VEHICLE SAFETY COMMUNICATIONS FOR COMMERCIAL VEHICLES: ISSUES AFFECTING DEPLOYMENT OF VEHICLE-TO-VEHICLE COMMUNICATIONS FOR HEAVY VEHICLES

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ABSTRACT

Wireless vehicle-to-vehicle communications (V2V) and the safety applications enabled by such technology are a major component of the U.S. DOT vehicle safety communications (VSC) program. The VSC program also supports wireless connectivity between vehicles and infrastructure (V2I) to deliver safety, mobility, and environmental benefits. To date, the focus of US DOT sponsored research in this area has been on light duty vehicles. However, to obtain maximum benefits, the V2V safety applications need to be deployed among all vehicles including heavy commercial vehicles. The U.S. DOT therefore initiated (in early 2010) several research efforts to examine the issues for adapting V2V safety applications for heavy commercial vehicles. These issues include interoperability with other vehicles, considerations due to vehicle size and geometry, data privacy and policy concerns, compatibility between heavy and light vehicles, and other issues related to special operating environments encountered by commercial vehicles. This paper describes the current technical research on V2V for commercial vehicles being conducted by U.S. DOT (i.e., interoperability, performance requirements and human factors considerations). For each of these studies, interviews were conducted with subject matter experts from the following entities: vehicle manufacturers; truck suppliers, commercial vehicle fleet operators, industry trade representatives, and academic researchers. The early V2V safety applications to be developed for heavy vehicles have been selected based on the most frequent crash types addressable by such technology as identified in previous studies conducted by Volpe. The studies summarized in this paper were limited to commercial vehicles including heavy truck tractors, single-unit trucks, and buses. Results from the studies identify priority issues that need to be addressed for successful deployment of V2V systems on commercial vehicles.

INTRODUCTION

The U.S. DOT is conducting research that has the potential to transform the transportation of goods and people by introducing a new generation of safety systems. Vehicle safety communications (VSC) combines leading edge technologies including: advanced wireless communications; on-board computer processing; advanced vehicle-sensors; navigation; and smart infrastructure to provide the capability for vehicles to identify threats and hazards on the roadway and communicate this information to drivers via alerts, warnings and real time road network information.

VSC consists of the wireless exchange of critical safety and operational data among vehicles within a given proximity of each other (V2V), and between vehicles and the highway infrastructure (V2I). The VSC technology and applications are intended primarily to avoid or mitigate motor vehicle crashes, but can also enable a wide range of, mobility and environmental benefits as well. The U.S. DOT research program is investigating VSC for all vehicle types (light vehicles, heavy vehicles, transit and freight). [1] Further, because the wireless communication protocols to support safety applications are specialized (i.e., not commercial services such as cellular or satellite), it has been recognized that some degree of dedicated telecommunications infrastructure would be needed to support security and other operational aspects of this concept. It should be noted however, that the U.S. DOT’s vision for vehicle safety communications is that a minimum level of such infrastructure will be deployed to provide the maximum level of safety and mobility benefits for highway and roadway safety and operational efficiency nationwide.

Precursor Technologies

Crash avoidance technologies such as forward collision warning (FCW), side object detection and others, have emerged over the last few years and have demonstrated the ability to help drivers avoid crashes in particular driving scenarios (or conflicts). Currently, these systems use onboard sensors, such as radar, lidar, or video cameras, to identify crash threats then warn drivers and/or take corrective action. These vehicle-based safety systems (also referred to as autonomous systems) will play a critical role helping to improve motor vehicle safety. However, the opportunity exists to improve the performance of these systems and to accelerate their widespread deployment by shifting the sensing capability from onboard sensors to inter-vehicle communications (often referred to as "cooperative" systems). U.S. DOT has conducted research with the automotive industry to demonstrate that V2V communications will improve the overall effectiveness of autonomous systems and that costs to consumers of such system can be reduced. Further, an analysis of alternative communication media (or protocols) has shown that Dedicated Short Range Communications (DSRC) at 5.9 GHz. is well suited to support V2V applications. DSRC is capable of effectively and reliably providing the capabilities necessary to implement vehicle safety communications applications, such as FCW, Lane Change Warning (LCM), Intersection Movement Assist (IMA), and others. [1]

The research discussed in this paper builds upon the previous work in this area conducted through collaboration between the National Highway Traffic Safety Administration (NHTSA) and vehicle manufacturers participating in the Crash Avoidance Metrics Partnership (CAMP)[1]. CAMP studies conducted between 2002 and 2009, including the Vehicle Safety Communications (VSC) [2] and Vehicle Safety Communications-Applications (VSC-A) [3] investigated the potential of V2V and V2I communications as a means of improving crash prevention, and the development of prototype systems and applications.

Successful deployment of V2V necessitates utilizing the entire vehicle fleet including heavy commercial vehicles. Commercial vehicles (CVs) include all vehicles with a GVWR greater than 10,000 lb. (4536 kg) and includes: tractor-semitrailers, single-unit trucks, buses, and motorcoaches. Therefore, it is important to understand all of the issues affecting these vehicles in order to achieve all of the expected benefits of V2V. These include interoperability with other vehicles, considerations due to vehicle size and geometry, data privacy concerns, compatibility between heavy and light vehicles, special operating environments, and the necessary requirements for the commercial vehicle driver-vehicle interface (DVI) which is significantly different than in passenger vehicles. This paper describes the current U.S. DOT research program on V2V for commercial vehicles and outlines the specific issues of concern that need to be addressed for successful deployment of V2V on these vehicle classes.

COMMERCIAL VEHICLE RESEARCH OBJECTIVES

In 2009, U.S. DOT began V2V research for CVs. The initial phase of the research is focused on identifying the fundamental issues that need to be resolved for successful deployment of V2V systems on commercial vehicles. These areas studied concurrently in 2010 are:

- Interoperability Issues
- Development of Performance Requirements for Safety Applications
- Driver -Vehicle Interface Needs Specification

The following sections describe the research projects in each of these areas.

INTEROPERABILITY ISSUES

The first area of study, *Interoperability Issues for Commercial Vehicles*, was a project conducted by the University of Michigan Transportation Research Institute (UMTRI), and included identification of issues relating to the operation of V2V systems among other equipped vehicles of different makes, models, and vehicle type. The emphasis of this project was to identify the additional challenges and needs that are uniquely associated with the use of DSRC-based safety applications on CVs. The focus was on whether and how the CV-unique aspects may impact standards, applications requirements, certification, and policy requirements in a way that may affect the timing or success of deployment. The project tasks included building and applying an understanding of DSRC operation and root causes of existing challenges, as identified by Subject Matter Experts (SMEs) and other sources. The understanding of operational factors gained was then put into the context of commercial vehicles, with UMTRI's experts' input, to find unique issues.

[1] CAMP VSC-A 2 Project Team consists of Ford, General Motors, Mercedes-Benz, Toyota, Honda, BMW, Nissan, Volkswagen, and Hyundai-Kia.

Research Assumptions

The following assumptions were maintained in this project:

- Limited to DSRC-based applications and devices and their associated standards.
- The potential and risks of integrating aftermarket devices into CVs.
- A focus on V2V.
- Consideration of aspects of V2I that use DSRC for safety only, as these potential applications may affect the communications requirements.
- The diverse range of CVs was considered, however emphasizing the most common types.

Summary of Literature Review

The first task was to gather and assimilate existing information regarding DSRC-based safety applications. This included information about five topic areas: light vehicle applications, communications standards, field performance studies, aftermarket devices, and approaches to certifying compliance. During this process, UMTRI identified potential issues and possible approaches to resolving or mitigating the concerns. The research questions that guided this effort were:

- How does CV V2V system performance change as the number of vehicles within DSRC range increases?
- What methods may be used to increase the reliability of systems under problematic conditions specific to CVs?
- Are there specific issues in testing and evaluating CV V2V applications?
- How can CV V2V components be certified as compliant and interoperable with each other and other devices?
- What are the vehicle size/compatibility issues for communication between light vehicles and CVs?
- What are the security concerns specific to CVs?
- What are the issues for aftermarket and retrofit equipment for CVs?
- What are the issues associated with data privacy in CVs?
- Are there CV specific data reliability requirements for vehicle safety applications?

In reviewing the literature, UMTRI identified the key technical issues that were cited in the literature. However, these issues were primarily within the context of light vehicle applications and needs. Therefore it was necessary to identify whether these issues also apply to commercial vehicles, and if so, whether solutions may have different characteristics for commercial vehicles. Also it was considered whether some issues that have been resolved over the past years for light vehicle applications still remain open issues for CVs. And finally, UMTRI searched for issues that are unique to CVs.

Interviewing CV Stakeholders

The next task was to gather information from commercial vehicle stakeholders regarding the potential safety applications and identify technical and non-technical concerns. This was accomplished using surveys and telephone interviews. UMTRI created two survey and interview protocols used in conversations with the SMEs which included heavy vehicle industry representatives and fleet operators. The first series of conversations addressed the functionalities and basic high-level functional requirements for V2V applications; vehicle classes associated with these requirements; and concerns about technical aspects of V2V communications, interactions with OEM data buses (e.g., for retrofits); and other concerns with integrating these systems into vehicles. This set of interviews included vehicle manufacturers and suppliers. Representatives of key industry groups (e.g., American Trucking Association, Commercial Vehicle Safety Alliance, etc.) were also interviewed. The second set of conversations were conducted with a set of fleet operators, and addressed several issues, among them discussion of driver issues, fleet operations opportunities and concerns; and data ownership and privacy. Representatives from a variety of fleets were interviewed, including small and large fleets, class 8 fleets, and users of smaller (Class 3-6) heavy vehicles.

Identify Priority Issues

In the final task, the inputs of the previous tasks were used to compile a list of issues that were unique to commercial vehicles, and to prioritize them. The priority was determined by considering the issue's potential impact on standards, compliance testing, or deployment timing and deployment success. The type of impact of each item was categorized as follows:

- Requirements for new or revised policy
- Viability for industry (cost vs. apparent added value in the marketplace)
- Technical performance risks
- Issues of acceptance by fleet operators
- Certification and compliance
- Standards and protocols
  - Scalability
  - Reliability
  - Prioritization of messages
  - Compatibility with J1708
  - Security
  - Authentication
  - Data validation, data integrity

Qualitative ratings of impact of the issues were given as minor, significant, and major. The second set of ratings was a qualitative indication of the relative difficulty of overcoming the concern. Dimensions for this rating included the chances of eliminating the concern, as well as the relative amount of time or resources likely needed. At the time of this writing, this project was still ongoing and results are being prepared by UMTRI to be submitted to U.S. DOT in a final report.

DEVELOPMENT OF PERFORMANCE REQUIREMENTS FOR SAFETY APPLICATIONS

The widespread deployment of V2V safety is dependent upon the understanding of the effectiveness of safety applications. The Virginia Tech Transportation Institute (VTTI) was tasked with determining the performance requirements for potential V2V safety applications that are appropriate for heavy commercial vehicles. To accomplish this objective, VTTI conducted the following tasks:

- A review of literature covering collision avoidance systems currently available for heavy CVs
- Interview representatives from the heavy-vehicle manufacturers, suppliers, and fleet operators to determine suitable crash avoidance technologies for the V2V communications
- Identify and develop performance requirements for the selected applications

Literature Review Preliminary Findings

<u>Communications</u>

The enabling technology for V2V safety applications is advanced wireless communications that allow the transmission of data between vehicles, and between vehicles and infrastructure. Examples of these wireless technologies include DSRC at 5.9 GHz, WiFi, and LTE. Some key performance parameters for communication technologies include transmission latency, transmission update rate, and transmission range. [4]

<u>Transmission latency</u>

Because of the time-sensitivity of vehicle crash scenarios, the safety applications require low-latency messages between vehicles. Some critical V2V safety applications require periodic transmissions as low as every 100 millisecond (ms) to address the identified crash scenarios. In fact, the IEEE 802.11p specification provides a minimum allowable transmission latency of 100 ms for periodic messages. DSRC offers the best potential (three orders of magnitude lower than other existing wireless technologies) for effectively supporting these low-latency requirements. [2]

<u>Transmission update rate</u>

Transmission update rate is defined as minimum rate (measured in Hz) at which the transmission needs to be repeated in order to ensure that the safety message is reliably conveyed between vehicles. [4] V2V communication challenges such as multipath fading, shadowing, Doppler shifts created by movement of the vehicles, and data packet collisions must be considered when selecting a minimum update rate. [5]

<u>Transmission range</u>

Shulman and Deering defined the maximum transmission range as the communication distance between two vehicles that is needed to effectively support a particular safety application. [4] The maximum communication range is dependent upon the utility of the broadcast data to adjacent vehicles for upstream and downstream traffic in the same and opposing directions. [6] Many of the proposed safety applications require a communication range between 100-1000 m; the typical range is around 300 m. [2, 7] For situations where the maximum range is not achievable, multi-hop (using vehicles to relay data broadcasts) may be a useful mechanism. [6]

Vehicle positioning

The key to all safety applications is an accurate spatial awareness of the crash scene (i.e., subject vehicle, adjacent vehicles, roadway, and infrastructure). With accurate autonomous spatial data, safety system algorithms can derive positional information including derivatives such as velocity and accelerations as well as distance measures such as gap and closing rate. While there are technologies for localized measurements such as radar, lidars, ultrasonic, or cameras, V2V safety applications require relative positional data from objects well beyond the operational ranges of these conventional sensors. At the root of more far-reaching measurement technologies is the global positioning system (GPS) which provides relatively accurate positioning and a common global clock. [8] While the basic GPS accuracy is sufficient for normal route guidance, safety systems require greater positioning accuracy (on the order of centimeters, especially for identified pre-crash safety scenarios. [2] Derivatives of GPS have improved the accuracy by refining the measurement with corrections. These technologies include DGPS with a reported accuracy of approximately 1 m, and real-time kinematic (RTK) positioning with centimeter accuracy. [8] Because the strength of GPS requires line-of-sight to numerous satellites, occlusions by overpasses, urban buildings, and deep valleys pose a problem in maintaining real-time positional data. A proposed solution is the fusion of GPS with inertial measurement units (IMUs) to maintain spatial awareness during these GPS blackout periods. [8] One GPS/IMU has been reported to provide a 2 cm horizontal and 5 cm vertical accuracy when the GPS signal is present, and maintain a 10 cm horizontal and 7 cm vertical accuracy during a 1-minute GPS signal blackout. [8]

Vehicle boundary envelopes

In addition to knowing the relative and absolute positioning of the objects within the crash scene, it is also vital to understand the boundary envelopes of the subject vehicle as well as other objects in the crash scene. This is particularly true for CVs where the vehicle lengths can typically range from 10 to 75 ft. (3 to 22.9 m). This length can be even longer in less populous areas in the western states such as Idaho, Nevada, and Montana, where CVs are allowed to pull triple trailers. Heights and widths of CVs (without special permits) typically range between 13.5 to 14.5 ft. (4.1 to 4.4 m) and 8.5 to 14 ft. (2.6 to 4.3 m), respectively. These dimensions vary with loads and must be accurately accounted for in crash avoidance algorithms.

Industry Outreach Preliminary Findings

Industry SMEs from the heavy vehicle manufacturers, suppliers, and fleet operators were interviewed to determine suitable crash avoidance technologies for V2V communications. Responses were received in the following areas:

Return on investment

An issue raised by several of the fleets was return on investment (ROI). Crash avoidance technologies can be expensive and fleets must justify their purchase. Fleets need to ensure that the technologies they invest in actually reduce crashes (thereby reducing operational costs) and are durable enough to recover the initial cost. Some of the issues related to ROI described by fleets include: the need for ongoing support of the technology by the vendor, the ability to transfer the technology to newer vehicle models, the expected life of the technology compared to the expected life of the tractor, and driver acceptance of the technology. As an example, one participant mentioned having purchased a crash avoidance system that his company assumed would last for 10 years. However, after four years of use, the company changed its model of tractor and could not transfer the technology to the new model tractors. The benefit from the technology therefore was greatly reduced: what was expected to be a 10-year investment only worked for 4 years. Another suggestion offered by an interviewed participant for increasing the technology ROI was a “plug-and-play box” that could be placed in a truck, so that if a carrier decided to switch technologies, the new technology could merely be “plugged in” and the truck would be able to accommodate it.

Installation

Several fleet participants described installation as an implementation issue with new technology. Having technology installed by the original equipment manufacturer (OEM) was generally viewed as more efficient than trying to retrofit a tractor with new technology. For example, one fleet participant described how bringing the vehicle in from the road and having to reinstall equipment in order to update to a new technology is an expense as it creates down time for the vehicle. “It is more efficient to put the technology in once and be done”.

Maintenance

Crash avoidance systems are only useful if they are maintained; therefore, it is important for drivers to understand that if the system gets damaged, they will need to have the truck repaired. Participants mentioned issues with external components and sensors. For example, one participant said, "that if a driver hits something, whether it is an animal or an object on the road, the antenna on their system is sticking right out in front of the truck and can be damaged". This presents a problem if the driver is unaware of the damaged, faulty sensor and continues to rely on the system. Crash avoidance systems need to be designed to minimize maintenance down times and susceptibility to damage from road debris and normal truck operations (such as dropping and hooking trailers). These systems should also provide feedback of degraded performance to both the driver and the fleet when appropriate.

System adjustability

Fleet participants described how they are sometimes frustrated by the inability to program or adjust their crash avoidance systems to perform in accordance with their company policies and procedures. For example, one fleet participant described how his company's drivers are trained to maintain at least a 7 second following distance from the vehicle in front of them, yet their crash avoidance system only alerts the driver when they are within 3 seconds of the vehicle in front of them. This company would prefer the ability to align the system parameters with their company policies.

While system adjustability does appear to be an issue for some fleets, another fleet participant described how his company is able to program their crash avoidance system. While the system is not adjustable by the driver, the company management can set the system parameters which are based on speed. For example, the participant described how at lower speeds it is acceptable to have the following distance be shorter than would be accepted at medium or high freeway speeds.

A few participants interviewed had comments regarding adjustability of volume of the alerts. For example, a fleet participant mentioned that his company allows drivers to reduce the volume of alerts to a certain minimum level that allows the co-driver to sleep. Yet another participant said that when testing a lane departure warning system with his company's team units, the team partner sleeping in the bunk liked hearing the alerts because it provided feedback to the resting team member that the driver was getting tired.

System reliability

Fleet participants described how the reliability of a crash avoidance system is important so that drivers maintain their trust in the system and do not become desensitized and ignore alerts. For example, a participant mentioned that lane departure warning systems are "too sensitive in some circumstances; they tend to go off more in construction zones where lane lines may be uneven and in snowy conditions where the system can detect tire tracks in the snow". Another participant described how he gets a "high rate of false alarms from the crash avoidance system every time the truck passes under an overpass".

While avoiding the problem of driver mistrust in a system resulting from false alerts is important, system reliability is especially critical in systems that intervene to reduce or mitigate a crash. During the interviews, one participant shared his concern that if a system brakes the vehicle to a complete stop then it needs to be identifying a vehicle and not some other non threat (e.g., a beverage can) on the road. This issue is important for vehicle control because of the implications of stopping on the highway with surrounding traffic.

Behavior monitoring

Crash avoidance technologies are being used by some fleets to monitor driver behavior. A fleet participant mentioned that they can examine data from the crash avoidance system on an exception report basis, review the lowest performing 20 percent of drivers on a weekly basis and conduct additional observation, evaluation, coaching, and training with the poorly performing drivers. Another fleet described how with their crash avoidance system they are able to view the environment surrounding an event, including where it occurred and the vehicle's speed 5 minutes prior to and 2 minutes following the event.

Data accessibility

The ability to use crash avoidance technologies to capture data about a crash as well as data regarding driver behavior (e.g., lane departures, following distances, etc.) is viewed as desirable by some fleets. Fleet participants that access data from crash avoidance systems said it is useful in identifying poor driver behavior and helpful in litigation. For example, a participant said that data from a crash avoidance system was used by his company in a liability case to show that the company was not at fault in a crash.

Not all fleets want access to data from their crash avoidance systems. Some of the reasons cited in the interviews for not wanting access to the data were a lack of resources to manage the data properly and a fear that if the data is accessible, yet not being used, that a company could be considered negligent. For example, one participant described how getting more data when manpower is staying the same can become problematic because "there was no one to monitor and analyze the data". In this case, the participant's preference was for the system to only alert the driver when necessary and not capture data.

Driver acceptance

Securing driver buy-in and acceptance of crash avoidance systems is important so that drivers are willing to use the systems. For instance, one fleet participant described how some drivers will tamper with the system in an attempt to disable it while others attempt to block alerts (e.g., using pillows to muffle the sound). Several fleet owners described ways that they work to gain driver acceptance, including cultivating a strong safety culture, seeking driver feedback on new technologies, and having managers test the systems to show drivers that management understands how the technology works. For example, the owner of one fleet described how he allows some of his drivers to test a new technology before being fully implemented and obtains the drivers' feedback. It is his opinion that considering drivers' reactions to a new system helps with driver acceptance of the systems that are ultimately used.

Driver distraction

Fleet participants indicated that crash avoidance technologies lose their benefit if they become a distraction to the driver. Participants said a system that encourages drivers to watch a display or screen more than the road is not beneficial. For instance, one participant described how his company was testing a lane departure warning system that had a small graph on the dash indicating where the truck was positioned in the lane. Drivers testing the system told their management that they were spending more time watching the graph than the road. Another participant said that his company was addressing distraction by integrating systems to reduce the number of technologies the driver needs to interact with while driving.

Driver overreliance

Fleet participants described the importance of having technologies that can improve safety while reminding drivers not to over rely on the technologies. Overreliance can be problematic if there is a technical problem with the system and the driver has invested too much trust in the technology. One participant described how his company actively reinforces the idea that technology is merely a tool to assist a driver and that drivers need to rely on their own ability and defensive driving skills.

Advanced capabilities

Fleet participants were interested in the advanced capabilities of a DSRC system over (or coupled with) their current sensor suites. For example, in regard to left turn across path, opposite direction (LTAP/OD) crash scenarios, a participant mentioned the advantage of wireless messages that have a wider distance or range. Figure 1 illustrates the LTAP/OD crash scenario. In rear-end scenarios, a participant described how he would be interested in V2V in trail communication (i.e., where one vehicle is creeping up on the other vehicle), so that the lead vehicle would be informed of the condition. Figure 2 shows the rear end crash scenario. Another participant liked the idea of knowing the "intentions of another vehicle". He gave the example of two vehicles side-by-side; if one vehicle starts moving towards the other vehicle, the system would warn the driver that there is an object in the vehicle's path.

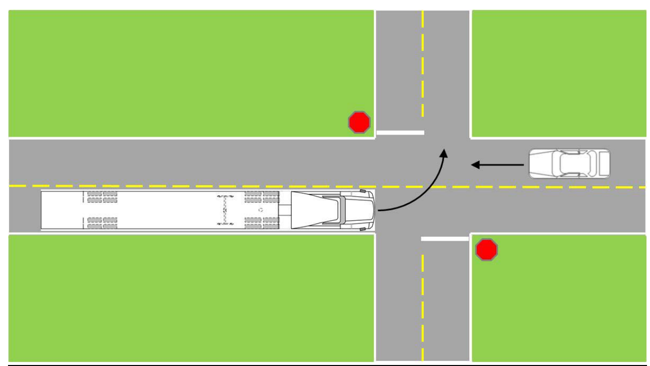

Figure 1. Left turn across path opposite direction (LTAP/OD) crash scenario. [12]

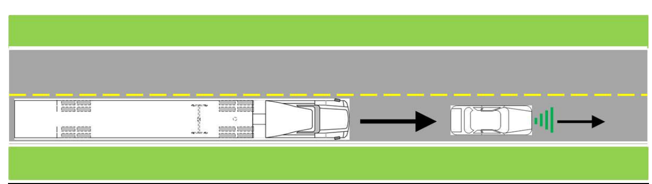

Figure 2. Rear end crash scenario. [12]

Behavior management

The ability to access more up-to-date information on driver behavior was mentioned as a potential benefit of DSRC. As one participant said "I want to know about behavior, do I have a driver who is constantly merging onto other vehicles? Do I have a driving behavior issue that I need to address?" Another participant liked the idea of having wireless communications transferring existing data back to the company's computer systems so that information on a critical event is available for management to use when talking to a driver the very same day.

Data management

A potential benefit of DSRC mentioned by fleet participants is the ability to capture data that can be used for legal and management purposes. For example, a participant said that in a rear-end crash scenario, his fleet would like to know what the truck was doing when it rear-ended a car. As was discussed previously, not all managers of fleets agree that access to crash and behavioral data is beneficial to their operations.

Integration

The ability to have one system provide multiple forms of crash avoidance information to a driver was mentioned by participants. As one participant noted, "Having one system would have huge advantages instead of having multitudes of different systems out there that are doing different things in different ways. Having one would certainly have its benefit, especially one that would bridge between normal driving public and commercial motor vehicle." Another participant said that he would like, "…something where all of the technology would be available in one package or in different modules attached to the truck, and that all use the same driver display or alert system so the driver needs only to look in one place for alerts".

V2V Safety Applications That Map To Real-World Crash Scenarios

With the advances in wireless communications and vehicle positioning, innovative safety applications can be applied to real-world crash scenarios that have been identified by Volpe. [11] While CVs have unique characteristics (e.g., size and weight) that must be considered in the development of safety applications, the real-world crash scenarios are similar whether a CV or light vehicle is involved. In previous work, CAMP evaluated a similar set of pre-crash scenarios and developed six safety applications: Emergency Electronic Brake Light (EEBL), FCW, Intersection Movement Assist (IMA), Blind Spot Warning + Lane Change Warning, Do Not Pass Warning (DNPW), and Control Loss Warning (CLW). [3] These applications served as a starting point for the CV safety applications considered by VTTI. The following list includes those applications that VTTI determined to be suitable for CVs.

Cooperative Forward Collision Warming (FCW)/Adaptive Cruise Control (ACC)

The FCW/ACC safety application determines when a rear-end collision is imminent and either issues an alert to the subject vehicle's driver or potentially produces an evasive maneuver (i.e., braking) to mitigate an impending collision with the vehicle ahead.

Emergency Electronic Brake Light (EEBL)/Enhanced Rear Signaling (ERS)

Because of their physical characteristics (e.g., size and weight), CVs may present obstacles for adjacent traffic. For instance, the width and height of the CV may limit the following traffic's view of the roadway ahead of the commercial vehicle. Unable to see beyond the commercial vehicle directly in front of them, the following vehicles' drivers will be hindered in their ability to anticipate and react to emergency events well ahead of them. When the CV brakes hard, the EEBL safety application enables the commercial vehicle to broadcast a self-generated message regarding its rapid deceleration to surrounding remote vehicles. [3, 4] In turn, the receiving vehicles determine the relevance of the message and either provide a warning to the driver or potentially produce an evasive maneuver (i.e., braking) to mitigate an impending collision with the commercial vehicle.

Another way commercial vehicles can create obstacles is due to their slower acceleration profile. Because of the large mass of these vehicles, commercial vehicles accelerate much slower than passenger vehicles, creating a larger than normal speed differential between vehicles traveling in the same direction. Working in the opposing direction as FCW, the ERS safety application would determine the rapid approach of following vehicles and broadcast a self-generated message of the imminent crash situation to the vehicles directly behind the commercial vehicle.

Blind Spot Warning (BSW)/Lane Change Warning (LCW)

During a lane change attempt (intended or unintended), the BSW/LCW will alert the subject vehicle's driver if the space adjacent to the subject vehicle is occupied by another vehicle. [3, 9] Compared to light vehicles, CVs are known for their large blind spots around the vehicle that pose a hazard to adjacent traffic. [10] As mentioned, CVs have variable lengths, widths, and heights that create shifting blind spots that must be accounted for in safety countermeasures.

Control Loss Warning (CLW)

The CLW safety application enables a CV to broadcast a self-generated control loss event to adjacent traffic. In turn, the receiving vehicles determine the relevance of the message and either provide a warning to the driver or potentially produce an evasive maneuver (i.e., braking) to mitigate an impending collision with the commercial vehicle. [3, 9]

Intersection Movement Assist (IMA)

The IMA safety application warns the CV driver when it is not safe to enter an intersection due to high collision probability with one or more remote vehicles in cross traffic. [3, 9]

Wrong Way Driver Warning (WWDW)

Using precise positioning information, the WWDW safety application provides a warning to the driver who is proceeding against the flow of traffic and a warning is broadcast to other vehicles in the at-risk area. [3]

Do Not Pass Warning (DNPW)

The DNPW safety application provides a warning to the CV driver when a slower moving vehicle cannot be safely passed using a passing zone which is occupied by oncoming vehicles. [3, 9]

Cooperative Stop Sign Violation Warning (CSSVW)

The CSSVW application uses both infrastructure-to-vehicle (I2V) and V2V communication to warn the subject-vehicle driver of an impending stop sign violation, and instructs the driver to stop at the legally prescribed location. The application also provides a warning to other drivers approaching the non-signalized intersection of the impending infraction.

Left Turn Assist

The Left Turn Assist safety application provides an impending crash warning to the subject vehicle's driver who is attempting a left turn at a signalized intersection without a phasing left turn arrow. [2]

Cooperative Traffic Signal Violation Warning (CTSVW)

The CTSVW application uses both (I2V) and V2V communication to warn the subject-vehicle driver of an impending traffic signal violation and instructs the driver to stop at the legally prescribed location. The application also provides a warning to other drivers approaching the signalized intersection of the impending infraction.

The success of future CV safety systems is dependent on the clear requirements to meet the needs identified by both crash analyses and the prescribed concept of operations. At the time of this writing VTTI was completing this task and a final report was being prepared detailing the performance requirements of the safety applications.

DRIVER-VEHICLE INTERFACE NEEDS SPECIFICATION

Overview

A key factor in determining the technical feasibility of migrating new and existing safety and mobility applications for future systems utilizing vehicle safety communications is the availability of an effective DVI for the system. At a minimum, there should be a clear understanding of relevant DVI requirements and potential solutions. In this context, "DVI" refers to the displays (i.e., visual, haptic, and or auditory) that the vehicle safety communications environment uses to communicate information to the driver, and the controls through which the driver interacts with the system. A project was initiated with the Battelle Center for Human Performance and Safety to investigate the specifications needed for an effective CV DVI.

The CV environment presents a number of challenges to the development of the DVI, including the: relatively long braking distances associated with commercial vehicles, extensive blind spot areas on all sides of the vehicle, and high levels of ambient vehicle noise and vibration around the driver. There are also advantages to developing the vehicle safety communications DVI within the heavy truck environment, including highly trained drivers and (typically) an organizational culture that encourages and rewards safe driving habits and overall performance.

It is expected that vehicles equipped with vehicle safety communications present a "message rich" environment to the CV driver, with a mix of: cautionary or advisory messages; time-critical messages such as collision warnings; messages related to navigation, routing, and travel decisions; and perhaps a special class of system status messages that communicate (e.g., transitions from full-manual control by the driver to at least partially automated control of certain vehicle subsystems). Poorly developed DVIs have the potential for confusing or distracting the drivers, leading to driver errors and, ultimately, crashes.

Importantly, from a driver's perspective, the source of information presented through a DVI (e.g., from the vehicle's sensors, from another vehicle's sensors, or from the infrastructure) is much less important than the timing, modality, format and reliability of the information presented. That is, the source matters less than the characteristics of the message itself.

Overall, the basic requirement for a vehicle safety communications DVI is that it is safe and effective. The DVI needs to avoid overloading the driver, interfering with the primary driving task, or contributing to driver errors or confusion. Also, the DVI should support quick and appropriate responses by the driver. In practice, assessing the feasibility of candidate applications or safety countermeasures to the connected vehicle environment (either V2V or V2I) requires consideration of a number of DVI features and related design questions, including the availability of specific design solutions or general design guidance for:

- The format, modality, location, and timing of messages, alerts, and warnings
- Strategies for minimizing false and nuisance alerts
- Integrating multiple subsystems within the vehicle environment, and prioritizing/managing messages presented to the driver
- Status, particularly as it relates to automated vehicle control functions
- Strategies for mitigating driver distraction
- Maintaining compatibility between message design and the desired driver response
- Special requirements of CV drivers

Industry Outreach Preliminary Findings

The objective of this task was to talk with SMEs to fill-in key information gaps identified in the literature review, and to provide some validation of existing findings that may be used in the development of the DVI functional requirements. In particular, multiple themes were identified for each of the information gaps covered in the interviews. While interviews involved mostly qualitative information and opinions on these topics, these findings still provide useful "starting points" for addressing these issues and developing the DVI functional requirements.

Although the SME responses to the interview questions covered a wide range of themes and subjects, a few overarching themes were apparent across several questions. These key points are summarized in the next sections for the following areas:

Driver distraction and workload

Driver distraction and workload are viewed by SMEs as some of the primary challenges facing drivers in the future. Moreover, technology was seen both as a potential solution for minimizing demands on drivers, and as a potential source of distraction. For example, several SMEs discussed beneficial applications of vehicle safety communications in terms of reducing demands on drivers by automating certain productivity and safety-related tasks, and also by providing reliable and actionable information to facilitate driver decision making. In contrast, potential drawbacks discussed included problems with poor DVI implementation and insufficient integration of technology (i.e., not integrating all systems that drivers use), which would likely make the driver's job more difficult. Another recurring concern was excessive false or nuisance alarms.

Information management should be a key function

This aspect has important implications for the driver workload and driver distraction issues described previously. A dominant theme in conversations with SMEs was the increase in information available to drivers, and importantly, the opportunities that vehicle safety communications could provide for managing information in a way that benefited driver safety and productivity. Information management involves several aspects; some of the most relevant ones for the DVI functional requirements are:

- Management of immediate information. This involves prioritization and integration of display messages (e.g., warning messages) so that drivers receive important, safety-critical information in a timely manner, while other “less critical” messages are presented when they will not interfere with the primary driving task.

- Integration of information from multiple systems. This includes some form of message arbitration to minimize the information that requires a driver response (i.e., offloading some information to autonomous systems in the CV so drivers are not overloaded).

- Supervisory role of drivers. There was a recognition that the driver’s relationship with some information could evolve to more of a supervisory role. This potentially opens up a new set of problems (i.e., driver vigilance, system trust); however, several of these issues are well understood in other domains, such as process control.

Driver acceptance

Driver acceptance of vehicle safety communications technology is also an issue that warrants special consideration. Ultimately, the effectiveness of any technology depends on drivers’ willingness to make full use of available capabilities. This in turn requires that the technology is designed in a way that it accommodates the characteristics of the driver population, including the increasing mix of younger and older drivers, with the addition of greater cultural diversity than was previously the case. Similarly, including drivers in the testing and development process was another aspect of promoting driver acceptance mentioned by several SMEs. The use of driver feedback was also cited as a potential factor in driver acceptance. In particular, the concern is that drivers would be reluctant to use the system if information is used in a punitive manner. However, using feedback for training opportunities was seen as a way to potentially improve driver acceptance.

Return on investment

A practical reality of vehicle safety communications in commercial vehicle operations is that productivity applications and overall ROI will be important drivers with respect to technology adoption. It is likely that applications for productivity information may in the future be incorporated in these systems, which requires special considerations with regard to integration with other components and information management.

Overall, the SME interviews conducted in this task provided a broad range of important insights about key information gaps. This information is being taken into consideration for developing the DVI functional requirements; however, care is being taken when applying this information, since it is qualitative in nature, and comes from a relatively limited number of SMEs. Overall, the SMEs provided numerous insights and ideas relative to both our short-term focus on the CV DVI functional requirements, as well as future CV DVI development, design, and evaluation activities.

Using the information gathered from the SME interviews and other sources, Battelle is currently developing guidelines for effective commercial vehicle DVIs for vehicles equipped with vehicle safety communications. This information is being prepared in a final report to U.S. DOT to be submitted at the conclusion of the project.

FUTURE ACTIVITIES

During the next phase of the CV vehicle safety communications program, prototype vehicles will be built with integrated V2V systems. These vehicles will undergo objective testing and participate in large scale field demonstrations of this technology being conducted by U.S. DOT beginning in 2012-13.

SUMMARY

This paper provided an overview of vehicle safety communications research for commercial vehicles being conducted by U.S. DOT. This program has made progress by identifying the fundamental issues that need to be resolved to implement V2V on this class of vehicles. Three research projects have been initiated in 2010 to study CV-specific interoperability issues, development of performance requirements for CV safety applications, and determine the CV-specific driver-vehicle interface (DVI) needs. This research directly supports the larger effort by U.S. DOT investigating V2V for all vehicle types. Resolution of the CV issues will help facilitate deployment of V2V for all vehicle types so that the potential safety benefits of V2V can be fully realized.

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