety applications addressed in CICAS. The objectives of this project are to:

1. Assess how previously identified critical safety scenarios in autonomous systems could be addressed and improved by DSRC+Positioning systems.
2. Define a set of DSRC+Positioning based vehicle safety applications and application specifications including minimum system performance requirements.
3. In coordination with NHTSA and VOLPE, develop a benefits versus market penetration analysis, and potential deployment models for a selected set of communication-based vehicle safety systems.
4. Develop a scalable, common vehicle safety communication architecture, protocols and messaging framework (interfaces) necessary to achieve interoperability and cohesiveness among different vehicle manufacturers.
5. 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.
6. Develop a feasible and deployable security solution for vehicle-to-vehicle safety communications.
7. Develop and verify set of objective test procedures for the vehicle safety communications applications.

Therefore, this project will complete the pre-competitive analyses necessary to support deployment of this technology.
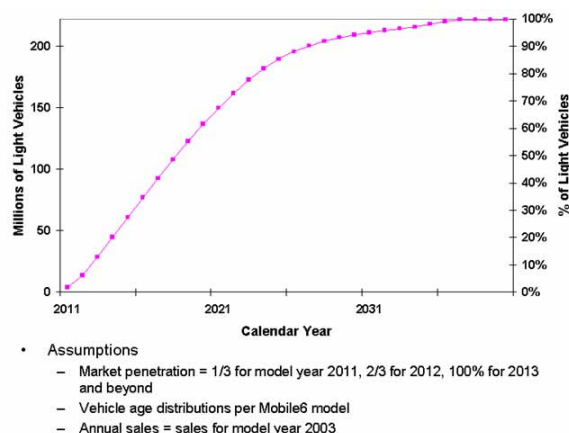

Figure 6. Possible Deployment of DSRC into the Vehicle Fleet

Figure 6[8], developed by the US DOT, shows the number and percentage of equipped vehicles in the United States, based on the deployment assumptions being discussed in the VII program. Of course, the effectiveness of vehicle-to-vehicle safety systems is proportional to the probability of an equipped vehicle being in conflict with another equipped vehicle when a critical event occurs. Other possible deployment models will be explored in the VSC-A project.

CONCLUSION

Vehicle communications have the possibility to transform automotive safety, enabling widespread deployment of effective Active Safety features. The results from the initial research in the United States are very encouraging. Work is now underway that will resolve the key pre-competitive issues needed for deployment, both for vehicle-to-infrastructure and vehicle-to-vehicle safety applications. In addition, deployment models are under investigation, both within the VII and VSC-A projects.

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