U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 811 772 May 2013

Development of Performance Requirements for Commercial Vehicle Safety Applications

Final Report

DISCLAIMER

Suggested APA Citation:

Bowman, D., Baker, S., Stone, S., Doerzaph, Z., & Hanowski, R. (2013, May). *Development of performance requirements for commercial vehicle safety applications*. (Report No. DOT HS 811 772). Washington, DC: National Highway Traffic Safety Administration.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 2013	3. REPORT TYPE AND DATES COVERED Final Report June 2010 – March 2011
4. TITLE AND SUBTITLE Development of Performance Requirements for Commercial Vehicle Safety Applications		5. FUNDING NUMBERS DTNH22-05-D-01019, Task Order #30
6. AUTHOR(S) Darrell Bowman, Stephanie Baker, Scott Stone, Zac Doerzaph, and Rich Hanowski		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Virginia Tech Transportation Institute 3500 Transportation Research Plaza (0536) Blacksburg, VA 24061		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590		10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT HS 811 772
11. SUPPLEMENTARY NOTES Task Order Manager: Alrik L. Svenson		
12a. DISTRIBUTION/AVAILABILITY STATEMENT Document is available to the public from the National Technical Information Service www.ntis.gov		12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The U.S. Department of Transportation is conducting research to accelerate the widespread adoption of vehicle-to-vehicle (V2V) technology in commercial vehicles such as heavy trucks and buses. The widespread deployment of V2V safety is dependent on understanding the effectiveness of safety applications. The objective of this study was to determine the high-level performance requirements for potential V2V safety applications that are appropriate for commercial vehicles. This objective was accomplished via a 9-month project that involved reviewing literature covering collision avoidance systems currently available on heavy commercial vehicles, interviewing commercial vehicle industry representatives (manufacturers, suppliers, and fleet operators) to determine suitable crash avoidance technologies for the V2V communication, and identifying and developing high-level performance requirements for the selected commercial vehicle safety applications.

14. SUBJECT TERMS Commercial motor vehicle, crash avoidance technologies, DSRC, Intelligent Transportation Systems, performance requirements, V2V			15. NUMBER OF PAGES 101 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (rev. 2-89)
Prescribed by ANSI Std. 239-18, 298-102

GLOSSARY OF TERMS

ACC	adaptive cruise control
ATRI	American Transportation Research Institute
BSD	blind spot detection
BSW	blind spot warning
CAMP	Crash Avoidance Metrics Partnership
CAN	controller area network
CFCW	cooperative forward collision warning
CLW	control loss warning
CSSVW	cooperative stop sign violation warning
CTSVW	cooperative traffic signal violation warning
CV	commercial vehicle
DGPS	differential global positioning system
DNPW	do not pass warning
DSRC	dedicated short-range communications
DVI	driver-vehicle interface
ECU	electronic control unit
EEBL	emergency electronic brake light
EOBR	electronic onboard recorder
EIA	electronic industries alliance
ERS	enhanced rear signaling
FCW	forward collision warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier safety Administration
FOT	field operational test
GES	General Estimates System
GHZ	gigahertz
GIS	geographic information system
GPS	global positioning system
GVWR	gross vehicle weight rating
ICF	informed consent form
IMA	intersection movement assist
IMU	inertial measurement unit
IVBSS	Integrated Vehicle-Based Safety Systems
LCA	lane change assistant
LCW	lane change warning
LDW	lane departure warning
LOS	line-of-sight
LTAP/OD	left turn across path opposite direction
LV	light vehicle
NHTSA	National Highway Traffic Safety Administration
NON-LOS	non-line-of-sight
OEM	original equipment manufacturer
RITA	Research and Innovative Technology Administration
ROI	return-on-investment

RTK	real-time kinematic
SCP	straight crossing path
TCD	traffic control device
TIMTC	Trucking Industry Mobility and Technology Coalition
TRB	Transportation Research Board
U.S. DOT	United States Department of Transportation
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VSC	vehicle safety communication
VTTI	Virginia Tech Transportation Institute
WWDW	wrong-way-driver warning

ACKNOWLEDGEMENTS

The authors of this report wish to thank Alrik Svenson of NHTSA for his constructive comments, advice, and support throughout this project. Svenson was the Task Order Manager (TOM). This research was conducted under NHTSA Contract # DTNH22-05-D-01019 (Task Order #30).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

INTRODUCTION

The U.S. Department of Transportation commissioned the current study to determine the high-level performance requirements for potential V2V safety applications suitable for commercial vehicle operations. The purpose of this project was threefold: (1) review the literature covering collision avoidance systems currently available for CVs, (2) interview representatives from CV and light-vehicle manufacturers, suppliers, and CV fleet operators to determine suitable crash avoidance technologies for the V2V communications, and (3) identify and develop high-level performance requirements for the selected V2V safety applications.

LITERATURE REVIEW

Key findings from the literature review included:

- CVs, distinct from passenger cars, are used primarily for business purposes and operational decisions are driven by profits and return-on-investment.
- Prominent collision avoidance/warning technologies for CVs include forward collision warning, lane departure warning, and side collision warning systems (i.e., lane change assist and blind spot detection).
- CV collision avoidance technologies from research studies include enhanced rear signaling and Integrated Vehicle Bases Safety Systems (which included the integration of FCW, LDW, lane change warning, and curve speed warning).
- The key findings from the IVBSS testing conducted by UMTRI (Sayer et al., 2010) included:
    - Majority of participating drivers believed the integrated system will increase their driving safety.
    - There remain challenges with current collision avoidance systems (e.g., FCW and lane change/merge) for discerning differences between actual threats from adjacent traffic and false detections of fixed roadside objects and the subject vehicle itself.
    - Because of their rarity, addressing multiple, simultaneous, or near-simultaneous threats might not be as critical as once thought for an integrated safety system.
- Collision avoidance technologies will soon be supported by V2V communications, especially dedicated short-range communications, to provide high-bandwidth, low-latency connectivity between vehicles, between vehicles and infrastructure, and between vehicles, infrastructure, and mobile consumer devices.
- According to CV industry feedback at a 2010 CV Safety Workshop (TIMTC, 2010), the key technologies that are expected to be useful in improving CV safety include blind spot detection, LDW, and FCW. The perceived benefits for adopting vehicle communications in CVs include increased safety, security, and productivity, positive ROI, and increased fuel economy. The barriers to adopting V2V communications in CVs include costs, maintaining a positive ROI, standardization, and integration issues.

- Recently, the John A. Volpe National Transportation System Center (i.e., Volpe) completed an analysis of various pre-crash scenarios and identified 17 target V2V pre-crash scenarios that have been categorized into six groups based on vehicle movements and orientations prior to the onset of the crash critical event. These pre-crash scenarios can serve as the basis for identifying and developing future commercial vehicle V2V safety applications.

HIGH-LEVEL PERFORMANCE REQUIREMENTS DEVELOPMENT

CV Industry Outreach

The research team conducted 17 interviews with both CV fleet managers and safety directors, and with CV and LV manufacturers and supplier engineers and managers. This diverse group provided insight into current usage of CV safety systems (Table 1), potential V2V usage in CV fleets (Table 2), and functional considerations for integrating DSRC-based technologies into CVs (Table 3).

Table 1. Primary Themes for Current Usage of CV Safety Systems (Fleet Comments)

Themes	Brief Description
Return-on-Investment	Ensure that the technologies they invest in will reduce crashes and last long enough to pay for themselves
Installation	Installation by the OEM was viewed as more efficient and less costly than trying to retrofit a tractor with new technology.
Maintenance	Crash avoidance systems are only useful if they are maintained and it is important for drivers to understand that if the systems get damaged they will need to take the trucks in for repair.
System Adjustability	Need the ability to program or adjust crash avoidance systems to conform to their company policies and procedures. Also, driver adjustments (e.g., volume) are important for team drivers, especially while in sleeper.
System Reliability	Reliability of a crash avoidance system is important for maintain drivers' faith in the systems.
Driver Behavior Monitoring	Identifies drivers who needed remediation.
Data Accessibility	Access to data from crash avoidance systems was important to some fleets for identifying poor driver behavior and helpful in litigation situations. While other fleet participants indicated that they did not want access to captured data because of the lack of resources to manage the data properly
Driver Acceptance	Securing driver buy-in and acceptance of crash avoidance systems is important so that drivers are willing to use them.
Driver Distraction	Crash avoidance technologies lose their benefit if they become a distraction to the driver.
Driver Overreliance	Can be problematic if there is a technical problem with the system and the driver has invested too much trust in the technology.

Table 2. Primary Themes for Potential V2V Technology Usage in CV Fleets

Themes	Brief Description
Advanced Capabilities of DSRC	Provides an advantage of having a larger coverage for alert messages
ROI	Because it may take quite some time for broad implementation of DSRC, fleets may not experience any benefit in the short term
Integration	"*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.*"
System Reliability	"*What happens if the technology fails? If we have disconnected drivers [those without DSRC systems], who is held accountable then*?"
Driver Behavior Management	Transmitting 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	Should capture the crash data from all vehicles, infrastructure, and mobile devices in the crash scene to provide a more complete picture of the events
Driver Acceptance	Would want to test the DSRC technology with their drivers to see if the drivers were accepting of the technology and perceived it as beneficial

Table 3. Primary Themes from the DSRC-Based Technology Integration Into CVs (Supplier and OEM Comments)

Themes	Brief Description
Customer Demand	OEMs do not offer safety systems on their vehicles because though they think the systems are a good idea, they only install crash avoidance technology if there is a market advantage or if a customer requests the product.
DSRC Radio Integration	DSRC radios should be provided to OEMs to be integrated into the vehicle's system architecture.
Implementation Impetus	"*If it becomes a requirement by the government, then it will push through very quickly. But if it's just a convenience item, I'm afraid it's going to be a hard sell.*"
ROI	Need to show some benefit from DSRC before fleets are going to purchase trucks with the technology
Standardization	A few of the OEMs were concerned that there needs to be a standard set of interface protocols so that all the DSRC safety systems can talk to each other.
Safety Benefits	Potential benefits from DSRC implementation include knowing the intentions of other vehicles, having better situational awareness, and reducing false alarms.

Themes	Brief Description
Driver Distraction	OEMs must balance integrating safety systems into the vehicle that will alert the driver to a potential crash while not distracting.
Mounting	Proper and secure mounting of crash avoidance technologies was an installation issue raised by several OEMs.
DSRC Antenna Placement	The DSRC suppliers mentioned optimizing the placement of the antenna on the CV, to the mount location of the roadside antenna, and considering the environment in which the CVs must operate when mounting the antenna. A DSCR supplier participant described how antenna placement in a DSRC scenario may help in determining the dimensions of the CV.
Trailer Data	A vehicle integration issue that came up during the interviews was that there are few standardized interfaces between tractors and trailers for data exchange.
V2I Benefits	Benefits of V2I communication include the ability for a vehicle to signal the intersection that it is either present or approaching and addressing frequent rollovers (e.g., providing sharp-curve warnings).

High-Level Performance Requirements From Literature

V2V Communications

The enabling technology for V2V safety applications is an advance in wireless communications that allows 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 (Shulman & Deering, 2007).

Vehicle Positioning

The key to all safety applications is an accurate spatial awareness of the driving scenario (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.

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 (i.e., outer dimensions) of the subject vehicle as well as other objects in the crash scene. This is especially true for CVs where the vehicle lengths can typically range from 20 to 75 feet. Heights and widths of CVs with special permits can be in excess of 13.5 feet and 8.5 feet, respectively. These dimensions vary with loads and must be accurately accounted for in crash avoidance algorithms.

Commercial Vehicle Size

Like a building, a CV can be large enough to present a barrier to the DSRC transmission. Therefore, non-line-of-sight DSRC transmissions may be necessary to effectively communicate between radios when in close proximity to CVs.

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 the identified real-world crash scenarios. 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. Several safety applications have been modified to account for the unique characteristics of CVs.

- **Cooperative Forward Collision Warning (CFCW)/Adaptive Cruise Control**
- **Emergency Electronic Brake Light (EEBL)/Enhanced Rear Signaling (ERS)**
- **Blind Spot Warning (BSW)/Lane Change Warning (LCW)**
- **Control Loss Warning (CLW)**
- **Intersection Movement Assist (IMA)**
- **Wrong-Way-Driver Warning (WWDW)**
- **Do Not Pass Warning (DNPW)**
- **Cooperative Stop Sign Violation Warning (CSSVW)**
- **Left Turn Assist**
- **Cooperative Traffic Signal Violation Warning (CTSVW)**

These promising safety applications and their associations with the pre-crash scenarios areshown in Figure 1. Table 4 provides the preliminary performance requirements for each of these safety applications. The requirements should be considered preliminary because they were derived from existing requirements (Shulman & Deering, 2007; Ahmed-Zaid et al., 2008; Maile, 2009) for various V2V and V2I safety systems and from interviews with industry stakeholders.

Pre-crash Scenarios \ Safety Applications		V2V						V2V and V2I			
		Cooperative FCW/ACC	EEBL/ERS	BSW/LCW	CLW	WWDW	Do Not Pass Warning	Cooperative Stop Sign Violation Warning	IMA	Left Turn Assist	Cooperative Traffic Signal Violation Warning
Rear-end	Lead vehicle stopped	●	●								
	Lead vehicle decelerating	●	●								
	Lead vehicle moving	●	●								
	Striking maneuver	●	●		●						
	Lead vehicle accelerating	●	●								
Lane change	Changing lanes/same direction			●							
	Turning/same direction	●								●	
	Drifting/same direction			●	●						
Opposite direction	No maneuver	●			●	●					
	Maneuver	●					●				
LTAP/OD	Non-signal	●							●		
	Signal	●								●	
Junction Crossing	SCP at non-signal	●							●		
	Turn at non-signal	●							●		
	Turn right at signal	●							●		
TCD Violation	Running red light	●			●				●		●
	Running stop sign	●			●			●	●		

Figure 1. Mapping Safety Applications to Pre-Crash Scenarios

Table 4. Summary of Performance Requirements for Commercial Vehicle V2V Safety Applications

Safety Application	Communication Type	Transmission Mode	Minimum Update Rate (Hz)	Latency (ms)	Primary Data Elements	Required Transmission Range (m)
Cooperative FCW	• Non-LOS V2V • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Road surface conditions • Load mass • Yaw-rate • Steering angle • Vehicles’ dimensions • Road curvature	~150 -500
EEBL/ERS	• Non-LOS V2V • One-way • Point-to-multipoint	Event-driven	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Load mass • Road curvature • Yaw-rate • Steering angle • Road surface conditions	~300
BSW/LCW	• LOS V2V • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Steering angle • Turn signal status • Vehicles’ dimensions	~150
Loss Control Warning	• Non-LOS V2V • One-way • Point-to-multipoint	Event-driven	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Yaw-rate	~150
Intersection Movement Assist	• Non-LOS V2V • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Road surface conditions • Directionality • Stopping position location • Vehicle’s dimensions • Traffic signal status	~300
Wrong Way Driver	• Non-LOS V2V • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings Vehicles’ speeds • Vehicles’ positions • Steering angle • Lane position	~500
Do Not Pass Warning	• Non-LOS V2V • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Turn signal status • Lane position	~500
CSSVW	• Non-LOS V2V and V2I • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Road surface conditions • Directionality • Vehicle’s dimensions • Stopping position location	~250
Left Turn Assist	• Non-LOS V2V and V2I • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles’ headings • Vehicles’ speeds • Vehicles’ positions • Road surface conditions • Directionality • Stopping position location • Vehicle’s dimensions • Traffic signal status	~300

Safety Application	Communication Type	Transmission Mode	Minimum Update Rate (Hz)	Latency (ms)	Primary Data Elements	Required Transmission Range (m)
CTSVW	• Non-LOS V2V and V2I • One-way • Point-to-multipoint	Periodic	~10	~100	• Vehicles' headings • Vehicles' Speeds • Vehicles' Positions • Road surface conditions • Directionality • Stopping position location • Vehicle's dimensions • Traffic signal status	~250

DISCUSSION AND CONCLUSIONS

As previously mentioned, the purpose of this project was threefold: (1) review the literature covering collision avoidance systems currently available for CVs, (2) interview representatives from CV and LV manufacturers, suppliers, and CV fleet operators to determine suitable crash avoidance technologies for the V2V communications, and (3) identify and develop high-level performance requirements for the selected V2V safety applications.

Key conclusions from the project included:

- Prominent collision avoidance/warning technologies for CVs include forward collision warning, lane departure warning, and side collision warning.
- Each of these systems presents several limitations (e.g., data loss from road curvature, weather, and detection of non-relevant objects) that may be addressed by V2V communications.
- Ten V2V/V2I safety applications were identified to address the 17 pre-crash scenarios (Figure 1).
- Of these 10, three applications have great potential with regard to safety benefits for the commercial vehicle industry. They are: cooperative FCW (mapping to 15 of the 17 pre-crash scenarios), IMA (mapping to 6 of the 17 pre-crash scenarios), and EEBL/ERS (mapping 5 of the 17 pre-crash scenarios).
- Because there are some crash similarities between CVs and LVs, the development of high-level performance requirements was able to leverage the years of LV V2V research completed by CAMP and others.
- The primary differences between LVs and CVs are their size, varied configurations, and loads.
- This project found no major issues that would prevent the implementation of V2V safety applications within the CV industry.
- There are several key factors that should be considered to foster the technology's adoption within CVs. These are:
    - From the CV fleet's perspective, the V2V safety applications must demonstrate an ROI, have the CV drivers' buy-in and acceptance, and present an integrated solution for overall vehicle safety.
    - The OEMs and suppliers, on the other hand, were more concerned with market drivers such as customer demand and government mandates. Another key factor discussed was standardization to allow seamless coordination between the CV manufacturers, vehicle-types (i.e., CV versus LV), infrastructure equipment, and myriad mobile communication devices.

Finally, the outreach to the CV industry, especially fleets, made it clear that more details about the Vehicle Safety Communication Initiative need to be disseminated to the CV industry so stakeholders can understand the principles behind the concept and how this will affect their day-to-day operations. This education effort will help with fleet and driver adoption of the technology and will hasten the approach to the "critical mass" needed for optimal V2V communication performance.

CHAPTER 1. INTRODUCTION

BACKGROUND

The U.S. DOT has conducted research with the automotive industry that demonstrated that inter-vehicle communications (which is to say, V2V) will improve the overall effectiveness of current active safety systems while reducing consumer cost. In addition, an analysis of communication alternatives has shown that, at this time, DSRC at 5.9 GHz is the only communication option capable of effectively and reliably providing this low-latency safety-of-life capability (RITA, 2010). V2V communication for safety is a major component of the U.S. DOT Vehicle Safety Communication program, which also sponsors research and other activities to support future connectivity between vehicles and infrastructure (V2I) to deliver safety, mobility, and environmental benefits.

PROJECT OBJECTIVES

The widespread deployment of V2V safety technology is dependent upon understanding the effectiveness of safety applications. The objective of this task order was to determine the high-level performance requirements for potential V2V safety applications that are appropriate for commercial vehicles. To accomplish this objective, the research team:

- Reviewed the literature covering collision avoidance systems currently available for heavy commercial vehicles;
- Interviewed representatives from the CV manufacturers, suppliers, and fleet operators to determine suitable crash avoidance technologies for V2V communications; and
- Identified and developed performance requirements for selected applications.

REPORT STRUCTURE

This report will provide a summary of the preliminary performance requirements for commercial vehicle V2V safety applications. Chapter 2 provides an overview of the methods for the literature review and CV industry outreach. In Chapter 3, a synopsis of CV crash avoidance technology trends is provided. The synopsis reviews current and emerging CV crash avoidance technologies applicable to V2V communications, recent advances in the U.S. DOT's Vehicle Safety Communication initiative as it relates to CVs, and an overview of the CV crash scenario framework. Chapter 4 provides the details for developing high-level performance requirements that were created through a synthesis of CV industry input and the literature. Chapter 4 also provides general functional considerations as well as V2V safety applications that map to CV crash scenarios and the high-level performance requirements associated with each safety application.

CHAPTER 2. METHODS

LITERATURE REVIEW

Researchers synthesized relevant research and information to provide a foundation for the research tasks. The primary sources of this information included: the crash scenario framework development by the Volpe Center, the IVBSS research, and the DOT Commercial Vehicle Workshop. Ancillary sources such as libraries, the TRB's Transportation Research Information Services database, and the Internet, were searched for relevant literature related to crash avoidance technologies for heavy vehicles suitable for wireless V2V communication using DSRC technology.

COMMERCIAL VEHICLE INDUSTRY INPUT

Because crash avoidance technologies are continuously advancing, the research team supplemented published sources with opinions and data about current, emerging crash avoidance system information from CV stakeholders. The key members of CV stakeholders included suppliers, manufacturers, and CV fleets. These individuals and organizations have firsthand experience and knowledge of vehicle safety systems, performance requirements, and implementation issues.

CV Suppliers

There are numerous CV suppliers that develop and sell vehicle safety systems; however, the research team targeted major suppliers that have established themselves in the CV market as suppliers of crash avoidance systems that would be applicable to V2V communications. These companies develop systems tailored to both the OEM and aftermarket sectors. As the developers of these crash avoidance technologies, these companies have a deep understanding of the functional requirements and implementation issues. The key topics discussed with CV suppliers included current and future crash avoidance systems, the state of development of these systems within the CV market, identification of those suitable for V2V communications, system integration issues with DSRC-based communication systems, and data requirements.

CV Manufacturers

There are four major CV manufacturers that sell vehicles in the U.S. market. These companies possess a unique knowledge of the vehicle integration issues (e.g., communication protocols with the vehicle's SAE J1939 Controller Area Network) that are associated with these safety systems. One CV manufacturer requested to remain anonymous as a condition of their participation in the project, so the organizational names will not be disclosed in this report. The key topics to be discussed with each CV manufacturer included current offerings of crash avoidance technology, identification of those technologies suitable for V2V communications, vehicle integration issues (especially with DSRC-based communication systems), and vehicle interface requirements (e.g., inputs, outputs, and data requirements).

CV Fleets

Eight fleets were targeted for participation in this project. These fleets provided insight into the operational issues associated with the crash avoidance systems of interest and the general implementation needs (i.e., installation, maintenance) of CV fleets.

A key part of this study involved outreach to the CV, light vehicle, and DSRC industries. Questionnaires and interviews were used to gather information from CV, LV, and DSRC stakeholders to determine suitable crash avoidance technologies for V2V communication, to identify performance requirements for selected applications, and to explore implementation issues with DSRC. The following subsections provide information on participants, data collection, and analysis used during the CV industry input task.

CV Industry Outreach Methods

Participants

Subject Pool

The subject pool for this study consisted primarily of key CV stakeholders employed by or associated with the CV industry (i.e., suppliers, manufacturers, and fleets). LV suppliers and DSRC suppliers were also included. CV, LV, and DSRC stakeholders were recruited for their specific knowledge and expertise regarding crash avoidance technologies and DSRC. Participants included engineers working for suppliers (CV, LV, and DSRC) involved in the development of advanced collision avoidance systems and DSRC, systems integration managers employed by manufacturers of advanced collision avoidance systems, and safety managers and key maintenance staff from commercial vehicle fleets.

Twenty participants from 16 companies were involved in the outreach. In one case, an LV supplier and CV manufacturer from different branches of the same company participated for a total of 17 interviews. The CV manufacturing participant filled out the questionnaire and both took part in separate interviews regarding their specific areas of expertise (i.e., LV supplier versus CV manufacturer). A summary of the outreach can be found in Table 5. The actual names are withheld for confidentiality.

Table 5. CV Industry Outreach Summary

	Number of Companies Contacted	Questionnaires Sent	Questionnaires Returned	Interviews Completed	Total Participants
CV Suppliers	8	5	3	3	5
CV Manufacturers	6	4	3	3	3
CV Fleets	10	8	7	7	8
LV Suppliers	2	1[1]	1[1]	2	2
DSRC Suppliers	2	2	2	2	2
Totals	**28**	**20**	**16**	**17**	**20**

[1]*One light vehicle supplier was not sent a questionnaire because his colleague (a CV manufacturer) from a different division within the same company completed it.*

Recruitment

Participants were identified using the research team's participant database and via word of mouth. Identified stakeholders were contacted via e-mail and asked to participate (Appendix A). Potential participants were told in the e-mail about the purpose of the study and the time commitment involved. Follow-up calls were made, when necessary, to reach potential participants who did not reply to the e-mail.

Table 5 provides a breakdown of the industry outreach. Of the 28 stakeholders contacted, 20 companies showed interest in participating and were sent a questionnaire. Out of the questionnaires distributed, 15 were completed and returned. Seventeen interviews were conducted with one to three participants per group interview. As was mentioned earlier, two participants from different branches (i.e., LV supplier and CV manufacturer) of the same company took part in interviews; only one of the participants (CV manufacturer) filled out a questionnaire.

Participant Protection

Several steps were taken to protect participant privacy. Once a stakeholder confirmed that he/she would like to participate in the study, an e-mail was sent with the questionnaire that summarized the purpose of the study and the time commitment required (Appendix B). The e-mail provided informed consent information, explaining that participation was voluntary and personal identities would remain anonymous. The e-mail stated that return of the questionnaire meant that the participant was providing his/her voluntary consent to participate in the study.

Once a participant returned the questionnaire, the participant was asked to take part in a 1-hour phone interview. One exception took place to this standard process. In one case, a CV manufacturing participant from one company completed a questionnaire and his colleague from the LV supplier branch of the same company also took part in an interview without completing a questionnaire.

Whether or not a questionnaire had been completed, prior to all phone interviews, participants were e-mailed an informed consent form to review and were asked to contact researchers with any questions or concerns before the interview. The ICF (Appendix C) described the purpose of the study, study procedures, general risks of the study, confidentiality procedures, and participants' rights and responsibilities. At the start of the phone interview, participants were reminded of the key sections of the ICF (time required, confidentiality, etc.) and asked to voice any concerns or questions to a researcher. Once any questions and concerns were addressed, researchers asked participants to provide their verbal consent to participate in the interview.

During data reduction and analysis, participant privacy was protected. All audio files were transcribed without the use of personal names so that no participant comments could be connected with names. The audio files and transcripts are kept on password-protected computers that are only accessible to researchers and data reductionists working on the project.

Data Collection

As part of the industry outreach process, the research team used questionnaires and interviews to gather opinions and data from stakeholders about current and emerging CV crash avoidance system information and DSRC technology. The purpose of these methods was to determine the performance requirements for potential V2V safety applications appropriate for heavy commercial vehicles.

Questionnaires

Participants were e-mailed a brief questionnaire and asked to fill out the questionnaire and e-mail it back to the researchers within 7 to10 days. As necessary, reminder emails and follow up phone conversations were made to motivate completion of the questionnaire. Requested time commitment for the questionnaire was estimated at 15 minutes. Of the 20 questionnaires distributed, 16 were returned. Table 5 provides a breakdown of how many participants from each stakeholder group completed the questionnaire.

Though the questionnaire format varied slightly depending on if it was being given to a supplier, a manufacturer, or a fleet stakeholder (Appendix D), all questionnaires included questions regarding a series of six crash types: lane change, rear-end, junction crossing, left turn across path opposite direction, opposite direction, and traffic control device violation. All questionnaires also included a series of questions regarding DSRC technology. The focus of each questionnaire is described below by stakeholder type.

- Supplier (CV, LV, and DSRC) questions focused on the performance requirements necessary to address each of the six crash types, current and emerging technologies to address each crash type, and opinions regarding DSRC implementation.
- Manufacturer questions focused on current technologies being implemented in vehicles by each of the six crash types, general vehicle-level requirements to consider when integrating technologies to address each crash type, and opinions about DSRC implementation in vehicles.
- Fleet questions focused on current crash avoidance technologies being implemented in fleets by crash type, implementation issues with these technologies, and opinions about DSRC implementation in fleets.

Interviews

Stakeholders who returned a questionnaire were requested to take part in a follow-up interview. The purpose of the questionnaire was to familiarize stakeholders with the interview discussion topics prior to the phone call and served as the basis of the discussion during the interview. Interviews included between one to three participants per stakeholder organization. The duration of the interviews varied but all were kept to under an hour in length with the average interview time being 43 minutes. The goal of the interviews was to review the questionnaire results and probe for additional detail on key questions.

Data Analysis

Seventeen interviews were completed as part of the industry outreach process. All interviews were audio-recorded and transcribed for data reduction purposes. The transcription process involved initial transcription of audio files by a data reductionist and then a complete review of the transcript for quality control purposes by a member of the research team. The 17 interviews resulted in over 12 hours of discussion about current crash avoidance technologies, V2V communication applicability and DSRC implementation.

The approach that was used to analyze the results of the interviews was an adaptation of framework analysis, a methodology developed in the 1980s at the National Centre for Social Research in Britain (Ritchie et al., 2003). The steps that were taken to carry out the framework analysis were as follows:

1. **Determining Analysis Focus:** Researchers determined that the focus of the framework analysis would be on industry opinions on several key issues including current crash avoidance systems, vehicle integration of crash avoidance systems, data elements for crash avoidance systems, applicability of DSRC by crash type (lane change, rear end, etc.) and DSRC implementation. Each of these areas of interest was covered in different stakeholder questionnaires and interviews. The issues or themes covered by groups were as follows:

    - Fleet: Crash Avoidance Systems and DSRC;
    - CV Manufacturer: Vehicle Integration of Crash Avoidance Systems and DSRC;
    - CV Supplier: Data Elements for Crash Avoidance Systems and DSRC;
    - DSRC Supplier: Applicability of DSRC by Crash Type and DSRC Implementation; and
    - LV Supplier: Applicability of DSRC by Crash Type and DSRC Implementation.

2. **Transcribing:** Each interview was transcribed in full by a data reductionist and then reviewed for quality control purposes by a member of the research team.

3. **Familiarization:** A member of the research team read over each of the transcripts to become familiar with the data set.

4. **Identifying Thematic Framework:** A member of the research team conducted a review of the data set and identified for each theme a list of key subthemes. The themes and subthemes were then arranged in a logical order and an index was created. For instance, in the fleet analysis under the crash avoidance systems theme, several subthemes emerged (i.e., installation, maintenance, driver distraction).

5. **Indexing**: The index was systematically applied to the data set and relevant comments were identified and highlighted in the transcripts.

6. **Charting**: A member of the research team arranged all of the indexed comments into Microsoft Excel spreadsheets. Each stakeholder group was given its own spreadsheet. The spreadsheets were then sorted by theme (e.g., fleet crash avoidance systems). These spreadsheets or thematic charts were further sorted by subtheme (crash avoidance system installation, maintenance, etc.).

7. **Interpretation:** As a last step in the framework analysis process, the themes and subthemes captured and detailed in the charts were used by the research team to better understand industry perspectives related to key areas (i.e., fleet perspectives on crash avoidance systems). Participant comments related to the themes were included in the summary for the results section of this report.

The results of the industry outreach were used to formulate high-level functional considerations when developing future CV crash avoidance technologies, especially ones incorporating V2V communications.

CHAPTER 3. COMMERCIAL VEHICLE SAFETY TRENDS

Commercial vehicle safety is a primary interest for the trucking industry, the general motoring public, and the National Highway Traffic Safety Administration and the Federal Motor Carrier Safety Administration. Its importance is echoed in a September 2010 speech made by U.S. Transportation Secretary Ray LaHood in which he stated that "From the outset, safety has been my number one priority at the [DOT]" (The Trucker, 2010). Every year, millions of dollars and tens of thousands of people are working to make the nation's roadways safer and improvements in CV operations are important to achieving that objective.

According to FMCSA, there were more than 3,700 fatal crashes involving large trucks (i.e., pick-ups, single-unit, or combination trucks greater than 10,000 pounds GVWR in 2008. This analysis also revealed that, while there had been a 65-percent increase in the number of miles traveled by large trucks between 1988 and 2008, there had been a 22-percent decline in their involvement in fatal crashes during that 20-year span (FMCSA, 2010b). This is a testament to the effort that the CV industry and government have made to improve CV safety. Still, CVs, per unit of travel, are involved in more fatal crashes than other classes of vehicles; 1.8 crashes per 100 million miles traveled in 2008 compared with 1.3 for passenger cars and 1.7 for light trucks (NHTSA, 2010).

There is a large body of safety research that addresses the nature and risks associated with CV crashes. This section will provide a synthesis of such work to serve as a basis for the development of high-level performance requirements for V2V safety applications in CVs.

COMMERCIAL VEHICLE CRASH AVOIDANCE TECHNOLOGIES

The trucking industry (i.e., vehicle manufacturers, suppliers, and fleets) develops and deploys both passive and active safety technologies to address the crash problem and improve overall CV operations. While passive safety systems, such as seat belts, are important to commercial driver safety, this report will focus primarily on active safety systems.

The active technologies employ a variety of sensors (e.g., radar, lidar, cameras, ultrasonic) positioned around the vehicle to detect the presence of stationary and moving objects. This information is relayed to a central processing unit for analysis to determine if a collision is imminent. If so, a signal is sent from a driver-vehicle interface to the driver through a visual, auditory, or haptic display and/or more advanced vehicles may automatically take control of steering, braking, or accelerating to mitigate the collision.

While safety is of the utmost importance to the trucking industry, CVs, distinct from passenger cars, are used for business purposes and many of the vehicle-related decisions such as purchasing safety technologies are rooted in a return-on-investment. Thus, FMCSA initiated several cost/benefit analyses (Houser et al., 2009; Murray et al., 2009a, 2009b) to help motor carriers make sound decisions regarding safety technologies. Based on these analyses, both small and large motor carriers expect a positive ROI within a 5-year period for prominent safety technologies such as FCW and lane departure systems (Jermakian, 2010).

PROMINENT COLLISION AVOIDANCE/WARNING SYSTEMS FOR COMMERCIAL VEHICLES

Forward Collision Warning System

The FCW system uses a sensor(s) (e.g., radar, camera, and laser) mounted on the front of the CV to monitor the roadway directly in front the vehicle. From the sensor data, the distance, azimuth angle, and relative speed of vehicle or objects in the CV's projected path can be computed (FMCSA, 2011a). If an impending collision is detected, the FCW system provides an alert to the driver to take an evasive maneuver, if required.

More advanced FCWs have been bundled with adaptive cruise control to provide a means for automatic input to slow the vehicle in an attempt to evade the impending collision. Much like FCW, the ACC system uses sensor data to maintain a driver-specified interval distance with the vehicle traveling ahead of it, using the engine throttle and, where possible, the engine brake and automatic transmission to decelerate the vehicle. This automated control provides a faster, more effective way for the vehicle to react to dangerous situations, which is useful for less experienced drivers (Figueiredo et al., 2001). When there is not an impending collision condition, the ACC works like a conventional cruise control system (FMCSA, 2011a). Figure 2 provides the FCW system architecture including major components (solid lines) and interfaces (dashed lines). The electronic control unit collects data from the forward-looking obstacle sensor. Through the vehicle network (J1939), the ECU monitors the vehicle's speed. The ECU outputs both a continuous visual system status and, as needed, a driver warning when a collision with a leading vehicle is imminent.

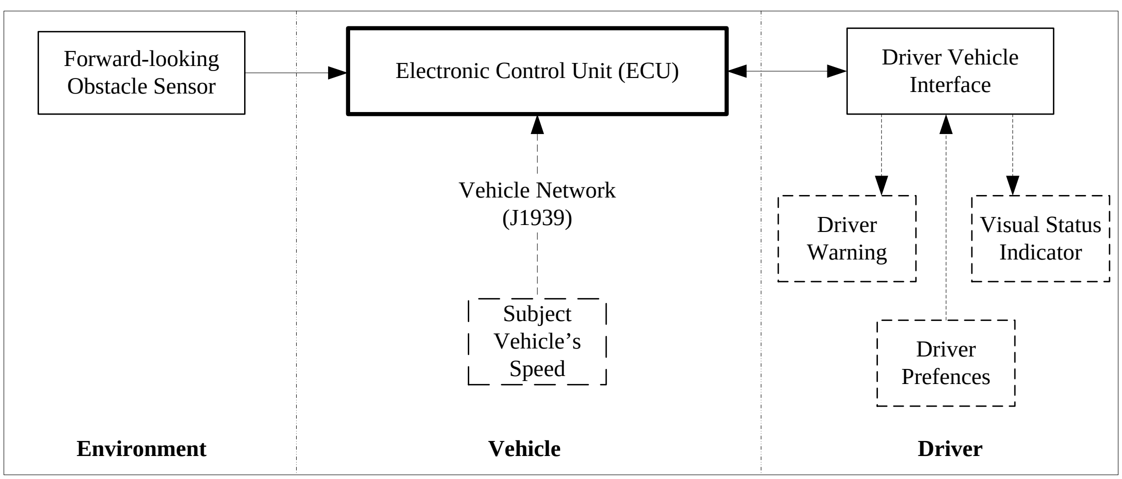


Figure 2. FCW System Architecture (Modified From ISO 15623: 2002)

Using field tests, Battelle (2007) reported that FCW, when coupled with advanced braking, could reduce the types of conflicts that result in rear-end collisions by 23 to 28 percent (Jermakian, 2010). Despite the benefits of the FCW, there are some limitations. Both sharp turns and rapid changes in elevation create momentary losses of sensor coverage as well as possible false alarms from reflections from non-relevant roadside objects.

Lane Departure Warning System

Lane departure warning systems use primarily video images captured by a forward-looking camera to discern the roadway lines or edges. From these data, the vehicle's lateral position within the lane, lateral velocity, and heading can be computed (Houser et al., 2005). The objective of this technology is to warn the driver of unintended lane departures, unintended lane change/merge crashes, or possible rollover conditions if the vehicle deviates or is about to deviate outside the lane (FMCSA, 2011b). Figure 3 provides the LDW system architecture including major components (solid lines) and interfaces (dashed lines). The ECU collects data from the lane boundary sensor. Through the vehicle network (J1939), the ECU monitors the vehicle's turn signal status and engine power. The ECU outputs both a continuous visual system status and, as needed, a driver warning when a lane departure occurs.

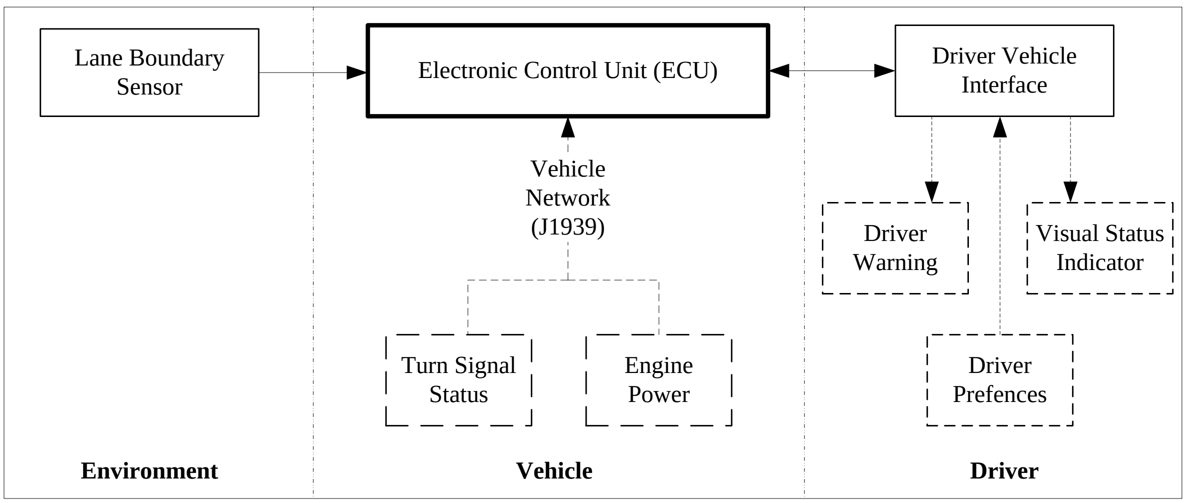


Figure 3. LDW System Architecture (Modified From Houser et al., 2005)

During a field test, Orban et al. (2006) found a 31- to 34-percent reduction in the driving conflicts that could result in single-vehicle roadway departures or rollovers for trucks equipped with LDW (Jermakian, 2010). Houser et al. (2005) provide driver-centered benefits that may be realized with the LDW:

- Assist the driver in consistently keeping a vehicle in the lane, thus reducing lane-departure crashes;
- Encourage turn signal usage when changing the lanes; and
- Reinforce the driver's awareness of maintaining a more central lane position and increase the driver's attentiveness to the driving task.

There are several limiting conditions in which the technology does not currently perform well. The first is lane detection problems from missing or degraded lane markings (including precipitation covering markings, and low visibility conditions from rain, fog, snow, and debris on the roadway or windshield. To work reliably, the system must detect the boundaries of the lane, usually indicated by single or double white or yellow markings that are solid, dashed, or dotted. The second is vehicle speed. Typically, these systems will not operate below a specific speed to reduce the occurrence of false alarms from normal low speed maneuvering. The final limiting condition is that most LDW become non-operational or have degraded performance in roadway junctions (FMCSA, 2011b).

Side Collision Warning System

Side collision warning systems (e.g., blind spot detection [BSD] and lane change assist) use sensors (i.e., radar, cameras, lasers, ultrasonic) mounted on the sides of the vehicle to monitor the lateral areas directly to either side of the CV, especially difficult-to-view areas called blind spots. This system is particularly helpful by assisting the driver in avoiding collisions during lane changes and merge situations (FMCSA, 2011c). ISO 17387:2008 provides system requirements for LCA. Instead of specifying functional components, ISO 17387:2008 requires that LCA operates according to a "system state" diagram (Figure 4). Once the activation criteria (e.g., ignition "on," manual switch or turn signal actuation, and vehicle speed) are met, the system transitions from "inactive" to "active" state. In the "active" state, the system will issue either a cautionary warning (i.e., "Warning Level 1") or an imminent warning (i.e., "Warning Level 2 and Above"), depending on the evaluation criteria (e.g., turn signal, steering input, lane position, and lateral clearance). Visvikis et al. (2008) state that the effectiveness of side collision warning systems can be limited by a number of factors such as road curvature, weather conditions, stationary objects along the roadway, and opposing traffic in the adjacent lane.

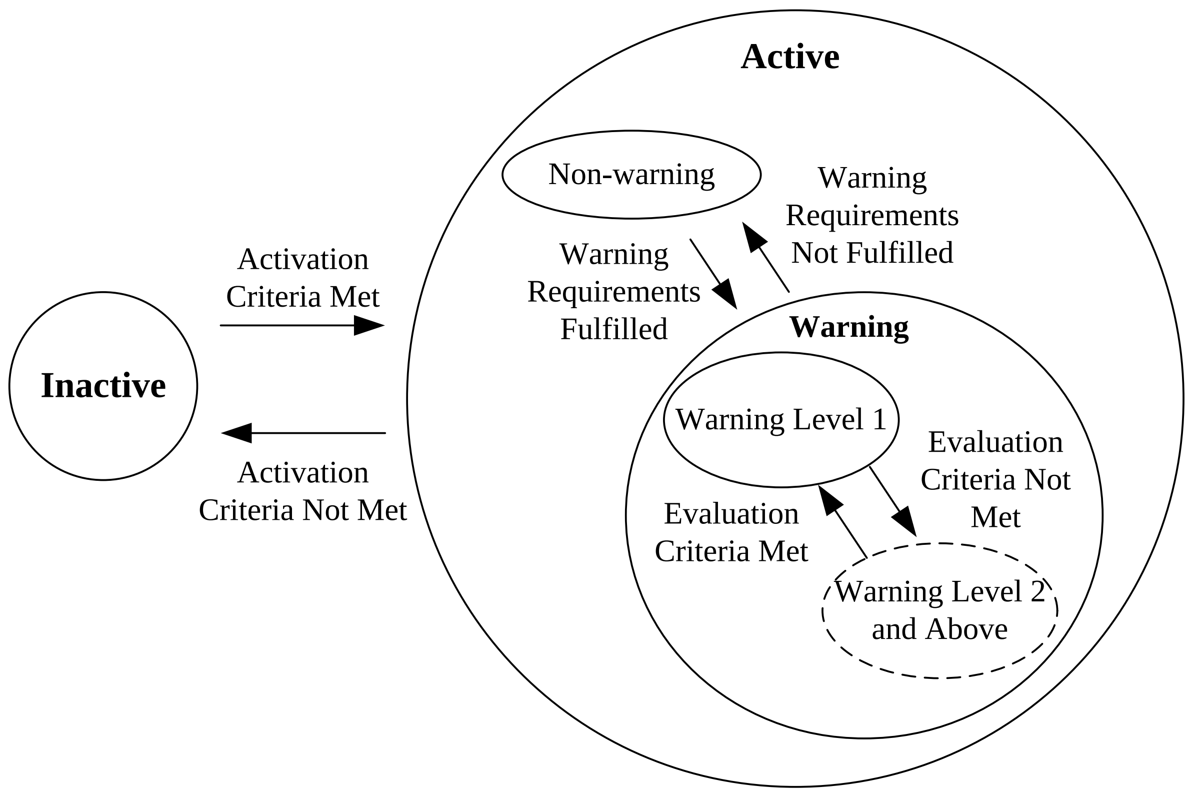


Figure 4. Side Collision Warning System Architecture (ISO 17387:2008)

COLLISION AVOIDANCE/WARNING SYSTEMS UNDER RESARCH FOR COMMERCIAL VEHICLES

Enhanced Rear Signaling

An analysis of two-vehicle crashes in 2000-2003 General Estimates System (GES) databases revealed that about 40 percent of those crashes involved heavy trucks being struck in the rear (Wassim & Smith, 2007). In 2006, there were approximately 23,500 rear-end crashes involving heavy trucks (i.e., GVWR greater than 10,000 pounds). Of these crashes, 135 resulted in fatalities and 1,603 resulted in incapacitating injuries (Trimble et al., 2009). In response, researchers have explored and developed enhanced rear signaling technology mounted on the vehicle's rear (such as the trailer for a tractor-trailer combination vehicle) to warn the following vehicle's driver of an impending collision; thus, reducing the potential for rear-end crashes.

For many years, research involving light vehicles has been ongoing regarding how to use rear lighting to help prevent rear-end crashes (Wierwille et al., 2003, 2005and 2009). More recently, rear-end crash avoidance research has shifted towards commercial trucking. During the first two phases of an FMCSA-funded research initiative, General Dynamics and Freese Enterprises were involved in the development of a prototype commercial vehicle ERS system that incorporated countermeasures generated from a GES database analysis of heavy-truck rear-end crashes (Freese & Freese, 2006; Pierowicz & Damon, 2004a; Pierowicz & Damon, 2004b). In 2009, Virginia Tech Transportation Institute was tasked with Phase III of this *Enhanced Rear Signaling for Commercial Vehicles* research.

The purpose of the Phase III effort was threefold: (1) conduct a GES database analysis using the most recent data available to report various break-outs/characterizations of rear-end truck crashes, (2) explore the benefits of the countermeasures developed in Phases I and II, and (3) develop a plan for a large-scale field operational test to assess countermeasures for rear-end truck crashes. Many different types of ERSs were investigated in this study across both the auditory and visual modalities. Visual warning signals were found to be the most beneficial at signaling following-vehicle drivers, more specifically, rear warning-light configurations. The research team recommended that the configuration shown in Figure 5 be implemented in an FOT based on its high performance and the potential success of future design implementation.

Figure 5. ERS Candidate System (Schaudt et al., 2010)

Integrated Vehicle-Based Safety Systems Program

An emerging trend with active safety systems is an integrated approach to crash warnings. Multiple sensor suites work in concert to keep vigilance on threats around the vehicle. Preliminary analyses by the DOT indicate that 58.7 percent (424,000) of police-reported, heavy-truck crashes can be addressed by the widespread deployment of integrated crash warning systems that address rear-end, roadway departure, and lane-change/merge collisions (Sayer et al., 2010). Sayer and his group also suggest that an integrated crash warning system, when compared with a non-integrated system, will provide improvements in threat assessment, warning accuracy, and system reliability, translating into reduced crashes and increased safety.

Recently, a cooperative agreement between the U.S. DOT and a team led by UMTRI explored potential safety benefits and driver acceptance associated with a prototype integrated crash-warning system. The goal of the IVBSS research was to develop a warning system that provided comprehensive, coordinated safety information to drivers to help prevent forward collision, lane change/merge, and road departure crashes for LVs and heavy commercial trucks (Lockheed Martin, 2010). The IVBSS prototype crash warning system integrated FCW, LDW, and side collision warning functionality.

The IVBSS CV program contained two phases. During Phase I, the system architecture was developed, the sensor suite was identified, human factors testing was conducted, and prototype DVI hardware was constructed to support the system evaluation. More importantly for this report, Phase I also included the development of functional requirements and system performance guidelines (LeBlanc, Nowak, Tang, Pomerleau, & Sardar, 2008). While these guidelines were developed specifically for the IVBSS program, they provide insight into preliminary guidelines for future CV safety applications. Phase II involved continued system refinement, creation of a test fleet equipped with the IVBSS system, extended pilot testing, an FOT, and analysis of FOT data (Sayer et al., 2010).

Although Sayer et al. (2010) presented a complete summary of the key findings, a subset that is pertinent for the current research is presented below. These findings are important for understanding what should be carried forward into future CV safety systems and how V2V communications might overcome challenges identified by the FOT results.

- Fifteen out of the 18 drivers stated they believed the integrated system will increase their driving safety. Drivers reported that the integrated system made them more aware of the traffic environment, particularly their position in the lane, and 7 drivers stated that the integrated system potentially helped them avoid a crash.

- If FCW systems are expected to properly discriminate between stopped vehicles and fixed roadside objects and overhead road structures, the development of location-based data sets that identify the locations at which repeated warnings are received with no driver response should be implemented.

- At least for the near future, performance of FCW systems that rely on autonomous, vehicle-based sensing will continue to be challenged with the reliable classification of stopped or fixed objects at the long ranges needed to provide sufficient time for CVs to avoid crashes. Virtually all of the FCWs in this field test were invalid, largely attributable to fixed roadside objects or overhead road structures that could be cataloged with repeated traversals where the driver did not respond to the initial warnings.

- The algorithm used in the lane change/merge subsystem for detecting vehicles adjacent to the trailer of the tractor-trailer combination had difficulty discriminating returns from the trailer and adjacent objects when the tractor was towing a double trailer. This may be due to swaying of the towed trailers or the metal converter dolly on which the second trailer rides. Additional testing of the trailer reflection algorithms should be evaluated, specifically with the double-trailer configuration. The challenge here is inherent to the nature of the radar and the tractor-only solution. In the future, a different type of radar or a different sensor suite design might be considered to address this challenge.

- For an integrated system, addressing multiple, simultaneous or near-simultaneous threats, might not be as critical as once thought. Multiple-threat scenarios are rare to begin with. When they did occur, drivers responded to the first warning presented, and their responses were appropriate for the indicated threat. For this commercial truck application with professional drivers, the effort and cost associated with the process of arbitrating warnings may not be justified.

COMMERCIAL VEHICLE SAFETY COMMUNICATION INITIATIVE

For nearly two decades, the government, researchers, and vehicle manufacturers have been working on a concept, similar to the connectivity afforded by the Internet, which will wirelessly link the entire transportation system (e.g., vehicles, roadside infrastructure, and mobile handheld devices). Although this concept has had a variety of names, the current initiative is referred to as vehicle safety communication (VSC). Simply put, VSC is connectivity (Cronin, 2010):

- With and between vehicles (of all modes);
- Between vehicles and infrastructure (i.e., roadside and centers); and
- Between vehicles, infrastructure, and travelers (i.e., wireless consumer devices).

The VSC core system will support a variety of data communications-based applications to provide safety, mobility, and environmental services to both mobile and non-mobile users (Lockheed Martin, 2010). Figure 6 depicts the overlapping domains of the VSC core system with vehicles, roadside infrastructure, traffic centers, and travelers.

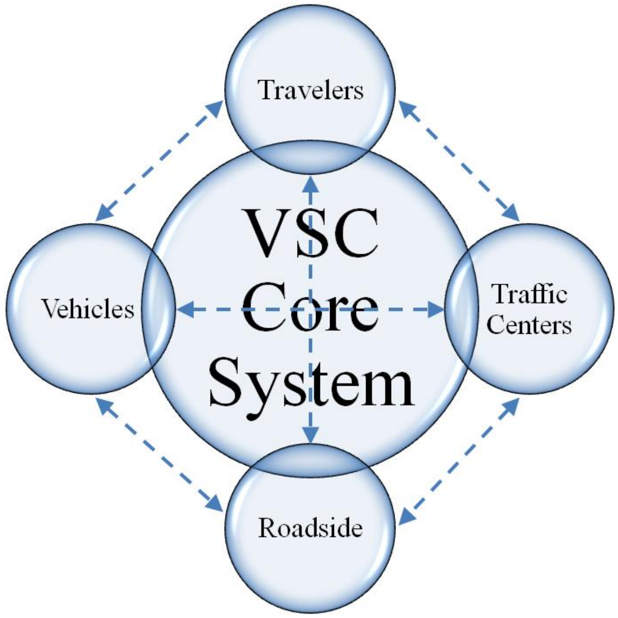


Figure 6. VSC Connectivity

From a safety perspective, the VCS concept aims to increase driver situational awareness and reduce or eliminate crashes through the wireless communication of cooperative data sets that allow for determination of adjacent-vehicle intentions and vehicle trace histories. From a mobility perspective, the VCS concept will tie together traffic control devices, vehicles, transit, parking, and weather to optimize traffic flow and minimize congestion. From an environmental perspective, the VCS concept seeks to capitalize on the optimized traffic flow and reduced congestion to decrease vehicle emissions and lower fuel consumption.

One transportation sector that holds promise for early implementation of this technology is commercial trucking. Commercial trucks have, for many years, incorporated advanced communication systems (i.e., satellite and wireless communications), tracking (i.e., GPS), and vehicle safety systems (i.e., radar). Commercial trucking also provides a practical mode of transportation with a manageable population of vehicles with a high ratio of number of miles driven per vehicle as compared to light vehicles driven by the general public. For these reasons, implementation of a V2V system within commercial trucking appears to be promising.

On April 21, 2010, there was a CV Stakeholder Workshop in San Antonio, Texas. This meeting was conducted as a collaboration between U.S. DOT, the American Transportation Research Institute, and the Trucking Industry Mobility and Technology Coalition. Complete details of the meeting can be found on TIMTC's truck Web site at www.freightmobility.com/TruckIntellidriveWorkshop.html.

As part of this CV safety workshop, five breakout discussion groups were formed to answer questions on the issues and concerns related to V2V and V2I safety. For this report, the key questions were:

- What applications of technologies do you think would be most useful to improve commercial vehicle safety?

The key technologies mentioned were blind spot detection (four of the five groups), LDW (four of five groups), and FCW with sufficient forward range (three of the five groups). Other technologies mentioned include:

  - Air disc brakes,
  - Stability control,
  - Driver monitor technologies (e.g., drowsiness, electronic onboard recorder),
  - Driver control (e.g., speed limiting),
  - Identification of vehicle and driver (e.g., e-screening), and
  - High-accuracy geographic information system (GIS) mapping (e.g., intersections, curves).

- What are the benefits of adoption of vehicle communications technology in CVs?

  For the groups that responded, the benefits included increased safety, security, productivity, positive ROI, and increased fuel economy.

- What are the barriers to the adoption of vehicle communications technology in CVs?

  For the groups that responded, the barriers included costs, acceptable ROI, standardization, and integration issues.

COMMERCIAL VEHICLE CRASH SCENARIO FRAMEWORK

Recently, Volpe completed an analysis of various pre-crash scenarios to identify intervention opportunities for crash avoidance systems that use short- to medium-range V2V communications. Based on data from the 2005-2008 GES crash databases, V2V crash avoidance systems could potentially address approximately 267,000 police-reported heavy-truck crashes per year, with a 95-percent confidence interval of 228,000 to 306,000 (Toma, Swanson, Smith, & Najm, in review). In the review of crash typologies, Volpe identified 22 pre-crash scenarios applicable to V2V-based crash avoidance countermeasures. Of these, four (i.e., control loss, backing, parking, and other) were removed from further analysis since these scenarios might be more efficiently addressed by autonomous vehicle-based crash avoidance systems or because the V2V data will serve more as input to an advisory system than as a crash-imminent warning system (Toma, Swanson, Smith, & Najm, in review). Figure 1 lists the 17 target V2V pre-crash scenarios that have been categorized into six groups based on vehicle movements and orientations prior to the onset of the crash critical event. Because of the similarities in pre-crash characteristics, these groups were used as the base unit for preliminary performance requirements. The following section provides a summary description of each pre-crash scenario based on the findings in the Toma et al. (2010) report.

CRASH TYPES

Rear-end Group

Based on Volpe's analysis of 2005-2008 GES databases, there were 69,326 rear-end crashes with the heavy truck as the striking vehicle (Toma, Swanson, Smith, & Najm, in review). Table 6 provides a listing of the actual counts and percentages of each rear-end crash scenario.

Table 6. Rear-End Pre-Crash Scenarios Involving Heavy Trucks 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
Rear-end/lead vehicle stopped	31,598	45.6
Rear-end/lead vehicle decelerating	17,568	25.3
Rear-end/lead vehicle moving	14,251	20.6
Rear-end/striking maneuver	4,687	6.8
Rear-end/lead vehicle accelerating	1,222	1.8
Total	69,326	100.0

Rear-End/Lead Vehicle Stopped

This crash scenario involves a subject vehicle that is traveling straight, and then closes in on a stopped lead vehicle (Figure 7).

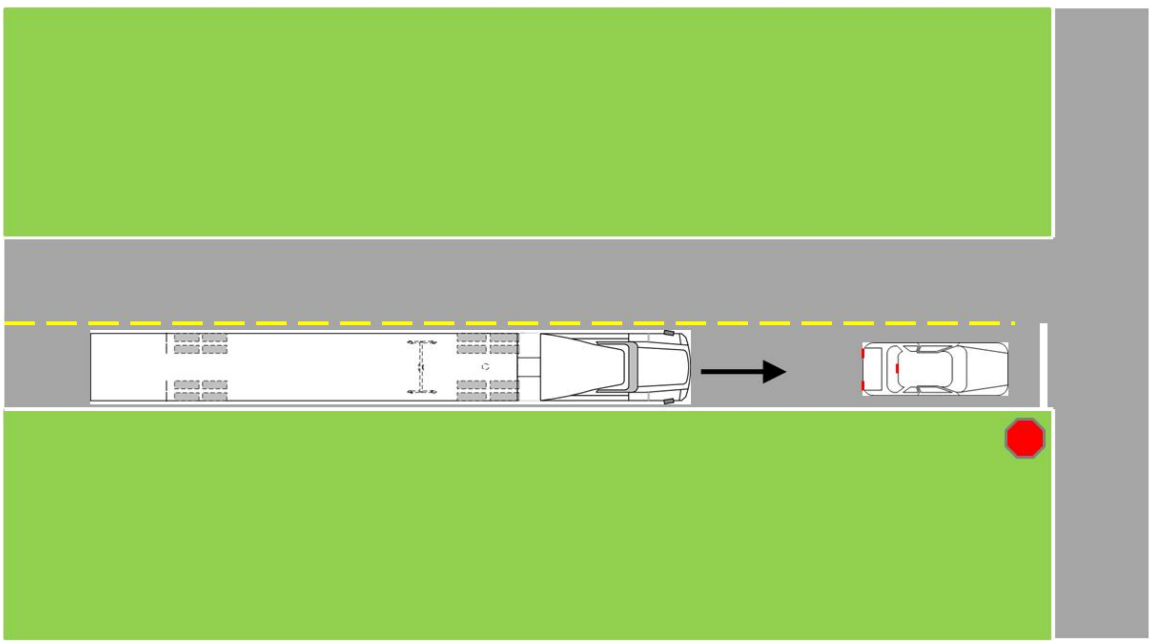


Figure 7. Rear-End/Lead Vehicle Stopped Crash Type

The majority of these crashes occur in the daylight (87.4%) on straight, dry roadways with no adverse weather (75.2%). The driver typically attempted to brake (42.2%) or brake and swerve to the left or right (5.3%). Often, the subject-vehicle driver made errors in judgment by assuming that the lead vehicle would continue to proceed (16.6%) and, thus, did not realize caution was needed (45.6%); therefore, traveled too fast for the conditions.

Rear-End/Lead Vehicle Decelerating

This crash scenario involves a subject vehicle traveling straight and following a lead vehicle, and then the lead vehicle sharply decelerates (Figure 8).

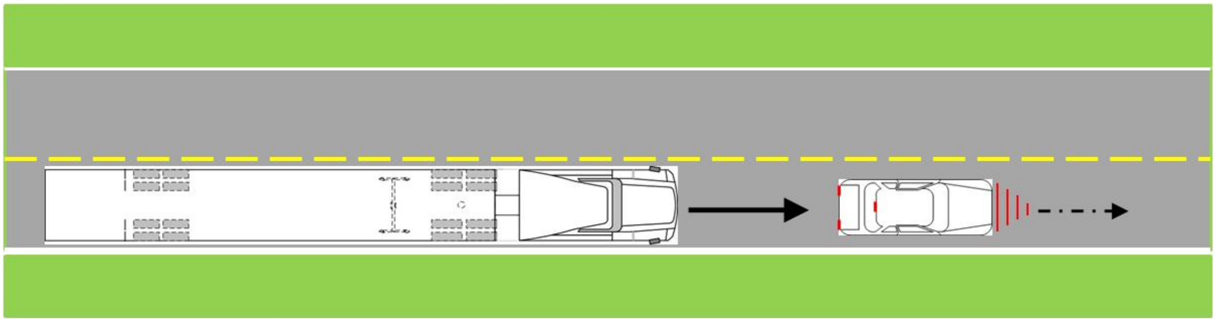


Figure 8. Rear-End/Lead Vehicle Decelerating Crash Type

The majority of these crashes occur in the daylight (88.5%) on straight, dry roadways with no adverse weather (72.9%). The driver typically attempted to brake (44.6%) or brake and swerve to the left (5.9%) or right (10.5%). Frequently, the subject-vehicle driver didn't realize the lead vehicle was so close (30.4%) and failed to look far enough ahead (32.6%). Typically, the subject vehicle was speeding (36.2%) and the driver was distracted (51.3%).

Rear-End/Lead Vehicle Moving at Slower Constant Speed

This crash scenario involves a subject vehicle that is going straight and then closes in on a lead vehicle moving at a slower constant speed (Figure 9).

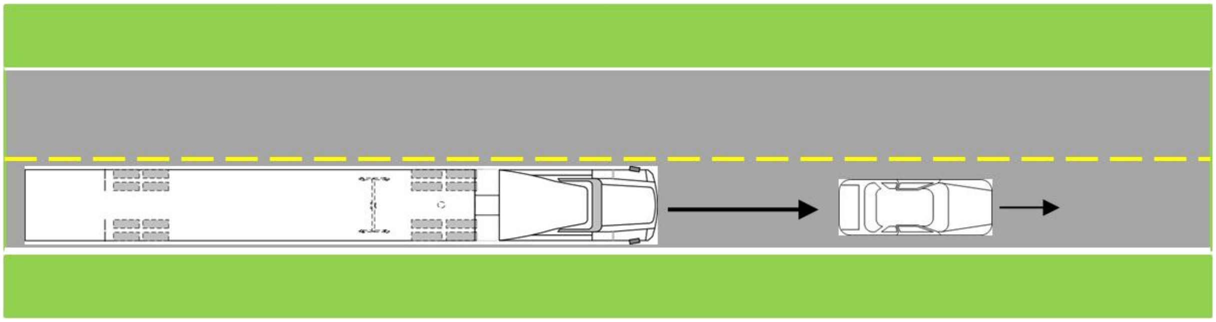


Figure 9. Rear-End/Lead Vehicle Moving at Slower Constant Speed Crash Type

The majority of these crashes occur in the daylight (67%) on straight, dry roadways with no adverse weather (77.8%). The driver typically attempted to brake (55.5%) or brake and swerve to the left (2.2%) or right (6.1%). As in the *lead vehicle decelerating* scenario, the subject-vehicle driver frequently didn't realize the lead vehicle was so close (31.3%) and failed to look far enough ahead (29.9%). Similar to the *lead vehicle stopped* scenario, the subject-vehicle driver did not realize caution was needed (27.2%).

Rear-End/Striking Maneuver

This crash scenario involves a subject vehicle that is changing lanes or passing, and then closes in on a lead vehicle (Figure 10).

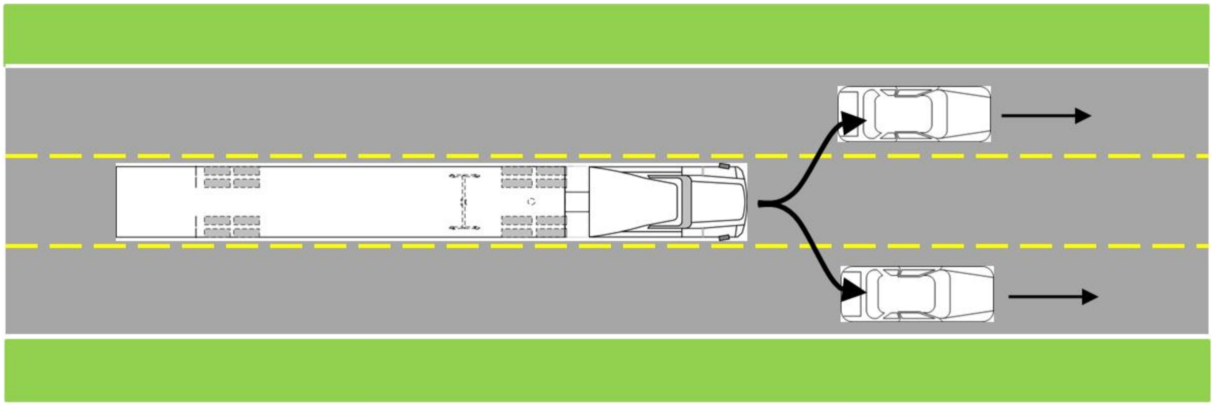


Figure 10. Rear-End/Striking Maneuver Crash Type

The majority of these crashes occur in the daylight (81.8%) on straight, dry roadways with no adverse weather (69.5%). The driver attempted to brake (12.9%), brake and swerve to the left (7.8%) or right (4.2%), or just steer to the left (2.3%) or right (5.5%). The subject-vehicle driver often reported some form of distraction (64.6%) prior to the crash.

Rear-End/Lead Vehicle Accelerating

This crash scenario involves a subject vehicle that is proceeding straight and then closes in on an accelerating lead vehicle (Figure 11).

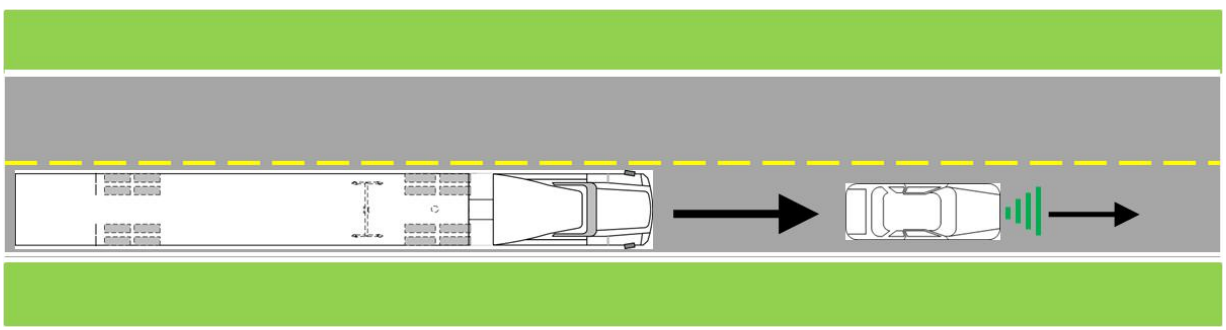


Figure 11. Rear-End/Lead Vehicle Accelerating Crash Type

The majority of these crashes occur in the daylight (89.1%) on straight, dry roadways with no adverse weather (79.7%). The driver typically attempted to steer to the left (57.1%), or brake and swerve to the left (2.2%) or right (6.1%). As with other rear-end scenarios, the subject-vehicle driver frequently didn’t realize the lead vehicle was so close (41.2%) and failed to look far enough ahead (59.3%).

Lane Change Group

Volpe’s analysis found that there were 98,315 lane change crashes with the heavy truck as the striking vehicle (Toma, Swanson, Smith, & Najm, in review). Table 7 provides a listing of the actual counts and percentages of each lane change pre-crash scenario.

Table 7. Lane Change Pre-Crash Scenarios Involving Heavy Trucks 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
Changing lanes/same direction	50,690	51.6
Turning/same direction	27,922	28.4
Drifting/same direction	19,703	20.0
Total	98,315	100.0

Changing Lanes/Same Direction

This crash scenario involves a subject vehicle changing lanes, and then encroaching into another vehicle traveling in the same direction (Figure 12).

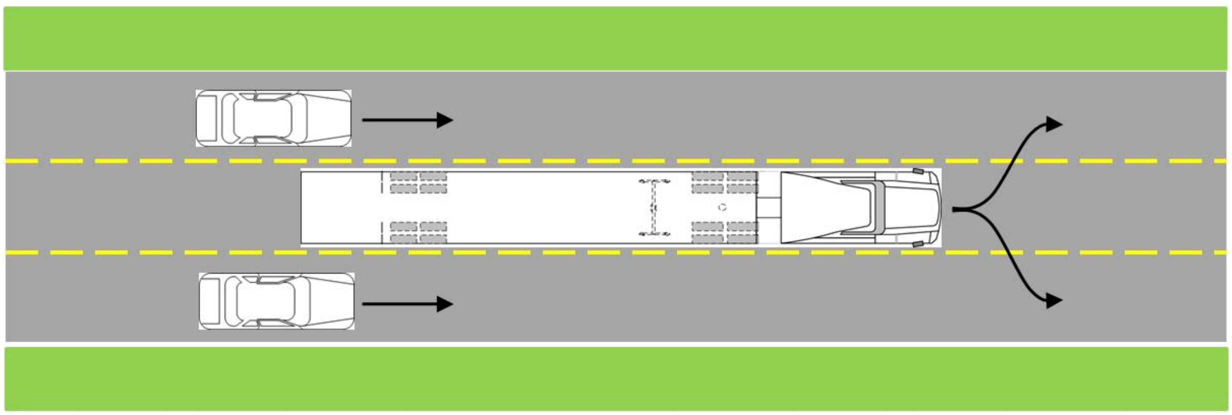


Figure 12. Changing Lanes/Same Direction Crash Type

The majority of these crashes occur in the daylight (79.9%) on straight, dry roadways with no adverse weather (78.4%). Most often, the driver attempted to steer right (10.4%). Often, the subject-vehicle driver made errors in judgment and assumed that the other vehicle's driver would yield right-of-way (24.4%), or the subject-vehicle driver misjudged the gap distance. When inadequate surveillance was cited, the subject-vehicle driver most often failed to look to the rear using mirrors prior to the lane transition (22.4%).

Turning/Same Direction

This crash scenario involves a subject vehicle turning left at an intersection, and then cuts across the path of another vehicle initially traveling in the same direction (Figure 13).

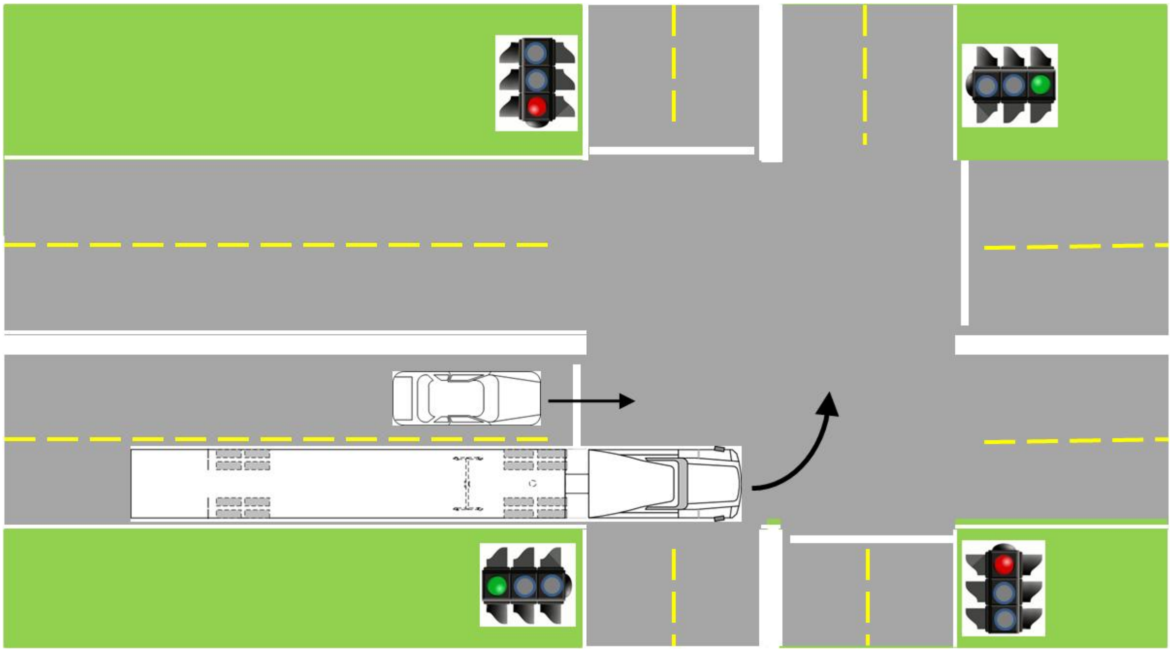


Figure 13. Turning/Same Direction Crash Type

The majority of these crashes occur in the daylight (86.4%) on straight, dry roadways with no adverse weather (80.4%). Inattention was often cited (37.5%). Interestingly, the driver was sometimes engaged in conversation on the CB radio (21.8%) and failed to look to the rear using mirrors (21.8%).

Drifting/Same Direction

This crash scenario involves a subject vehicle that is proceeding straight, and then drifts into an adjacent vehicle traveling in the same direction (Figure 14).

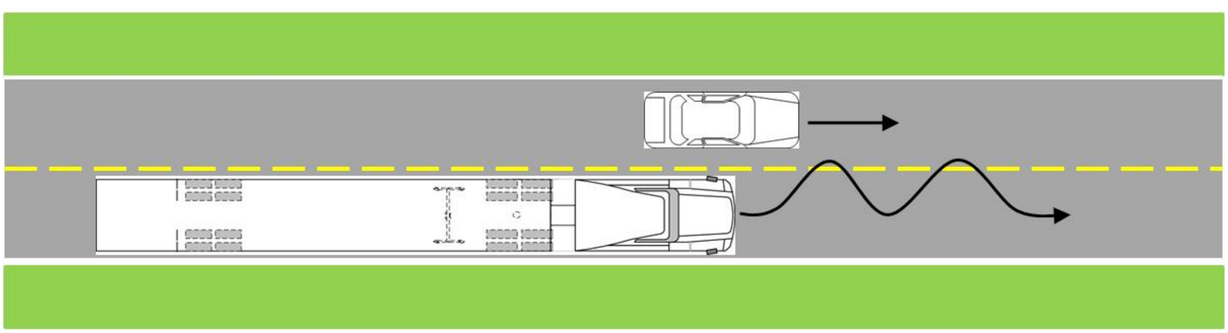


Figure 14. Drifting/Same Direction Crash Type

The majority of these crashes occur in the daylight (76.7%) on straight, dry roadways with no adverse weather (68.2%). When inadequate surveillance was cited, the driver often failed to look to the side (22.4%), or looked but did not see (39.1%) the adjacent traffic.

Opposite Direction Group

Volpe reported that there were 14,330 opposite direction, or head-on, crashes with the heavy trucks as the striking vehicles (Toma, Swanson, Smith, & Najm, in review). Table 8 provides a listing of the actual counts and percentages of each opposite direction pre-crash scenario.

Table 8. Opposite Direction Pre-Crash Scenarios Involving Heavy Trucks 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
Opposite direction/no maneuver	13,352	93.2
Opposite direction/maneuver	978	6.8
Total	14,330	100.0

Opposite Direction/No Maneuver

This crash scenario involves a subject vehicle that is traveling straight, and then drifts and encroaches into another vehicle traveling in the opposite direction (Figure 15).

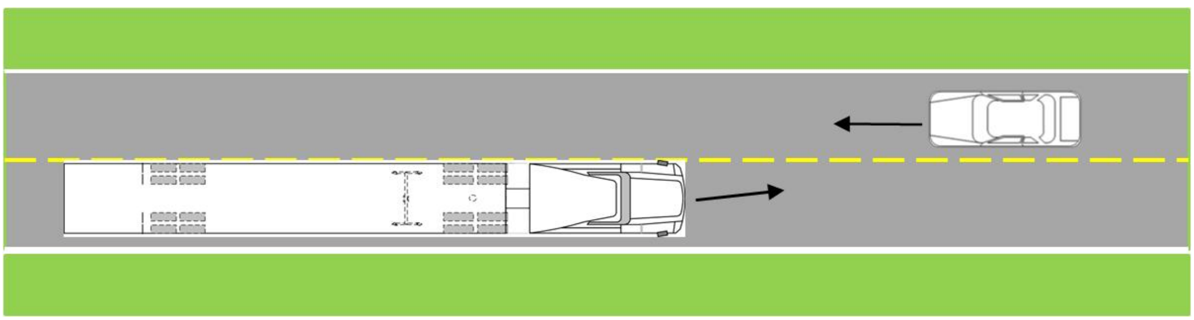


Figure 15. Opposite Direction/No Maneuver Crash Type

The majority of these crashes occur in the daylight (80.3%) on either curved (38.6%) or straight (38.1%), dry roadways with no adverse weather. The driver typically attempted to steer right (54.8%). Driver fatigue is often cited as a contributing factor (62.8%).

Opposite Direction/Maneuver

This crash scenario involves a subject vehicle that is passing another vehicle, and encroaches into another vehicle traveling in the opposite direction (Figure 16).

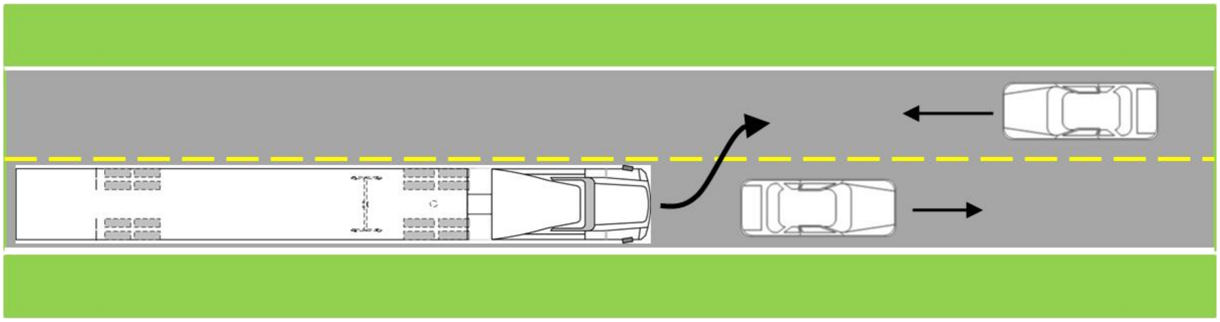


Figure 16. Opposite Direction/Maneuver Crash Type.

The majority of these crashes occur in the daylight (79.8%) on straight, dry roadways with no adverse weather (62.4%). Most often, the driver attempted to either steer right (55.9%) or left (40.9%). Inadequate evasive action is often (58.5%) cited as a contributing factor in this crash type.

Left Turn Across Path/Opposite Direction (LTAP/OD) Group

Based on Volpe's analysis of 2005-2008 GES databases, there were 10,687 LTAP/OD crashes with the heavy truck as the striking vehicle (Toma, Swanson, Smith, & Najm, in review). Table 9 provides a listing of the actual counts and percentages of each LTAP/OD pre-crash scenario.

Table 9. LTAP/OD Pre-Crash Scenarios Involving Heavy Trucks 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
LTAP/OD at non-signal	5,257	49.2
LTAP/OD at signal	5,430	50.8
Total	10,687	100.0

LTAP/OD at Non-Signal

This crash scenario involves a subject vehicle that is turning left at an intersection without traffic controls, and then cuts across the path of another vehicle crossing from an opposite direction (Figure 17).

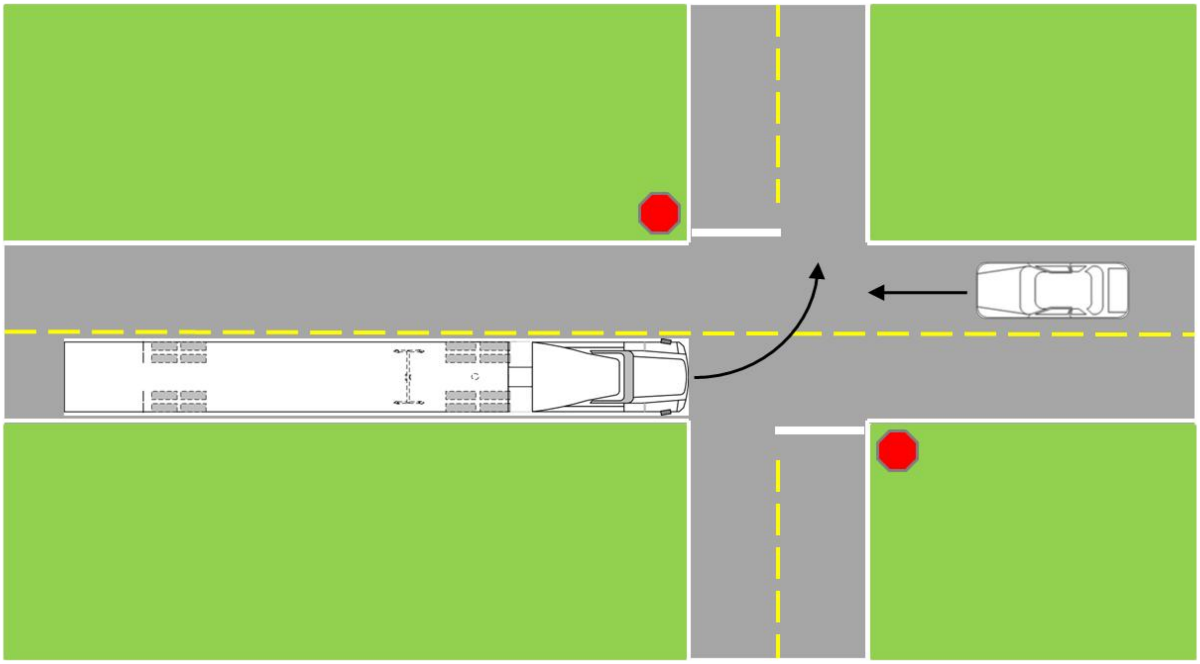


Figure 17. LTAP/OD at Non-Signal Crash Type

The majority of these crashes occur in the daylight (82.0%) on straight, dry roadways with no adverse weather (75.1%). The driver of the vehicle turning left either made errors in judgment by assuming that the other vehicle's driver would yield right-of-way (34.0%), misjudged the velocity of the approaching vehicle (21.7%), or misjudged both the gap and velocity of the approaching vehicle (36.0%). The driver of the approaching vehicle often attempted to avoid the crash with a braking action (64.2%).

LTAP/OD at Signal

This crash scenario involves a subject vehicle that is turning left at a signalized intersection, and then cuts across the path of another vehicle crossing from an opposite direction (Figure 18).

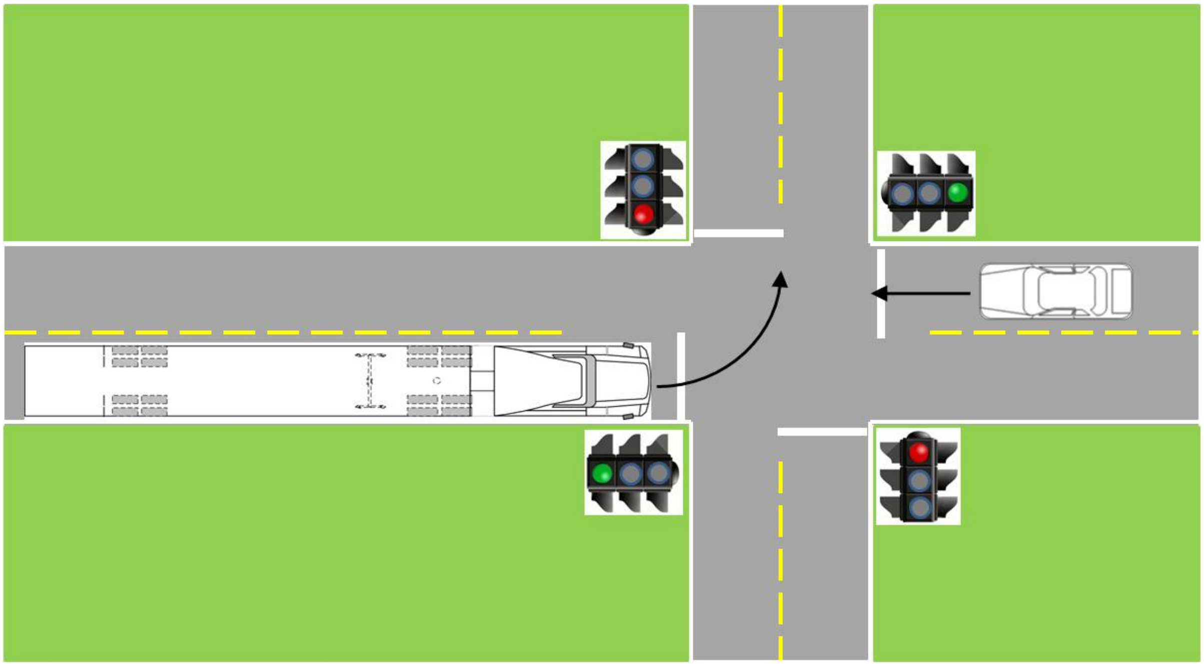


Figure 18. LTAP/OD at Signal Crash Type

The majority of these crashes occur in the daylight (78.0%) on straight, dry roadways with no adverse weather (76.4%). When inadequate surveillance was cited, the driver of the turning vehicle often failed to look far enough ahead (35.1%) or failed to look to the side (31.7%). The driver of the approaching vehicle often attempted to avoid the crash with a braking action (45.9%).

Junction Crossing Group

Volpe's analysis of 2005-2008 GES databases found 29,533 junction crossing crashes involving heavy trucks (Toma, Swanson, Smith, & Najm, in review). Table 10 provides a listing of the actual counts and percentages of each lane change pre-crash scenario.

Table 10. Junction Crossing Pre-Crash Scenarios Involving Heavy Trucks (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
SCP at non-signal	22,452	76.0
Turn at non-signal	4,299	14.6
Turn right at signal	2,782	9.4
Total	29,533	100.0

SCP at Non-Signal

This crash scenario involves a subject vehicle stopping at a road junction, and then proceeding against lateral crossing traffic (Figure 19).

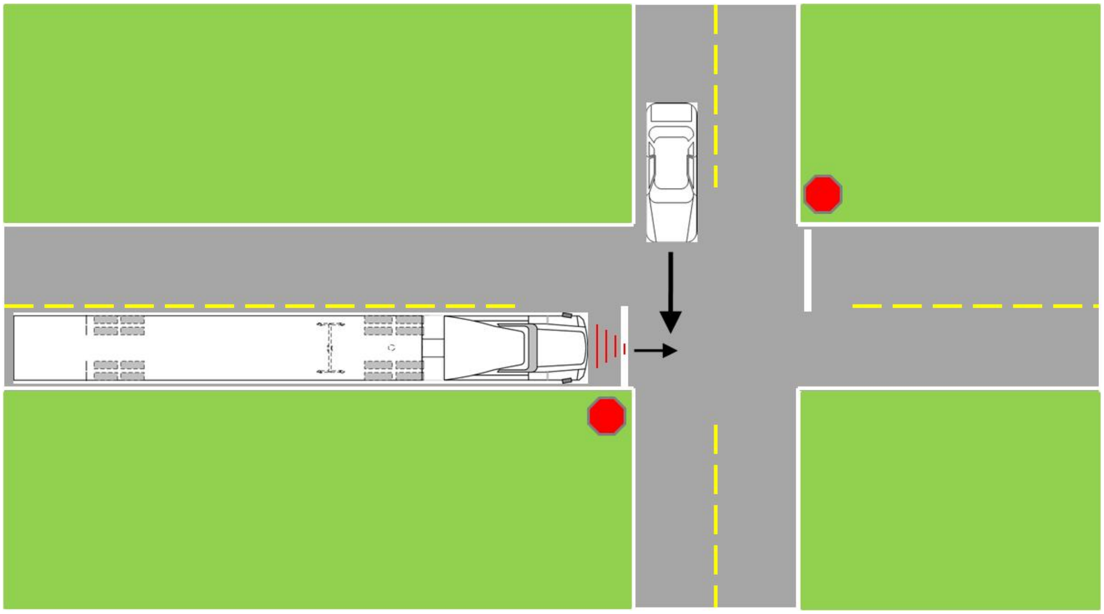


Figure 19. SCP at Non-Signal Crash Type

The majority of these crashes occur in the daylight (83.7%) on straight, dry roadways with no adverse weather (78.2%). It is common for these crashes to occur at an intersection with a stop sign (47.8%), but they also occur at driveways, alleys without traffic controls (24.5%), or intersections without traffic controls (10.9%). The driver of the subject vehicle made errors in judgment and assumed that the other vehicle driver would yield right-of-way (20.5%).

Turn at Non-Signal

This crash scenario involves a subject vehicle that stops at a road junction and then proceeds to turn left against lateral crossing traffic (Figure 20).

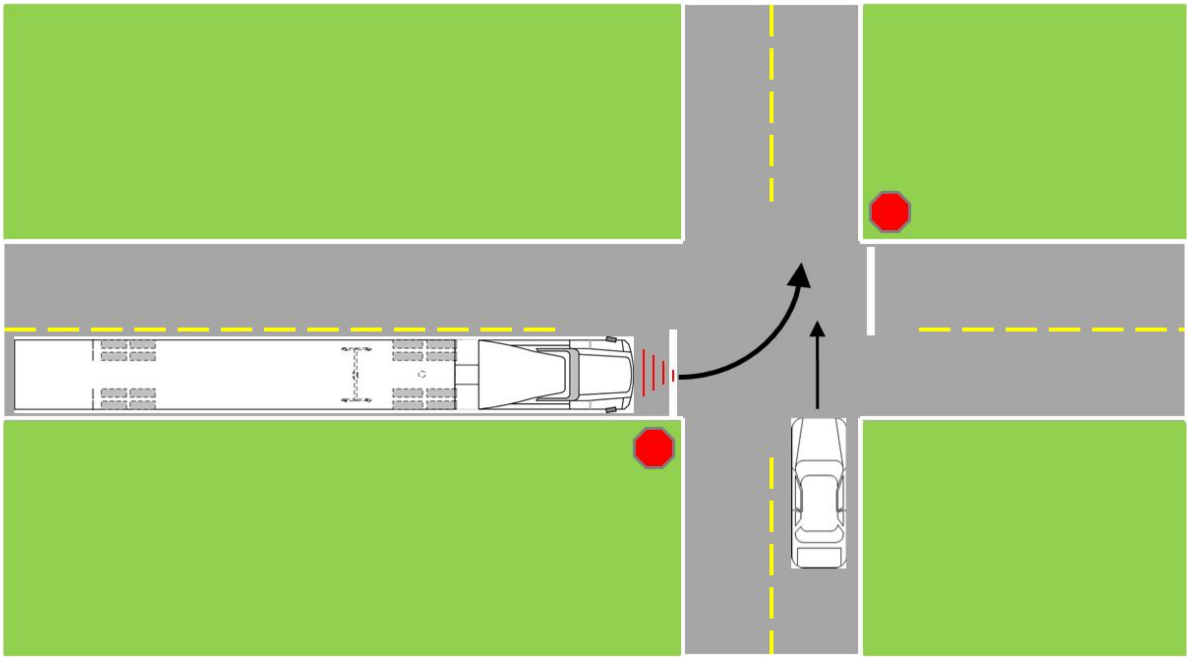


Figure 20. Turn at Non-Signal Crash Type

The majority of these crashes occur in the daylight (81.9%) on straight, dry roadways with no adverse weather (78.0%). It is common for these crashes to occur at an intersection without traffic controls (27.3%), but they also occur at intersections with stop signs (23.3%) or driveways and alleys without traffic controls (21.9%).

Turn Right at Signal

This crash scenario involves a subject vehicle that stops at a signalized intersection and then proceeds to turn right into the path of another vehicle crossing laterally from the subject vehicle's initial stop position (Figure 21).

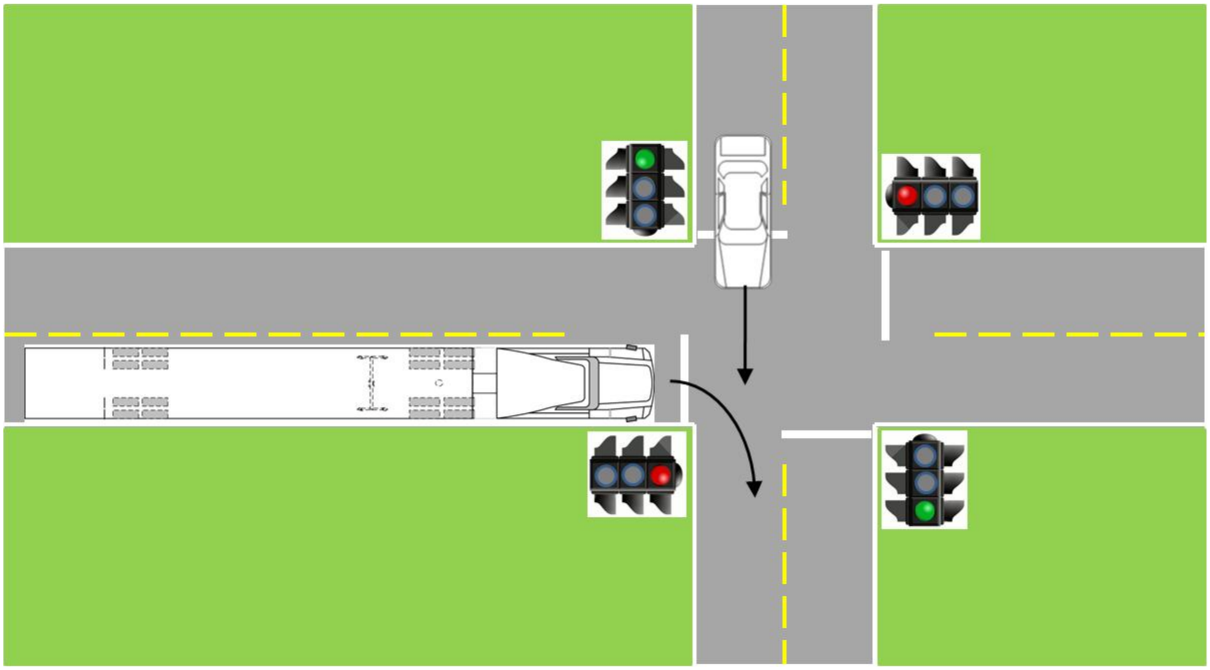


Figure 21. Right Turn at Signal Crash Type

The majority of these crashes occur in the daylight (79.6%) on straight, dry roadways with no adverse weather (83.9%). It is common for these crashes to occur at an intersection with a tri-color traffic signal (93.0%).

Traffic Control Device (TCD) Violation Group

Based on Volpe's analysis of 2005-2008 GES databases, there were 10,845 TCD Violation crashes with the heavy truck as the striking vehicle (Toma, Swanson, Smith, & Najm, in review). Table 11 provides a listing of the actual counts and percentages of each TCD violation pre-crash scenario.

Table 11. TCD Violation Pre-Crash Scenarios Involving Heavy Trucks 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Count	Percent
Running red light	9,404	86.7
Running stop sign	1,441	13.3
Total	10,845	100.0

Running Red Light

This crash scenario involves a subject vehicle proceeding through a red light, traveling straight through the intersection, and colliding with another straight-crossing vehicle from a lateral direction (Figure 22).

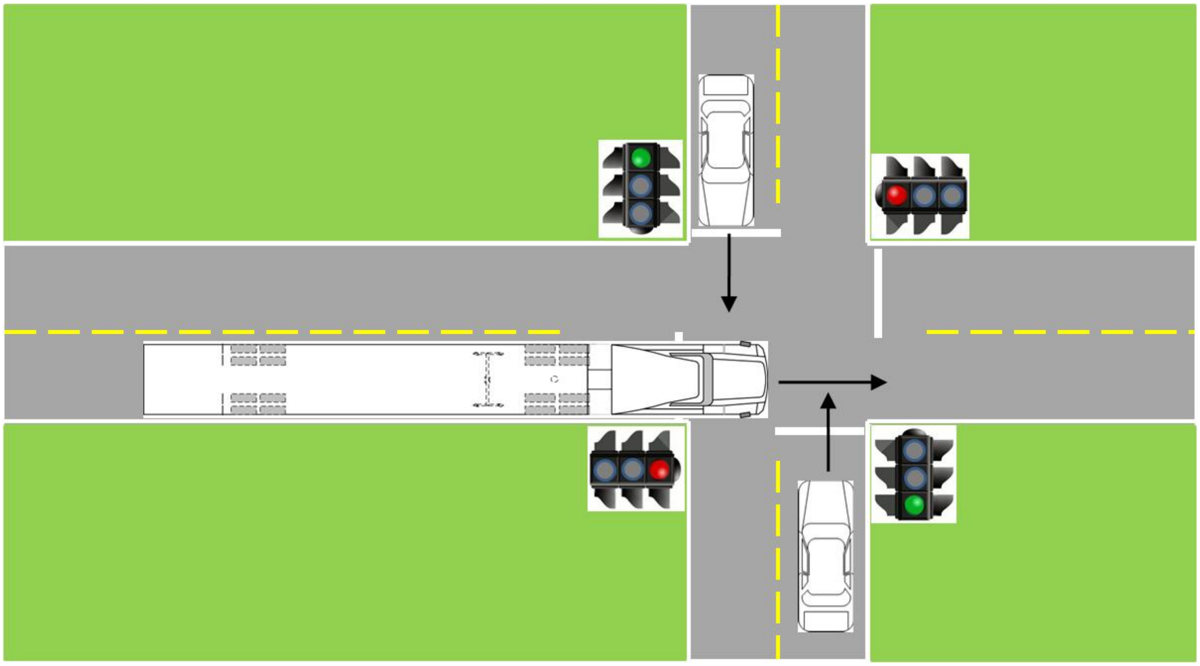


Figure 22. Running Red Light Crash Type

The majority of these crashes occur in the daylight (80.5%) on straight, dry roadways with no adverse weather (73.0%). Frequently, these crashes occur at an intersection with a tri-color traffic signal (92.8%). Distraction (46.4%), inadequate surveillance (40.6%), and inattention (30.6%) are commonly cited in these crashes.

Running Stop Sign

This crash scenario involves a subject vehicle proceeding through a stop sign at an intersection and colliding with another straight-crossing vehicle from a lateral direction (Figure 23).

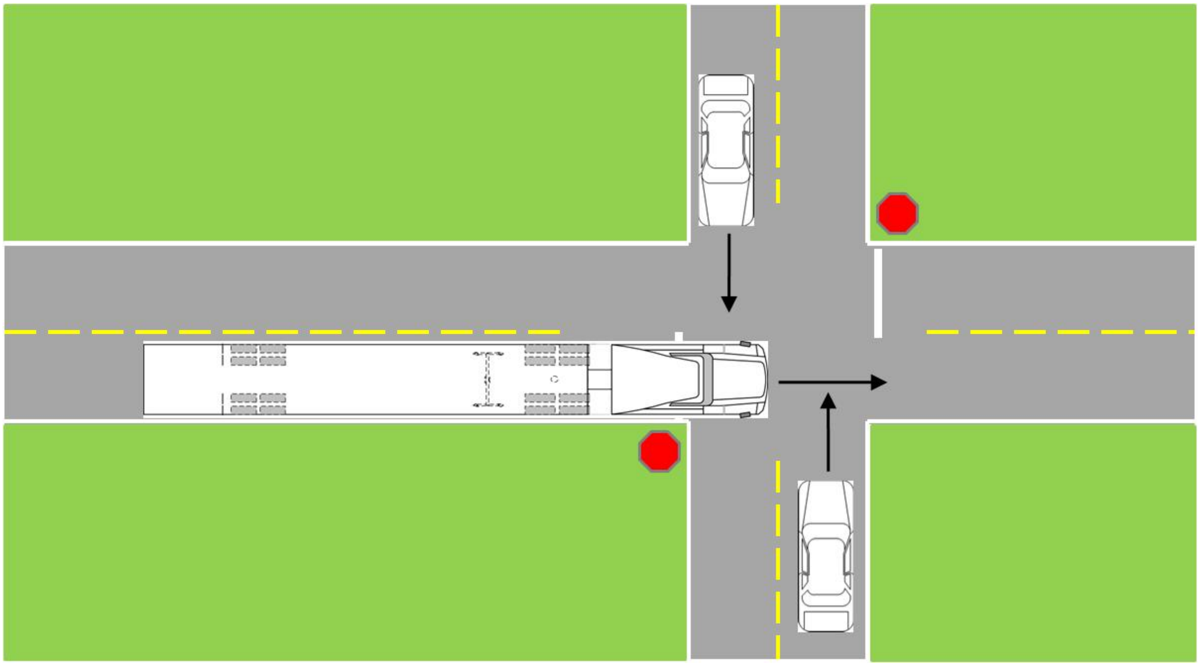


Figure 23. Running Stop Sign Crash Type

The majority of these crashes occur in the daylight (86.6%) on straight, dry roadways with no adverse weather (75.3%). As expected, these crashes occur at an intersection with a stop sign (98.1%). Distraction (49.4%), inadequate surveillance (49.5%), and driver fatigue (47.2%) are commonly cited in these crashes.

CHAPTER 4. PERFORMANCE GUIDELINES DEVELOPMENT

The success of future CV safety systems is dependent on the clear requirements to meet the needs identified by both crash database analyses and the prescribed concept of operations (Lockheed Martin, 2010). According to the systems engineering standard Electronic Industries Alliance (EIA) 632, a "requirement" is defined as "something that governs what, how well, and under what conditions a product will achieve a given purpose" (FHWA, 2010). As the connected vehicle program progresses from concept to execution, decision-makers will be developing a system architecture showing all components and interfaces and identifying how security processes will ensure the integrity of the system and protect the privacy of its users. To develop this system architecture, system requirements (i.e., functional and performance) for V2V safety applications need to be defined. A functional requirement is defined as the necessary task, action, or activity that must be accomplished (that is, what needs to be done). Performance requirements are defined as the extent to which a function must be executed (that is, how well it has to be done) (Systems Engineering, 2010). The goal of this task is to synthesize all the input from the CV Industry Outreach and the Literature Review to establish both high-level functional and performance requirements for the crash avoidance technologies that map to real-world crash scenarios. Future safety-system developers can use these high-level requirements to derive more technically specific requirements for their individual systems.

The requirements should be considered preliminary because they were derived from existing requirements for various safety systems and formulated to meet the needs identified. This section describes the preliminary performance requirements from the literature synthesis as well as implementation and end-user considerations from the vehicle industry outreach.

GENERAL FUNCTIONAL CONSIDERATIONS FROM INDUSTRY OUTREACH

The results of the industry outreach were used to formulate functional considerations when developing future CV crash avoidance technology. This section will first discuss the CV fleets' experiences with current crash avoidance technologies as well as their expectations regarding V2V safety applications. Next, the discussion with OEMs and suppliers will be presented on the implementation considerations with current crash avoidance technologies as well as future V2V safety applications.

Current Crash Avoidance Technology Usage in Commercial Fleets

Return-on-Investment

An issue raised by several of the fleets was ROI. Crash avoidance technologies can be expensive and fleets must justify their purchase cost. Fleets want to be sure that the technologies they invest in will reduce crashes and last long enough to pay for themselves. Some of the issues with ROI described by fleets include the cost of the technology, the problem size (i.e., lane departure, rear end collision) the technology is meant to prevent, 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. Yet, after 4 years of use, the company changed their model of tractor and couldn't transfer the technology to the new tractors. The benefit from the technology was greatly reduced; what they expected to be a 10-year investment only worked for 4 years.

One fleet participant had a suggestion for addressing some of the ROI issues. He said that he wants a plug-and-play box that could be placed into a truck so that if a carrier decided to switch technologies, the new technology could be plugged in and the truck could accommodate it.

Installation

Several fleet participants described installation as an implementation issue with new technology. Having technology installed by the OEM was viewed as more efficient and less costly than trying to retrofit a tractor with new technology. For example, one fleet participant described how bringing equipment in from the road and having to touch it again to install new technology is an expense as it creates down time. He said, "It is easier to put the technology in once and be done."

Maintenance

Maintenance of crash avoidance systems was an issue raised in the interviews. Crash avoidance systems are only useful if they are maintained and it is important for drivers to understand that, if the system gets damaged, they will need to take the truck in for repairs. 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.

System Adjustability

Fleet participants described how they are sometimes frustrated by the inability to program or adjust their crash avoidance systems to perform in-line with their company policies and procedures. For example, one fleet participant described how they train their drivers to stay at least 7 seconds back 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, one fleet participant described how his company is able to program their crash avoidance system. While the system is not adjustable by the driver, management can set the system parameters that are based on speed. For example, the participant described how, at lower speeds, it is acceptable to have the following distance be set to a shorter distance than would be acceptable for medium or freeway speeds. A few participants mentioned that they do not want their drivers having the ability to adjust or shut down a crash avoidance system. As one participant said regarding system adjustment, "There are some systems where the driver can just simply turn it off, and my feeling is that if it's a safety system, you don't pick and choose when you want to be safe or not. It's there, it's always on, and it's a part of their everyday operation."

A few interview participants also had comments regarding the volume adjustability of alerts. For example, a fleet participant mentioned that they allow their drivers to turn down the volume of alerts to a certain minimum level that allows the co-driver to sleep. As one participant said, "we don't want it so loud that it wakes up the driver trying to sleep." Yet another participant said that when they tested their LDW system with their team units, the team partner sleeping in the bunk liked hearing the alerts because it alerted the resting team member that his driving team partner was becoming tired.

System Reliability

Fleet participants described that the reliability of a crash avoidance system is important for drivers to maintain their trust in the system and not become desensitized to it and ignore alerts. For example, a participant mentioned that LDW systems are too sensitive in some circumstances; they tend to go off more in construction zones where lane lines may be messy and in snowy conditions where the system can pick up tracks in the snow. Another participant described how they get a high percentage of false alarms from their crash avoidance system every time the truck goes under an overpass. Yet, as one participant said, "It picks up the bridge abutment that you go by when you are in the right hand lane but I don't really see much of a way around that, it also picks up the car that might be there. So it is kind of hard to tune out one without losing the other." A fleet participant mentioned monitoring the alert rates and trying to identify early a system that is not functioning properly so that it can be fixed.

System reliability was also mentioned as an issue in regard to team drivers. As one participant mentioned, some systems "…seem to pick up anything on the road and when you've got someone trying to sleep in the sleeper that is a problem."

While avoiding the issues of driver mistrust and team driver sleep disruption 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 is going to bring a truck to a complete stop it must be "…identifying a vehicle and not a Coke can in the road." System reliability is crucial in such instances because of the implications of stopping on the highway with traffic behind a truck.

Behavior Monitoring

Crash avoidance technologies are being used by some fleets to monitor driver behavior. A fleet described how, with their crash avoidance system, they are able to view the environment surrounding an event including where it occurred and the driver's speed 5 minutes before and 2 minutes after the event. As one participant said "When we look at it from a safety perspective, it is all ultimately the behavior. Whether it is the behavior of our driver or the behavior of the other driver, it is a driving behavior. So we try and do everything we can and want stuff that will give us information about that behavior."

A few fleets described how they use behavior monitoring to pinpoint the drivers who need remediation. One fleet participant mentioned looking at data from their crash avoidance system on an exceptional report basis, reviewing the worst 20 percent of drivers on a weekly basis and performing additional observation, evaluation, coaching, and training with those drivers. Another fleet described a similar approach, using behavior monitoring to create monthly risk reviews on all their drivers to identify the small batch of drivers that need intervention.

Behavior monitoring is a management tool for fleets that want to do more than alert their drivers. As one fleet described, "It's not good enough to just alert the driver if you want to change the behavior, they have to know that it's important enough for somebody else to manage it, and that when bad things occur or poor behavior occurs it's going to be addressed by their direct supervisor."

Data Accessibility

The ability to use crash avoidance technologies to capture data about a crash as well as data regarding driver behavior (lane departures, following distances, etc.) is viewed as desirable by some fleets. Fleet participants that want access to data from crash avoidance systems said that the data are useful in identifying poor driver behavior and determining fault in litigation. For example, a participant said that data from a crash avoidance system were used by his company in litigation to show that the company was not at fault in an accident. As a result, the company saved $18.5 million. A few participants also said that they'd like to see it become easier to obtain the data by crash avoidance systems in a manner and format that they can manage.

Not all fleets want access to data from their crash avoidance systems. A fleet participant mentioned that his company chose the particular lane departure warning system that they did because it did not capture data. 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 were accessible, yet not being used, 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 is no one to monitor and analyze the data. He said he'd prefer the system to just alert the driver when necessary and not capture data.

Driver Acceptance

Securing driver buy-in and acceptance of crash avoidance systems is important so drivers will be willing to use them. For instance, one fleet participant described how some drivers will tamper with the system in an attempt to disable it while others will use pillows to muffle alerts. Several fleets described ways that they work to gain driver acceptance, including cultivating a strong safety culture, seeking driver feedback on new technologies, choosing technologies with few false alarms that alert when necessary, and having managers test the systems to show drivers that management understands how the technology works. For example, one participant described how he allows some of his drivers to test a new technology before it is fully implemented into the fleet and then he listens to the drivers' feedback. He believes that considering driver's opinions regarding a new system helps with driver acceptance of the systems that are ultimately used. Another participant mentioned that driver acceptance is a criterion his company considers when purchasing new technology because the company doesn't want to risk putting a technology in their trucks that is going to increase driver turnover.

Driver Distraction

Fleet participants indicated that crash avoidance technologies lose their benefit if they become a distraction to the driver. Systems that distract drivers at night with bright glares were mentioned as problematic. Participants also said systems that encourage drivers to watch a display or screen more than the road are not beneficial. For instance, one participant described how his company was testing an LDW system that had a small graph on the dash indicating where the truck was in the lane. Drivers testing the system told management that they were spending more time watching the graph than the road. Another participant said that his company was addressing distraction via 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 with its drivers that technology is just a tool and that drivers need to rely first on their own ability and defensive driving posture.

Potential V2V Technology Usage in Commercial Fleets

Advanced Capabilities of DSRC

Fleet participants were interested in the potentially advanced capabilities of a DSRC system over their current sensor suites. Several participants liked the advantage of having a wider range or longer distance for alert messages. For example, in regard to LTAP/OD crash scenarios, a participant mentioned the advantage of wireless messages that have a longer distance or wider range. In rear-end scenarios, a participant described how he'd be interested in V2V in trail communication where, if one vehicle is creeping up on the other vehicle, the lead vehicle could be made aware of it. Another participant said he 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 way.

Return on Investment

A concern was raised that, because it may take quite some time for broad implementation of DSRC, fleets may not experience any benefit in the short term. As one participant said, "I don't know that I would be able to recommend or that I would get approval for something that immediately or in short term really wouldn't provide some value or potential help to the driver to reduce accidents." A suggestion made by one participant to deal with the lack of benefit during this early implementation period would be to provide some incentives to companies that are willing to be early adopters. Providing incentives for early adopters might help more companies be able to afford implementing DSRC sooner.

Integration

The ability to have one system provide multiple forms of crash avoidance information to a driver was mentioned by several participants. As one participant said "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'd like to see something where all of the technology would be available in one package or in different modules attached to the truck, such that all would use the same driver display or alert system so the driver has only one place he or she has to look or listen for alerts.

The issue of integration in terms of all vehicles having the DSRC technology was also discussed. A participant shared his concern about what would happen when some vehicles have the technology and others do not. He said "I would just be fearful of what would happen in the interim." Another participant said "To make it really effective you'd have to get the general public to do this and I guess then you'd get the manufacturers or require them to spec it in with the vehicles."

System Reliability

An issue for some fleets was system reliability in a DSRC environment. For example, one participant was concerned that, if a truck is on a two-lane road and traffic is coming in the opposite direction, the DSRC system would consider that scenario an alert. He was concerned that frequent false alerts would cause problems for team drivers (i.e., drivers in a sleeper). As one participant said "What happens if the technology fails? If we have disconnected drivers, who is held accountable then?"

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 and the struck vehicle were doing in the moment just prior to the crash. Future crash avoidance systems could capture the crash data from all vehicles, infrastructure, and mobile devices at the crash scene to provide a more complete picture of the events. As is discussed in the Current Crash Avoidance Technology Usage in Commercial Fleets section of this report, not all fleets agree that access to crash and behavioral data is beneficial to their operations; thus, this feature should be selectable by the fleet management.

Driver Acceptance

Driver acceptance of DSRC was a concern mentioned during the interviews. A few fleets said they'd want to test the DSRC technology with their drivers to see if the drivers were accepting of the technology and perceived it as beneficial. As one participant said "If the drivers told me it was definitely a benefit then more than likely we would be interested in it."

DSRC-Based Crash Avoidance Technology Integration into Commercial Vehicles

Customer Demand

OEM participants described how important customer demand is for the manufacturers incorporating crash avoidance technologies in vehicles. For example, an OEM said that his company does not put safety systems on their vehicles because they think the systems are a good idea, they only install crash avoidance technology if there is a market advantage or if a customer requests the product. As one participant said "Honestly, a lot of these products are required by customer pull through, and if they weren't being purchased we wouldn't be engineering them."

DSRC Radio Integration

Implementation of the DSRC radio was an issue raised during the interviews. A few OEM participants described how they envision the DSRC radio being implemented. One participant described how his company envisions that there will be DSRC suppliers that will make the devices and sell them to OEMs who will in turn integrate them into their vehicles. Another participant described how he thought the safety systems should link to a single DSRC radio. He said "I think to be most effective you would need to integrate it [the DSRC radio] into the vehicle and then let the safety systems integrate into that."

A few heavy-vehicle supplier participants said that DSRC should augment sensors until the technology is implemented in all vehicles. As one participant said "At least in the short term I would think it would have to be augmenting it [current sensors] and especially to cover where some of the vehicles that don't have that (*DSRC*)."

The CV suppliers also discussed DSRC implementation and how it may impact vehicle architecture. A participant said that DSRC is likely to be part of the vehicle architecture, pulling information from the sensors. Another participant said that there would need to be some way to process both the information coming into the vehicle and the information going out of the vehicle. For example, when asked if he thought DSRC would change the vehicle architecture, this participant said "There would have to be some because there would have to be probably a dedicated reporting device to the DSRC; you can't have multiple people shouting different stuff from the same vehicle."

The light-vehicle suppliers interviewed described DSRC as an added sensor that would augment current sensors to provide more information at a potentially reduced cost. As one participant said "For us, communication is an additional sensor that provides us with more awareness of our environment, it looks further ahead than radars and cameras can." In terms of economic value, a participant said "Any sensing that gives you added benefit in multiple arenas starts to, I think, reduce costs."

Another issue raised regarding DSRC is that until DSRC has achieved substantial market penetration it can only be used to augment sensors. A participant explained that DSRC would not be able to replace current sensors "… because replacing it would require almost a 100-percent market penetration. The thing is, unless you have every car, bicyclist, pedestrian, and chicken on the road with a DSRC system, you cannot do vehicle control based on communication. Whether we would ever do anything based on communication alone, I don't see that happening. Especially, not until you have really huge market penetration." Another participant supported this argument saying "if the vehicles are going to communicate with each other in order to not have accidents, the only time they are actually going to replace the sensors that are in there today is when absolutely every vehicle has one in it I would think or near it."

Implementation Impetus

During the interviews a few OEMs shared their concern that fleets may not see the benefit of DSRC and so won't purchase trucks with the technology. Participants shared their opinion that the fleets will want to see some clear benefit from DSRC and, if they don't, it is unlikely they'll implement it unless it is mandated and they have no choice. One participant who was asked how he saw DSRC implementation taking place said: "If it becomes a requirement by the government, then it will push through very quickly. But if it's just a convenience item, I'm afraid it's going to be a hard sell."

Both light-vehicle supplier participants said that they think a government mandate will eventually be necessary for DSRC implementation. There is a lack of benefit for those who implement DSRC if others choose not to do so. As one participant said, "It almost seems like at some point you would almost have to mandate it to get enough usage or implementation to get enough application that it had a big benefit, because it almost relies on other people having it to give you the benefit."

DSRC suppliers discussed how they see a government mandate of DSRC being important to broad implementation. In the interim, pilot programs and incentives may be used to stimulate implementation, but ultimately regulation will be necessary because there isn't a lot of benefit to DSRC until it is broadly implemented. As one participant said, "A lot of it is political, a lot of it's obviously economic, and why would auto manufacturers include DSRC within their vehicles if there's no market for it because at the end of the day they're trying to make a buck. I think once NHTSA provides regulatory compliance, then you're going to see both the private vehicles and commercial vehicle manufacturers start to include DSRC."

A participant commented that he thinks the mandate will include not only the use of DSRC as an active safety system, but also some sort of standardized format for the sensory data provided to the DSRC channel and the DSRC application. Another participant said he thought that government-mandated installation of DSRC would occur in CVs before passenger vehicles.

Participants discussed how getting enough market penetration in passenger vehicles and CVs is critical to DSRC. A participant said market penetration needs to happen across commercial and personal vehicles because: "It's kind of pointless to have a vehicle-to-vehicle communication-based system and then the trucks are not being seen by any of the other vehicles." The benefits of the technology are tied to wide implementation. This issue for the light-vehicle suppliers was closely tied to government mandates as several participants viewed government mandating of DSRC as a necessary step towards the achievement of adequate market penetration.

ROI

A few of the OEMs discussed the need to show some benefit from DSRC before fleets are going to purchase trucks with the technology. The participants felt that the fleets will need to understand what DSRC is going to give them, what benefit they are going to experience from investment in this technology. For example, a participant said that if the fleets are going to experience a reduction in accidents as a result of implementing DSRC, then it will be worth something to them.

Another participant shared how as an equipment manufacturer his company is going to be hard-pressed to justify the ROI to the customer if there is very little perceived value. He said if the DSRC transceiver is being put in a truck just for future applications, then "… nope, not going to happen." This participant felt that until there is a government mandate or a viable commercial impact it is not going to be to his company's advantage to increase the cost of their vehicle at all for DSRC technology integration.

During the CV supplier interviews, a few participants discussed the need for having enough vehicles with DSRC before it would be of value. These participants indicated that not having enough vehicles to form a critical mass of communicating vehicles doesn't make sense. As one participant said, if there is nobody to communicate with, "What do you know? If there isn't density, there isn't value."

Standardization

The issue of standardization was raised during the OEM interviews. A few of the OEMs were concerned that there needs to be a standard set so that all the DSRC safety systems can talk to each other. As one participant said, "In my mind, about the only way it could work would be if there were some common standard architectures, some standard protocols about what data. Because when you are going V2V you are going to be transmitting data from one source and another source is going to be reading it. I would think that there's got to be some kind of standardization and it would really have to be across the industry because any vehicle could run into any other manufacturer's vehicles. Unless everyone is using the same kind of standards and protocols, you are not going to be able to read each other." Another participant said his company will not be interested in DSRC until some solid standards have been set because he doesn't want to have to put in multiple interfaces just so their trucks can function across the whole country. He said his company "…certainly won't get excited about doing anything with it until things settle down."

A few issues regarding standards were raised during the CV supplier interviews as well. For example, a participant shared his feeling that there would need to be standards that his company could have some level of confidence in. He said "I think it would be an industry-wide thing coming up with that before they did it." Another participant said that while standardization is important, another issue relates to who oversees the implementation of the standards. He said "Standardization is great but who is going to police the standard and approve everybody to the standard?"

Safety Benefits

A variety of potential benefits from DSRC implementation were mentioned by participants, including knowing the intentions of other vehicles, having better situational awareness, and reducing false alarms. For example, in terms of situational awareness, one participant described how in bad weather conditions (where low visibility is an issue) it would be good to know where other vehicles are in relation to your vehicle, as such knowledge could help prevent rear-end crashes.

A few participants said there would be benefit to knowing the intentions of other vehicles; for example, knowing that they are intending to turn. As one participant said, "If somebody's in front of you got their turn signal on, and you can't see it for some reason and something could tell you that, which certainly helps." Another participant said that V2V might be able to help in opposite direction crashes; he said: "Long range at least now you don't have the technology to do anything for opposing traffic but as the vehicle gets closer to you, I would think between the camera and the radar, in especially the V2V you could possibly do something there."

Driver Distraction

Concern with driver distraction was raised during the interviews by several OEM participants. OEMs must balance integrating safety systems into the vehicle that will alert the driver to a potential accident while not distracting the driver. The OEM also has to consider how the various safety systems being put into the vehicle will work together to ensure that they will not overload the driver, particularly in a critical event situation. Driver displays can be especially problematic because they draw the driver's eyes away from the forward roadway. OEMs must also consider the false alarm rates of the various technologies and try to avoid installing ones that have too many false alarms that may distract the driver. As one participant said, "We have really really, really struggled with a lot of the systems. For example, the camera-based systems, in order to be effective, require that the driver take his eyes off the road and look at the camera and assess the situation and then reestablish focus on the road. I don't think that's a good thing to do. But I just said in the previous series of questions that the most effective mitigation technique was a wide-view camera, but yet it's compromised by the fact that the driver has to take his eyes off the road, focus on the view, see what's there, and then make his mind up on what to do."

Integrating only critical safety systems into one driver display located directly in front of the driver was mentioned by a participant as a way to minimize distraction. He said that some of the larger fleets his company was working with were rethinking how much information the driver really needs to have in an effort to minimize distraction. He said "Probably there's way too much information being presented to the drivers today. I'm pretty sure they are kind of in an overload mode."

Mounting

Proper and secure mounting of crash avoidance technologies was an installation issue raised by several OEMs. If systems are not mounted properly the alignment of the radar may be off or the camera view may be compromised. For instance, one participant described how a video system must be mounted on the windshield in a location where the windshield is sure to be cleaned by the wipers or the windshield may get too dirty for the camera to work properly. Another participant described the importance of proper mounting of radar. “Definitely mounting with a radar sensor is one of the critical things. You have to be careful with how they are mounted, you have to be careful of the alignment, you have to come up with a mounting system that will maintain the alignment, and you have to have some level of adjustability in it so they can be serviced in the field.”

Mounting crash avoidance technology properly may require a great deal of work and vehicle modification. A participant described how mounting a particular safety system in their vehicles required modification of the vehicle in several ways. The participant said mounting the system “… was a project, it involved electrical, mechanical manufacturing procurement purchasing, it was basically a complete design project to install that system in the truck.”

DSRC Antenna Placement

Many DSRC implementation issues regarding antennas were raised during the DSRC supplier interviews. The DSRC suppliers mentioned, for instance, optimizing the placement of the antenna on the CV, where to mount roadside antenna, and considering the environment in which the CVs must operate when mounting the antenna. For example, one participant mentioned the challenges of placing antenna on CVs that operate in mining situations where conditions are harsh.

A participant described how antenna placement in a DSRC scenario may help in determining the dimensions of the CV. He explained that “There’s several messages within 2735 that the basic safety message, the probe, and also this cooperative cruise control, which is an active cruise control utilizing DSRC, that look at the antenna placement and then its location within the vehicle so that we can provide that true boundary of the vehicle. That was done for private vehicles, and I would expect as we’re developing out our message sets for the Commercial Vehicle Infrastructure Integration project that we’re going do that same sort of work, where we’re gathering the actual dimensions of our commercial vehicle and providing that information and offset it within that message set.”

System Care

Caring for the safety systems in terms of proper cleaning and maintenance is important to ensure that the system is correctly aligned and operating properly. However, at times this can be difficult because crash avoidance technologies often must be placed in areas where they are vulnerable to damage during maintenance activities or from dirt and road debris during vehicle operation. For example, a participant described how one safety system places the radar sensor in the very front center of the truck, fairly low to the ground. This positions the radar in the area of the truck’s front bumper, which poses problems because mechanics have steps on the bumpers and hooks for when trucks get stuck and need to get pulled out by tow rigs. Because the radar sensor needs to be in that location, he said: “It gets abused considerably.”

Trailer Data

A vehicle integration issue that came up during the interviews was that there are very few standardized interfaces between tractors and trailers for data exchange. A couple of scenarios were mentioned in regard to problems with tractor and trailer data exchange. For instance, one

OEM described how fleets might buy their tractors from his OEM yet they might buy their trailers from another company. The tractor and trailer may not in this case have the same sensors installed and, therefore, they cannot communicate.

Another OEM described how a fleet may mix and match their tractors with various trailers. Such tractor and trailer configurations make it very difficult to align the sensors on the entire tractor-trailer to ensure that data from the tractor are being put together with data from the trailer. Under such a scenario the operator cannot get a view of his or her entire vehicle. This is particularly an issue with lane-change crashes because, as one participant said, “I don’t think we are going to be able to sense the entire lane adjacent to the vehicle for the entire length of a combination with a radar based on the tractor. We don’t have a clear field of view down the full side of the vehicle.”

A participant offered an idea for how to solve the tractor-trailer data exchange issue; he said “The solution to this is ultimately going to be sensors mounted on the trailer working in unison with sensors on the tractor.”

V2I Benefits

During the interviews a few companies shared some of the benefits they see from DSRC in terms of V2I. For example, a participant mentioned that it will be helpful if a vehicle is able to signal the intersection that it is either present or approaching. Another participant described how his company is interested in V2I because the most frequent crash type their trucks have are rollovers. This participant described how V2I “… can actually go beyond curve warnings with GPS positioning and knowing the vehicle state, knowing the radius of the curve coming up—it actually is possible, or will be possible to actually brake the vehicle and slow it down if it’s going too fast into a corner.” Though rollovers were not a crash type explored during this study, the benefits of DSRC in terms of V2I were discussed whenever participants brought them up.

Data Elements Required for Identified Crash Types

Rear-End Crash Data Elements

The data elements mentioned regarding the rear-end crash type included: distance and position of forward vehicle, slower moving vehicles, stopped vehicles and objects, vehicle speed, lane position, accelerometer to measure drift, lane change, yaw rate, brake pressure, and load mass. Several adjacent perspective data elements were mentioned, including range or distance between two vehicles, relative velocity between the truck and the vehicle in front of it, and the angle. As one participant said “It would be good to have a measurement of what that vehicle in front of it was doing at the time. Was it rolling along at 55 mph or was it coming to an abrupt stop for some curious reason? Did it just cut into your lane a moment beforehand and then slam on the brakes?” The roadway elements mentioned for rear end were level of roadway, curvature, surface conditions (i.e., ice, rain, snow), and surface materials (i.e., gravel, asphalt, potholes). For example, one participant described the importance of lane position and curvature; he said: “You want to order vehicles that are in your lane, and if you’re on a slight curve and you’re turning in that curve, it wants to predict, using that radar, what’s in your lane, instead of warning you of what’s in an adjacent lane, kind of a thing.”

Lane Change Crash Data Elements

The data elements for lane changes discussed by participants during the heavy-vehicle supplier interviews included: side detection, sight down the length of the tractor and trailer, vehicle geometry (i.e., height, width of truck), vehicle speed, steering, and correct target identification. The roadway elements mentioned were lane markings and curvature of the road. One participant explained how lane definition and the ability to track vehicles in adjacent lanes is important: "I mean that is really what it comes down to, having the technology to define what your lane is and to be able to track the vehicle that it considers in your lane next to it**."**

Opposite Direction Crash Data Elements

Opposite direction data elements discussed during the interviews included: lane departure, distance, closing speed, and field of view. Roadway elements were not mentioned for this crash type. A concern for opposite direction crashes appeared to be lane departure; therefore, roadway elements that apply to lane departure would appear to apply to this crash type as well (i.e., lane markings and curvature of the road). As one participant said, "Usually a head-on collision is 'cause somebody drifts out of their lane and so certainly a lane departure system can aid in preventing that."

LTAP/OD Crash Data Elements

LTAP/OD data elements mentioned by heavy-vehicle supplier participants included:
subject heading and speed, yaw of tractor, adjacent object heading and speed, position of other vehicles in order to determine range, and angular field of view. The roadway elements mentioned were curvature of the road and roadway type from GPS. One participant said this crash type is problematic because: "I don't think our angular field of view allows us to have perspective of a crossing vehicle that is going to be a threat in time enough."

Applicability of DSRC to Identified Crash Types

Rear-End Crashes

Rear-end collision scenarios were discussed and participants mentioned a few data elements that would need to be provided by DSRC, such as: where a vehicle is located, if the vehicle is in the subject vehicle's lane of travel or not, and the closing speed. As one participant explained, to avoid a collision "… you have to determine, depending on your speed, 80 meters or so in advance, that there's a vehicle in front of you. And you only know the vehicle is stopped and you also get some information about the past history of that vehicle. And, based on the position, the past history, and your own heading, you can determine if that vehicle is in your lane of travel or not." Yet this participant noted that the ability to determine whether a vehicle is in the subject vehicle's lane of travel or not is an intricate problem.

The other light-vehicle supplier described how closing speed and position information are key factors in rear-end crash scenarios. He added that: "Depending on the sensing technology you've got, you've got some ability to sense everything, but if you had some kind of a GPS-based information that could confirm, then you probably could broaden your sensing for your operating times and conditions that you could operate under."

Lane Change Crashes

Light-vehicle and DSRC suppliers discussed the applicability of DSRC to lane change crashes. In such crash scenarios one participant said DSRC would let the subject vehicle know where other vehicles are relative to the subject vehicle. The participant said this relative positioning, or target classification, would need to be accurate enough to determine whether other vehicles are in neighboring lanes or the same lane. Such accurate lane detection would allow a vehicle to know if another vehicle was in its blind spot. He also commented that the range of the DSRC would help with lane changes. He said that the communication range is pretty large, "We are talking something about 300 meters, that means you know you can predict that there is a vehicle going to be in your blind spot in 4 seconds, which is much longer than you would take for a lane change maneuver."

In a similar discussion, another participant described how DSRC would need to sense what is behind the subject vehicle in an adjacent lane. Knowing the range and relative velocity of someone coming up from behind would be important in a lane-change crash scenario. He said getting rearward sensing information from sensors is very expensive, and getting it from DSRC could be more economical. Yet he noted the difficulty for current technology or DSRC to sense what is behind in an adjacent lane when the road is not straight. He said: "If you're not on a straight road, it can be pretty confusing to keep track of what is the path I was just traversing and what is my adjacent lane. That might be difficult for V2V to resolve."

One DSRC-supplier participant said that DSRC can notify drivers within the adjacent area that the vehicle is straying from its lane or that the signal indicator has been turned on. This participant also described how other vision systems that monitor blind spots could send a message via DSRC to an adjacent vehicle, warning that "Hey, this truck is coming over." Another participant said how DSRC will help in lane-change scenarios if the technology has non-line-of-sight capability or if several antennas are placed on the CV because CVs themselves can actually block sight lines that can be a problem across crash types.

Opposite Direction Crashes

Light-vehicle suppliers discussed several data elements that would be important to know for DSRC in an opposite direction crash scenario. One participant said it would be important to know the other vehicle's trajectories relative to the road and the speed at which it is approaching. He also said: "I think there would be benefit in just knowing that the adjacent lane is predominantly oncoming traffic; that probably would be good information just in itself. And then how far is the subject vehicle from where oncoming traffic ought to be, that's of value."

The other light-vehicle supplier commented on how, in passing scenarios, it will be difficult to perform accurate target classification because the distance the subject vehicle would have to look ahead is relatively large depending on the speed of the vehicle. He gave the example of a vehicle traveling 45 miles per hour needing to look ahead about a kilometer for a passing maneuver. He said: "Accurate target classification that far ahead is somewhat of a challenge, especially if you have a curved road, or the road is not completely straight. Then things get a little bit difficult."

Another participant said that the DSRC board unit could be tied into the sensory system so that when the sensors identify the subject vehicle straying out of the lane it can not only alert the driver 'Hey, wake up! You're straying' but it can send the message out to vehicles in the area to alert them that the vehicle is drifting out of its lane. Another participant commented on how DSRC would help in situations where the driver does not have line of sight because it is possible for the DSRC to work in non-line-of-sight scenarios. For example, if the driver knew that a vehicle was coming in the opposite direction, even though it couldn't be seen, he or she would not attempt a passing maneuver.

LTAP/OD Crashes

During the interviews participants discussed LTAP/OD scenarios and the data elements that DSRC might provide, including: detection of objects in the forward path, oncoming traffic in the adjacent lane (i.e., range, range rates, closing velocities, trajectory, swerving behavior), turn signal indications, lane layouts, maps, and how well other vehicles are staying in their lanes. The field of view to see things coming in from a perpendicular angle was also mentioned as important. Regarding such information, one participant said "V2V seems like pretty much the only way to economically get that information in my mind from what I've seen."

Another participant raised an issue with the complexity of LTAP/OD and junction-crossing crash scenarios that will be difficult for V2V to address. For example, he said "You want to turn left and your system tells you, 'looks good, based on the distance of the oncoming car from the intersection.' But suddenly you have a pedestrian crossing the road, now what do you do? Now suddenly you brake and you're stopped in the middle of the intersection with an oncoming car. Those kinds of scenarios are relatively complex."

Traffic Control Devices Crashes

Light-vehicle participants discussed several pieces of information that DSRC could provide for TCD violation, including that lane in the intersection the subject vehicle is in, a map of the intersection, the color of the light, and if the light is about to change. These pieces of information are important because, as one participant said, "You do not want your systems to scream at you 'stop or you'll die' if you are in the through lane that has green and the left turn lane is red and you're just matched to the wrong lane. People frown on that."

A participant described how instrumenting the intersections and sending out the messages is really V2I, yet V2V could come into play if a subject vehicle has a green light to drive across an intersection and another car with V2V– but not V2I – capability violates the traffic signal. In such a scenario the subject vehicle would at least get a warning that "okay, it's going to crash into your truck" if it continues on the same path, independent of what's happening with the traffic signals.

DSRC applicability to TCD violations was also discussed during the DSRC supplier interviews. Both participants described how a vehicle could receive from the infrastructure signal phase and timing information. For example, one participant said that drivers could benefit from receiving in-vehicle signage information to aid in their driving decisions.

The infrastructure could also provide to DSRC-equipped vehicles a map of the intersection, and this information could be combined with the location, speed, and turning intentions of vehicles in the area. For instance, in a TCD violation scenario, if the subject vehicle was intending to turn at the intersection, the driver could be warned if necessary that "you're not going to make it, and you're going to cause a collision." Because the vehicle would be sending out information about its position and intention to turn, other DSRC-equipped vehicles in the area would also be alerted to the vehicle's intention to make a risky turn at the intersection.

GENERAL FUNCTIONAL CONSIDERATIONS FROM LITERATURE

V2V Communications Functional Considerations

The enabling technology for V2V safety applications has resulted from advances in 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 (Shulman & Deering, 2007).

Transmission Latency

Because of the time-sensitivity of vehicle crash scenarios, the safety applications will require low-latency messages between vehicles. Some critical V2V safety applications require periodic transmissions as frequent as every 100 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 (CAMP, 2005, p. 45).

Transmission Update Rate

Transmission update rate is defined as minimum rate (in Hertz) at which the transmission should be repeated (Shulman & Deering, 2007) to ensure that the safety message is reliably conveyed between vehicles. V2V communication challenges such as multipath fading, shadowing, Doppler shifts created by movement of the vehicles, and data packet collisions (Yang et al., 2004) must be considered when selecting a minimum update rate.

Transmission Range

Shulman and Deering (2007) defined the maximum transmission range as the communication distance between two vehicles that is needed to effectively support a particular safety application. 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 (Chen et al., 2010). Many of the proposed safety applications require a communication range between 100 –1000 m (CAMP, 2005); the typical range is around 300 m (Bai & Krishnan, 2006). For situations where the maximum range is not achievable, multi-hop (using vehicles to relay data broadcasts) may be a useful mechanism (Chen et al., 2010).

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 GPS navigation, which provides relatively accurate positioning and a common global clock (Caveney, 2010). While the basic GPS accuracy is sufficient for normal route guidance, safety systems require greater positioning accuracy (on the order of centimeters [CAMP, 2005]), especially in identified pre-crash safety scenarios. Derivatives of GPS have improved this accuracy by refining the measurement with corrections. These technologies include DGPS with a reported accuracy of approximately 1 m, and RTK positioning with centimeter accuracy (Caveney, 2010). 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 (Caveney, 2010). One GPS/IMU has been reported to provide a 2 cm horizontal and a 5 cm vertical accuracy when the GPS signal is present, and maintain a 10 cm horizontal and a 7 cm vertical accuracy during a 1-minute GPS signal blackout (Caveney, 2010).

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 (i.e., outer dimensions) of the subject vehicle as well as other objects in the crash scene. This is especially true for CVs where the vehicle lengths can typically range from 20 to 75 feet. 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 with special permits can be in excess of 13.5 feet and 8.5 feet, respectively. These dimensions vary with loads and must be accurately accounted for in crash avoidance algorithms. Currently, LVs use an offset value in the SAE J2735 safety message (Hedges & Perry, 2008) to indicate the vehicle’s boundary in relation to the DSRC antenna. For CVs this offset value may be large (up to 75 feet long in some cases). To further complicate this offset value, the configuration (i.e., with or without trailer, and the number and type of trailer) may vary by load. To effectively communicate the CVs’ outer boundaries to crash algorithms, this offset value needs to be updated whenever the configuration changes. While loads are important for determining configuration, they are also important in understanding the dynamic characteristics (e.g., acceleration, turning radius) of the CV’s. This information may be necessary for proper crash alerting/mitigating algorithms.

Commercial Vehicle Size

Like buildings, CVs are large enough to present a barrier to the DSRC transmission. Therefore, non-line-of-sight DSRC transmissions may be necessary to effectively communicate between radios when in close proximity to CVs.

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 the identified real-world crash scenarios. 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, the Crash Avoidance Metrics Partnership evaluated a similar set of pre-crash scenarios and developed six safety applications: forward collision warning, emergency electronic brake light, blind spot warning + lane change warning, control loss warning, intersection movement assist, and do not pass warning (Ahmed-Zaid et al., 2008). These served as a basis for the following identified CV safety applications. Several safety applications have been modified to account for the unique characteristics of CVs.

The success of future CV safety systems is dependent on the clear requirements to meet the needs identified by both accident database analyses and the prescribed concept of operations. The requirements should be considered preliminary because they were derived from existing requirements (Shulman & Deering, 2007; Ahmed-Zaid et al., 2008; Maile, 2009) for various V2V and V2I safety systems and interviews with industry stakeholders.

CAMP (2005) provides several definitions to be considered in the development of DSRC-communication requirements. These include:

- **Types of communication** describe:
    - The source and destination of the transmission (i.e., V2V, V2I).
    - The directionality of a broadcast transmission (i.e., one-way, two-way)
    - The intended target of the broadcast transmission (i.e., point-to-point, point-to-multipoint)
- **Transmission mode** describes whether the transmission is prompted by an event (i.e., event-driven) or whether it was transmitted automatically at regular intervals (i.e., periodic).
- **Maximum frequency** is the rate at which a transmission should be repeated (i.e., 1 Hz).
- **Allowable latency** is the maximum duration of time allowable between when information is available to be transmitted and when it is received (e.g., 100 msec.).
- **Key data to be transmitted or received** lists the required data elements to be communicated in the transmission.
- **Maximum required range of communication** is the maximum communication distance between two DSRC units that is allowable for effective support of a particular application.

Cooperative Forward Collision Warning (CFCW)

The cooperative FCW 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. The CFCW safety application has the greatest potential to mitigate commercial vehicle crashes, mapping to 15 of the 17 pre-crash scenarios. Table 12 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit. Because of the potential for blocked DSRC transmissions by the CVs between the transmitting vehicle and following vehicles, this safety application will require non-line-of-sight DSRC.

Table 12. CFCW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Rear-end/lead vehicle stopped	31,598
Rear-end/lead vehicle decelerating	17,568
Rear-end/lead vehicle moving	14,251
Rear-end/striking maneuver	4,687
Rear-end/lead vehicle accelerating	1,222
Turning/same direction	27,922
Opposite direction/no maneuver	13,352
Opposite direction/maneuver	978
LTAP/OD at non-signal	5,257
LTAP/OD at signal	5,430
Straight crossing paths at non-signal	22,452
Turn at non-signal	4,299
Turn right at signal	2,782
Running red light	9,404
Running stop sign	1,441

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 ms
- **Key data to be transmitted or received**:
  - Vehicles' heading
  - Vehicles' speed
  - Vehicles' positions
  - Road surface condition
  - Load mass
  - Yaw-rate
  - Steering angle
  - Vehicle's outer dimensions

    - Road curvature
- **Required range of communication**: approximately 150 m for rear-end crashes, but may need to be extended to approximately 500 m for opposite direction crashes due to high relative velocities between opposing vehicles.

Emergency Electronic Brake Light/Enhanced Rear Signaling

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 (Ahmed-Zaid et al., 2008; CAMP, 2005). 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. EEBL/ERS maps to 5 of the 17 pre-crash scenarios. Table 13 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 13. EEBL/ERS Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Rear-end/lead vehicle stopped	31,598
Rear-end/lead vehicle decelerating	17,568
Rear-end/lead vehicle moving	14,251
Rear-end/striking maneuver	4,687
Rear-end/lead vehicle accelerating	1,222

Communication Requirements

- **Types of communication**: Non-LOS V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Event-driven
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 ms
- **Key data to be transmitted or received**:
    - Vehicles' heading
    - Vehicles' speed

- Vehicles' positions
  - Road surface condition
  - Load mass
  - Yaw-rate
  - Steering angle
  - Road curvature
- **Maximum required range of communication**: approximately 300 m

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 (Maile, 2009; Ahmed-Zaid et al., 2008). Compared to light vehicles, CVs are known for their large blind spots around the vehicle that pose a hazard to adjacent traffic (FMCSA, 2010). As mentioned, CVs have variable lengths, widths, and heights that create shifting blind spots that must be accounted for in safety countermeasures. Because of the adjacency of the vehicles involved, line-of-sight DSRC communications will be sufficient. BSW/LCW maps to 2 of the 17 pre-crash scenarios. Table 14 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 14. BSW/LCW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Changing lanes/same direction	50,690
Drifting/same direction	19,703

Communication Requirements

- **Types of communication**: LOS V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 ms
- **Key data to be transmitted or received**:
  - Vehicles' heading
  - Vehicles' speed
  - Vehicles' positions
  - Steering angle
  - Turn signal status
  - Vehicles' outer dimensions
- **Maximum required range of communication**: approximately 150 m

Control Loss Warning

The CLW safety application enables a commercial vehicle 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 (Maile, 2009; Ahmed-Zaid et al., 2008). CLW maps to 3 of the 17 pre-crash scenarios. Table 15 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 15. CLW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Rear-end/striking maneuver	4,687
Drifting/same direction	19,703
Opposite direction/no maneuver	13,352

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Event-driven
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 ms
- **Key data to be transmitted or received**:
  - Vehicles' heading
  - Vehicles' speed
  - Vehicles' positions
  - Yaw-rate
- **Maximum required range of communication**: approximately 150 m

Intersection Movement Assist

The IMA safety application warns the commercial vehicle driver when it is not safe to enter an intersection due to high collision probability with one or more remote vehicles in cross traffic (Maile, 2009; Ahmed-Zaid et al., 2008). IMA maps to 6 of the 17 pre-crash scenarios. Table 16 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 16. IMA Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
LTAP/OD at non-signal	5,257
Straight crossing paths (SCP) at non-signal	22,452
Turn at non-signal	4,299
Turn right at signal	2,782
Running red light	9,404
Running stop sign	1,441

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V and V2I DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
    - Vehicles' heading
    - Vehicles' speed
    - Vehicles' positions
    - Road surface condition
    - Directionality
    - Stopping position location
    - Vehicles' outer dimensions
    - Traffic signal status
- **Maximum required range of communication**: approximately 300 m

Wrong-Way-Driver Warning

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 (Camp, 2005). WWDW maps to1 of the 17 pre-crash scenarios. Table 17 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 17. WWDW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Opposite direction/no maneuver	13,352

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
    - Vehicles' heading
    - Vehicles' speed
    - Vehicles' positions
    - Directionality
    - Steering angle
    - Lane Position

- **Maximum required range of communication**: approximately 500 m

Do Not Pass Warning

The DNPW safety application provides a warning to the commercial driver when a slower moving vehicle cannot be safely passed using a passing zone that is occupied by oncoming vehicles (Maile, 2009; Ahmed-Zaid et al., 2008). DNPW maps to1 of the 17 pre-crash scenarios. Table 18 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 18. DNPW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Opposite direction/maneuver	978

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
    - Vehicles' heading
    - Vehicles' speed
    - Vehicles' positions
    - Turn signal status
    - Lane Position
- **Maximum required range of communication**: approximately 500 m

Cooperative Stop Sign Violation Warning

The CSSVW application uses both infrastructure-to-vehicle 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 (CAMP, 2005). The application also provides a warning to other drivers approaching the non-signalized intersection of the impending infraction. CSSVW maps to1 of the 17 pre-crash scenarios. Table 19 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 19. CSSVW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Running stop sign	1,441

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V and V2I DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
  - Vehicles' heading
  - Vehicles' speed
  - Vehicles' positions
  - Road surface condition
  - Directionality
  - Stopping position location
  - Vehicles' outer dimensions
- **Maximum required range of communication**: approximately 250 m

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 (CAMP, 2005). Left Turn Assist maps to2 of the 17 pre-crash scenarios. Table 20 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 20. Left Turn Assist Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Turning/same direction	27,922
LTAP/OD at signal	5,430

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V and V2I DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
  - Vehicles' heading
  - Vehicles' speed
  - Vehicles' positions
  - Road surface condition
  - Directionality
  - Stopping position location
  - Vehicles' outer dimensions

    - Traffic signal status
- **Maximum required range of communication**: approximately 300 m

Cooperative Traffic Signal Violation Warning

The CTSVW application uses both V2I 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 (CAMP, 2005). The application also provides a warning to other drivers approaching the signalized intersection of the impending infraction. CTSVW maps to1 of the 17 pre-crash scenarios. Table 21 provides a listing of the applicable crash scenarios and associated crash counts to provide a sense of the application's potential safety benefit.

Table 21. CTSVW Associated Pre-Crash Scenarios 2005-2008 GES (Toma, Swanson, Smith, & Najm, in review)

Pre-Crash Scenario	Crash Count
Running red light	9,404

Communication Requirements

- **Types of communication**: Non-line-of-sight V2V and V2I DSRC, one-way, point-to-multipoint
- **Transmission mode**: Periodic
- **Maximum frequency:** approximately 10 Hz
- **Allowable latency**: approximately 100 msec.
- **Key data to be transmitted or received**:
    - Vehicles' heading
    - Vehicles' speed
    - Vehicles' positions
    - Road surface condition
    - Directionality
    - Stopping position location
    - Vehicles' outer dimensions
    - Traffic signal status
- **Maximum required range of communication**: approximately 250 m

CHAPTER 5. DISCUSSION AND CONCLUSIONS

As reported by Toma et al. (2010), V2V crash avoidance systems could potentially address approximately 267,000 police-reported heavy-truck crashes per year, with a 95-percent confidence interval of 228,000 to 306,000. For this reason, the U.S. DOT commissioned this study to determine the high-level performance requirements for potential V2V safety applications suitable for CV operations. As previously mentioned, the purpose of this project was threefold: (1) review the literature covering collision avoidance systems currently available for CVs, (2) interview representatives from the CV and LV manufacturers, suppliers, and CV fleet operators to determine suitable crash avoidance technologies for the V2V communications, and (3) identify and develop high-level performance requirements for the selected V2V safety applications.

There are three prominent collision avoidance/warning technologies currently employed in CV operations with some success. These include FCW, LDW, and side collision warning systems (i.e., lane change assist and blind spot detection). Each of these systems presents several limitations (e.g., data loss from road curvature, weather, and detection of non-relevant objects) that may be addressed by V2V communications.

Ten V2V/V2I safety applications were identified to address the 17 pre-crash scenarios. Of these 10, three applications have great potential with regard to safety benefits for the commercial vehicle industry. They are: cooperative FCW (mapping to 15 of the 17 pre-crash scenarios), IMA (mapping to 6 of the 17 pre-crash scenarios), and EEBL/ERS (mapping 5 of the 17 pre-crash scenarios).

Because there are some crash similarities between CVs and LVs, the development of high-level performance requirements was able to leverage the years of LV V2V research completed by CAMP and others. Where there were distinct differences between the classes of vehicles, the performance requirements were modified or augmented. The primary differences between LVs and CVs are their size, varied configurations, and loads. Developers of V2V communication-based safety systems must consider the ramifications of the CV size for two reasons. As with buildings, CVs are large enough to present a barrier to the DSRC transmission; therefore, non-line-of-sight transmissions may be necessary to effectively communicate between radios when in close proximity to CVs. Another reason is determining the actual outer boundary of the vehicle. Currently, LVs use an offset value in the SAE J2735 safety message to indicate the vehicle's boundary in relation to the DSRC antenna. For CVs this offset value may be large (over 70 feet in some cases). To further complicate this offset value, the configuration (i.e., with or without trailer, and the number and type of trailers) may vary by load. To effectively communicate the CVs' outer boundaries to crash algorithms, this offset value needs to be updated whenever the configuration changes. While loads are important for determining vehicle configuration, they are also important in understanding the dynamic characteristics (e.g., acceleration, turning radius) of the CVs. This information may be necessary for proper crash alerting/mitigating algorithms.

Another important consideration for developers of CV crash avoidance systems is that CVs, distinct from passenger cars, are used primarily for business purposes; thus, operational decisions are driven by profits. Therefore, CV OEMs and fleets always consider the safety system's ROI in decisions related to offer and purchase new safety systems, respectively. Demonstrating the value of new V2V safety applications in CV operations should be a priority for system developers to ensure early adoption of technology.

This project found no major issues that would prevent the implementation of V2V safety applications within the CV industry; however, there are several key factors that should be considered to promote the technology's adoption within CVs. From the CV fleet's perspective, the V2V safety applications must demonstrate an ROI, have the CV drivers' buy-in and acceptance, and present an integrated solution for overall vehicle safety. Fleets are looking for safety systems that can be adjusted to their individual safety policies and programs as well as be accepted by their drivers without presenting a distraction or enticing drivers to over-rely on the system. For the V2V communication technology, CV fleets were optimistic about the advanced capabilities of DSRC to provide sensing coverage over a wider range or at longer distances. They also expressed the preference for an integrated safety solution for primary crash types. They were, however, concerned with the market penetration ("critical mass") necessary to make DSRC an effective tool for sensing the intentions of adjacent traffic. The OEMs and suppliers, on the other hand, were more concerned with market drivers such as customer demand and government mandates. Another key factor discussed was standardization to allow seamless coordination between the CV manufacturers, vehicle-types (i.e., CV versus LV), infrastructure equipment, and myriad mobile communication devices. Finally, the outreach to the CV industry, especially fleets, made it clear that more details about the Vehicle Safety Communication Initiative need to be disseminated to the CV industry so stakeholders can understand the principles behind the concept and how this will affect their day-to-day operations. This education effort will help with fleet and driver adoption of the technology and will hasten the approach to the "critical mass" needed for optimal V2V communication performance.

REFERENCES

1. Toma, S., Swanson, E., Smith, J., & Najm, W. (in review). Description of heavy truck pre-crash scenarios for safety applications based on vehicle-to-vehicle communications. Washington, DC: National Highway Traffic Safety Administration.

2. Sayer, J., Bogard, S., Funkhouser, D., LeBlanc, D., Bao, S., Blankespoor, A., …., & Winkler, C. (2010). Integrated vehicle-based safety systems: Heavy-truck field operational test key findings report. (Report No. DOT HS 811 362). Washington, DC: National Highway Traffic Safety Administration. Available at http://deepblue.lib.umich.edu/bitstream/2027.42/77988/1/102672.pdf

3. Trucking Industry Mobility and Technology Coalition (TIMTC). (2010, April). IntelliDrive for Commercial Vehicle: Draft Meeting Notes. Retrieved from www.freightmobility.com/pdfs/IntelliDriveSMWorkshopNotes.pdf.

4. Caveney, D. (2010). Cooperative Vehicle Safety Applications. In H. Hartenstein & K. Laberteaux (Eds.), *VANET: Vehicular Applications and Inter-Networking Technologies*, pp. 21-48. West Sussex, UK: Wiley & Sons.

5. Research and Innovative Technology Administration. (2010). *DSRC: The Future of Safer Driving*. Retrieved from http://www.its.dot.gov/factsheets/dsrc_factsheet.htm.

6. Ritchie, J., Spencer, L., & O'Conner, W. (2003). Carrying Out Qualitative Analysis. In J. Ritchie & J. Lewis (Eds.), *Qualitative Research Practice*, pp. 220. London: Sage.

7. Shulman, M., & Deering, R. (2007). *Vehicle Safety Communications in the United States*. Retrieved from www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv20/07-0010-O.pdf.

8. Crash Avoidance Metric Partnership (CAMP). (2005, March). Vehicle Safety Communications Project Task 3 Final Report – Identify Intelligent Vehicle Safety Applications Enabled by DSRC. (Report No. DOT HS 809 859). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2005/CAMP3scr.pdf

9. Yang, X., Liu, J., Zhao, F., & Vaidya, N. (2004, August). A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning. *Proceedings of the International Conference MobiQuitous*, August, pp. 114-123. Available at http://research.microsoft.com/en-us/um/people/zhao/pubs/yang_x_v2v.pdf

10. Chen, R., Wen-Long J., & Regan, A. (2010). Broadcasting Safety Information in Vehicular Networks: Issues and Approaches. *IEEE Network*. *24*(1) pp. 20-25.

11. Bai, F., & Krishman, H. (2006, September). Reliability Analysis of DSRC Wireless Communication for Vehicle Safety Applications. *Proceedings of the IEEE Intelligent Transportation Systems Conference*, Toronto, Canada, pp. 355-362.

12. Ahmed-Zaid, F., Bai, F., Bai, S., Basnayake, C., Bellur, B., Brovold, S., …., & VanSickle, S. (2008, September). *Vehicle Safety Communications – Applications (VSC-A) First Annual Report – December 7, 2006 through December 31, 2007*. (Report No. DOT HS 811 073). Washington, DC: National Highway Traffic Safety Administration & Research and Innovative Technolgy Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2008/811073.pdf.

13. Federal Motor Carrier Safety Administration. (2010a). *No-Zone Campaign Information*. Retrieved from www.sharetheroadsafely.org/noZone/noZone.asp.

14. Maile, M. (2009). *Vehicle Safety Communications – Applications (VSC-A) Project: Crash Scenarios and Safety Applications*. (PowerPoint Slides). Retrieved from www.sae.org/events/gim/presentations/2009/michaelmaile.pdf.

15. The Trucker (2010). DOT's LaHood says NTSB recommendations completed show safety priority. September 27. Retrieved from www.thetrucker.com/News/Stories/2010/9/27/DOTsLaHoodsaysNTSBrecommendationscompletedshowsafetypriority.aspx

16. FMCSA. (2010b). *Large Truck and Bus Crash Facts 2008*. (Report No. FMCSA-RRA-10-043). Washington, DC: Author. Available at http://ai.volpe.dot.gov/CarrierResearchResults/HTML/2008Crashfacts/2008LargeTruckandBusCrashFacts.htm

17. NHTSA. (2010). Traffic Safety Facts 2009 Early Edition. (Report No. DOT HS 811 402). Washington, DC: Author. Available at www-nrd.nhtsa.dot.gov/Pubs/811402.pdf.

18. Houser, A., Murray, D., Shackelford, S., Kreeb, R., & Dunn, T. (2009). *Analysis of benefits and costs of lane departure warning systems for the trucking industry*. (Report No. FMCSA-RRT-09-022). Washington, DC: Federal Motor Carrier Safety Administration.

19. Murray, D., Shackelford, S., & Houser, A. (2009a). *Analysis of benefits and costs of roll stability control systems for the trucking industry*. (Report No. FMCSA-RRT-09-020). Washington, DC: Federal Motor Carrier Safety Administration.

20. Murray, D., Shackelford, S., & Houser, A. (2009b). *Analysis of benefits and costs of forward collision warning systems for the trucking industry*. (Report No. FMCSA-RRT-09-021). Washington, DC: Federal Motor Carrier Safety Administration.

21. Jermakian, J. (2010). *Crash Avoidance Potential of Four Large Truck Technologies*. Arlington, VA: Insurance Institute for Highway Safety .

22. FMCSA. (2011a). Forward Collision Warning Systems With Adaptive Cruise Control. Retrieved from www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/collision-warning.htm

23. Figueiredo, L., Jesus, I, Machado, J., Ferreira, J., & Santos, J. (2001). Toward the development of intelligent transportation systems. In *Proceedings of the 4th IEEE Intelligent Transportation Systems Conference, Oakland*, CA, pp. 1207-1212.

24. Battelle. (2007, January). *Evaluation of the Volvo Intelligent Vehicle Initiative field operational test version 1.3*. Cooperative Agreement No. DTFH61-96-C-00077, Task Order 7721. Washington, DC: Federal Highway Administration. Available at http://ntl.bts.gov/lib/jpodocs/repts_te/14352_files/14352.pdf

25. FMCSA. (2011b). Lane Departure Warnings. Retrieved from www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/lane-departure.htm.

26. Orban, J. Hadden, J., Stark, G., & Brown, V. (2006). *Evaluation of the Mack Intelligent Vehicle Initiative Field Operational Test*. (Report No. FMCSA-06-016). Washington, DC: Federal Motor Carrier Safety Administration.

27. Houser, A., Pierowicz, J., Fuglewicz, S. (2005). Concept of operations and voluntary operational requirements for lane departure warning system (LDWS) on-board commercial motor vehicles. (Report No. FMCSA-MCRR-05-005). Washington, DC: Federal Motor Carrier Safety Administration.

28. FMCSA. (2011c). Side Collision Warning Systems. Retrieved from www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/Side-Collision-Warning-Systems.htm.

29. Visvikis, C., Smith, T., Pitcher, M., & Smith, S. (2008). *Study on lane departure warning and lane change assistant systems: final report*. (PPR 374). Crowthorne, Berkshire, UK: Transport Research Laboratory, European Commission. Retrieved from http://ec.europa.eu/enterprise/sectors/automotive/files/projects/report_ldwlca_en.pdf.

30. Wassim, G., & Smith, J. (2007). *Development of Crash Imminent Test Scenarios for Integrated Vehicle-Based Safety Systems*. (Report No. DOT HS 810 757). Washington, DC: National Highway Traffic Safety Administration.

31. Trimble, T. T., Medina, A. F., Schaudt, W. A., Bowman, D., & Hanowski, R. J. (2009, October). *Enhanced rear signaling (ERS) for heavy trucks: Phase III – development of field operational test; Task 3a report: Phase 1 GES database analysis update*. Contract No. DTMC75-07-D-00006, Task Order 2. Washington, DC: Federal Motor Carrier Safety Administration.

32. Wierwille, W. W., Lee, S. E., & DeHart, M. C. (2003, April). *Enhanced rear lighting and signaling systems: Testing and optimization of high-level and stopped/slowly-moving vehicle rear-signaling systems , Task 2 Report*. (Report no. DOT HS 809 597). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2003/Task%202%20Report.pdf

33. Wierwille, W. W., Lee, S. E., & DeHart, M. C. (2005, March). *Project Final Report Emphasizing Task 3 Results: Test Road Experiment on High-Level Rear Lighting*.(Report No. DOT HS 809 864). Washington, DC: National Highway Traffic Safety Administration. Availahble at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2005/Task_3_Results.pdf

34. Wierwille, W. W., Llaneras, R. E., & Neurauter, L. (2009). *Evaluation of enhanced brake lights using surrogate safety metrics: Task 1 report: Further characterization and development of rear brake light signals*. (Report No. DOT HS 811 127). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811127.pdf

35. Freese, J., & Freese, S. (2006, October). *Enhanced rear signaling for commercial motor vehicles; Final report*. Contract No. 1406-04-06-PO-60596. Washington, DC: Federal Motor Carrier Safety Administration.

36. Pierowicz, J., & Damon, G. (2004a). *Enhanced rear signaling for commercial vehicles: Task 2c subtask 6 report: GES review of heavy truck vehicle types involved in rear-end crashes*. Contract No. DTMC75-03-C-00018. Washington, DC: Federal Motor Carrier Safety Administration.

37. Pierowicz, J., & Damon, G. (2004b). *Enhanced rear signaling for commercial vehicles: Task 2c subtask 4 report: Additional analysis of GES datafile*. Contract No. DTMC75-03-C-00018. Washington, DC: Federal Motor Carrier Safety Administration.

38. Lockheed Martin (2010). *IntelliDrive Core System Concept of Operations (ConOps)*. DTFH61-10-F-00045. October 28th. Washington, DC: National Highway Traffic Safety Administration.

39. LeBlanc, D., Nowak, M., Tang, Z., Pomerleau, D., & Sardar, H. (2008, March). System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) – Heavy Truck Platform. UMTRI-2008-19, Washington, DC: National Highway Traffic Safety Administration. Available at http://deepblue.lib.umich.edu/bitstream/2027.42/58194/1/100879.pdf

40. Cronin, B. (2010, January). *Overview of IntelliDrive.* (PowerPoint presentation).. IntelliDrive Webinar: Safety Applications for Commercial Vehicles. Retrieved from www.fmcsa.dot.gov/facts-research/media/webinar-10-01-20-slides.pdf.

41. Federal Highway Administration, CA Division. (2009, November). System Engineering Guidebook for ITS Version 3.0: 3.5.1 *Requirements Development (System and Sub-system Level Requirements)*. Retrieved from www.fhwa.dot.gov/cadiv/segb/views/document/sections/Section3/3_5_1.htm.

42. *Systems Engineering Fundamentals*. (2001, January). Fort Belvoir, VA: Defense Acquisition University Press. Available at www.dau.mil/pubs/pdf/SEFGuide%2001-01.pdf

APPENDIX A.
RECRUITMENT EMAIL

E-mail Title: Participation in Development of Performance Requirements for CV Safety Systems.

Dear NAME,

Hello, my name is ____________, from the Virginia Tech Transportation Institute in Blacksburg, Virginia. As part of a National Highway Transportation Safety Administration (NHTSA) sponsored research study examining performance requirements for vehicle-to-vehicle (V2V) safety applications for heavy commercial vehicles, we are surveying and interviewing vehicle industry representatives (manufacturers, suppliers, industry groups, and fleet operators) to get insight on minimum performance requirements for available and future crash avoidance systems. We'd also like to learn more about operational experiences with current systems.

I received your contact information from ______________________ (INSERT source).

We are interested in having vehicle industry representatives complete a brief (i.e., 15 minute) questionnaire and take part in an interview, most likely via teleconference, to learn more about performance requirements for potential V2V safety applications for heavy commercial vehicles. All information provided through the questionnaire and interview will be kept confidential, and only group summarized responses will be reported to the NHTSA.

We would appreciate your participation. If you are interested in participating, please reply to this e-mail and I will send you the questionnaire to complete and set up a time for an interview. We will need you to complete and return the questionnaire by (INSERT date). If you have any questions regarding the project, please feel free to contact me.

Also, if you know of any interested commercial vehicle industry representatives, feel free to share my contact information with them.

Thank you in advance,

Name
Title
Center for Truck and Bus Safety, Virginia Tech Transportation Institute

e-mail: [redacted]
telephone: [redacted]
fax: [redacted]
website: www.vtti.vt.edu
Virginia Tech Transportation Institute
3500 Transportation Research Plaza, Blacksburg, VA 26040

APPENDIX B.

INFORMED CONSENT INFORMATION FOR QUESTIONNAIRE

E-mail Title: Questionnaire regarding V2V safety applications.

Dear NAME,

Thank you for agreeing to participate in the Virginia Tech Transportation Institute (VTTI) project *Development of Performance Requirements for Commercial Vehicle Safety Systems*. Attached is a questionnaire that asks for your opinions regarding current and future crash avoidance systems and for your operational experiences with these systems.

The purpose of this research study is to examine the performance requirements for potential vehicle-to-vehicle (V2V) safety applications that are appropriate for heavy commercial vehicles. The questionnaire should take no more than 15 minutes to complete. To participate, you must be associated with or employed in the vehicle industry and be at least 18 years old. There are no direct benefits or compensation to you. You may enjoy the ability to share your opinions and help guide the development of performance requirements for V2V safety applications in heavy commercial vehicles.

The risks associated with this questionnaire include possible discomfort with sharing your opinions in a questionnaire. The questionnaire does not ask for your name or any other directly identifying information. Results will only be shared as group averages (for example: 22% of - respondents said . . .) and discussion of open ended responses (for example: respondents mentioned . . .). All information we collect in this questionnaire will be kept confidential and will be stored on secure access-restricted servers at VTTI. Completing this questionnaire is voluntary. You may choose to not answer any question, or end the questionnaire, at any time without penalty. If you have any questions prior to starting this questionnaire, you may contact the investigators, NAME ([redacted]) or NAME ([redacted]).It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research. Access to the data will be under the supervision of Darrell Bowman, Rich Hanowski, Tammy Trimble, Scott Stone, Justin Morgan, Zac Doerzaph, and Stephanie Baker (VTTI Research Team). Darrell Bowman or Rich Hanowski may grant other VTTI researchers access to de-identified data (e.g. no names attached) collected in this study to be used in additional IRB approved research projects. All data collected in this study will be saved for at least 5 years and a decision to destroy the data will be made at that time.

If you choose to participate, please:

1. Open and review the attached questionnaire.
2. Complete the questionnaire.
3. Save the document with your responses.
4. E-mail the completed questionnaire back to me (INSERT [redacted]) by (INSERT date).

If you should have any questions about the protection of human research participants regarding this study, you may contact Dr. David Moore, Chair, Virginia Tech Institutional Review Board for the Protection of Human Subjects, telephone [redacted]; address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

By completing the questionnaire, you confirm that you are at least 18 years old and currently associated with or employed in the vehicle industry. In addition, you acknowledge that you have read the consent information above and give your voluntary consent to participate in this study. Thank you in advance for your time.

Name
Title
Center for Truck and Bus Safety,
Virginia Tech Transportation Institute

e-mail: NAME@vtti.vt.edu
telephone: [redacted]
fax: [redacted]
VTTI website: www.vtti.vt.edu
Virginia Tech Transportation Institute
3500 Transportation Research Plaza,
Blacksburg, VA 26040

APPENDIX C.

INFORMED CONSENT INFORMATION FOR INDIVIDUAL AND SMALL GROUP PHONE INTERVIEWS

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Development of Performance Requirements for Commercial Vehicle Safety Systems

Investigators: Darrell Bowman, Rich Hanowski, Tammy Trimble, Scott Stone, Justin Morgan, Zac Doerzaph, and Stephanie Baker of the Virginia Tech Transportation Institute, Virginia Tech.

I. THE PURPOSE OF THIS RESEARCH PROJECT

The purpose of this research study is to examine the performance requirements for potential vehicle-to-vehicle (V2V) safety applications that are appropriate for heavy commercial vehicles. During the phone interview we will ask you for your opinions regarding minimum performance requirements for available and future crash avoidance systems as well as your operational experiences with current systems.

II. PROCEDURES

You have been invited to take part in a phone interview. The interview will last no more than 60 minutes and will be audio recorded. The interview will be an informal discussion where you will have the opportunity to share your thoughts and opinions about V2V safety applications.

III. RISKS

There is minimal risk involved in this study. The minimal risks include: possible minor discomfort from expressing your opinions to researchers, and in some cases, other participants who may be taking part in the phone interview.

IV. BENEFITS

No promise or guarantee of benefits will be made to encourage your participation. You may find the discussion interesting and your opinions may influence the development of technologies to improve safety and ultimately reduce crashes.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this interview will be treated with confidentiality. Coding (i.e., Participant#01) will be used so participant names will not be linked with any data collected. Data that is reported or shared with any outside group or people will be in summary form so that your participation will remain anonymous. The interview will be audio recorded. The data from this study will be stored at the Virginia Tech Transportation Institute. The audio recordings will be destroyed after they are transcribed.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research. Access to the data will be under the supervision of Darrell Bowman, Rich

Hanowski, Tammy Trimble, Scott Stone, Justin Morgan, Zac Doerzaph, and Stephanie Baker (VTTI Research Team). Darrell Bowman or Rich Hanowski may grant other VTTI researchers access to de-identified data (e.g. no names attached) collected in this study to be used in additional IRB approved research projects. All data collected in this study will be saved for at least 5 years and a decision to destroy the data will be made at that time.

VI. COMPENSATION
No offer or promise of compensation or benefit for your participation is being made to you.

VII. FREEDOM TO WITHDRAW
As a voluntary participant in this study, you are free to withdraw at any time for any reason. No penalties will be assessed if you choose to withdraw at any point from the study. You are also free to refrain from answering any questions that you would rather not answer.

VIII. APPROVAL OF RESEARCH
This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University. This approval is good for the period of time listed at the end of this document.

IX. PARTICIPANT'S RESPONSIBILITIES
If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To be physically free of any substances (alcohol, drugs, etc.) that might impair your ability to participate in the interview discussion.
2. Acknowledge that you are at least 18 years old and currently associated with or employed in the vehicle industry.

X. PARTICIPANT'S PERMISSION
I have read and understand the requirements, procedures, and conditions of this project. I have had all of my questions answered. By providing my verbal consent at the start of the phone interview, I voluntarily agree to participate in this study and have my voice recorded during the interview. If I participate in this study, I understand that I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any questions about this research or its conduct, I may contact:
Darrell Bowman, *Project Manager and Principal Investigator* [redacted]

If I should have any questions about the protection of human research participants regarding this study, I may contact:
Dr. David Moore,
Chair of the Virginia Tech Institutional Review Board for the Protection of Human Subjects
[redacted]moored@vt.edu
Research Compliance Office
1880 Pratt Drive, Suite 2006 (0497)
Blacksburg, VA 24061

APPENDIX D.
DATA COLLECTION DOCUMENTS

This appendix includes questionnaire and interview data collection documents:

Questionnaires

- Suppliers (LV, CV, and DSRC)
- Manufacturers
- Fleets

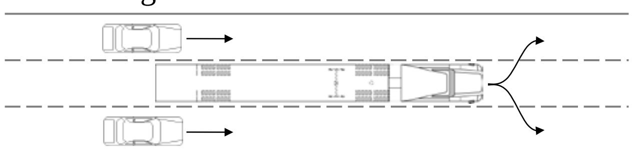
Vehicle Supplier –

Crash Avoidance Technology Questionnaire

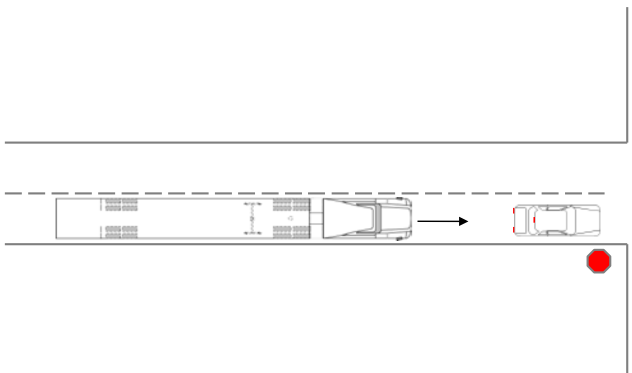
BACKGROUND

The US Department of Transportation (DOT) has a high interest in accelerating the widespread deployment of connected commercial vehicles (e.g., trucks, buses, transit). The DOT's Motivation for widespread deployment of connected vehicle safety is dependent on understanding the effectiveness of safety applications in commercial vehicles. Within this context, the DOT has contracted the Virginia Tech Transportation Institute (VTTI) to obtain industry input; specifically with regard to current and upcoming crash avoidance technologies. The following questions are focused around the six crash types DOT has identified for further research. The crash types include:

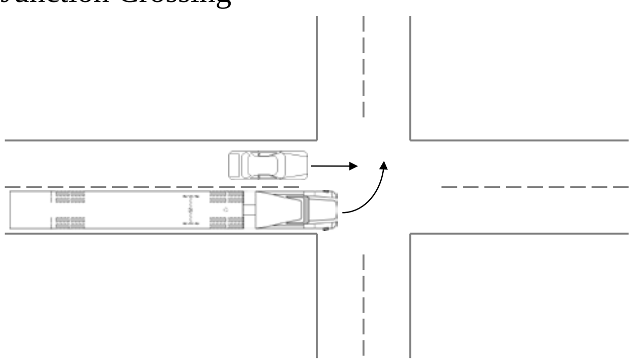
1. Lane Change



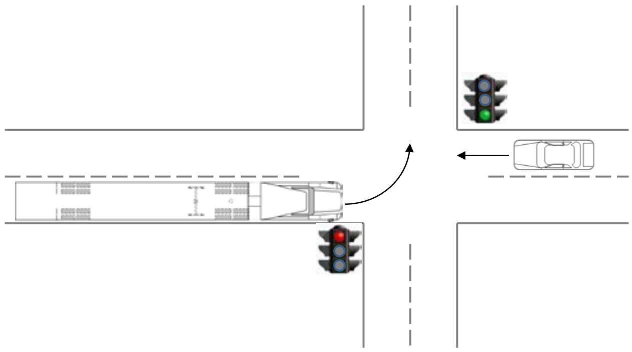
2. Rear-End



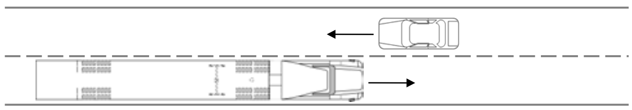
3. Junction Crossing



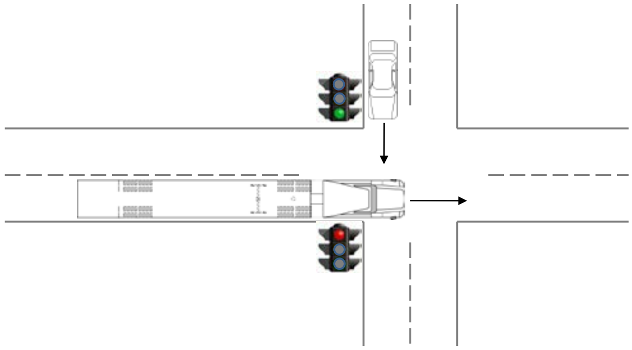
4. Left Turn Across Path, Opposite Direction



5. Opposite Direction



6. Traffic Control Device Violation



It is expected that industry currently has existing, emerging, or theoretical technologies to address most of the crash types. VTTI has assembled the following questions to capture the current state of technology and knowledge within the industry. The questions provide an opportunity for industry to provide the DOT background information that will aid in the development of research programs to accelerate widespread deployment of accident avoidance technologies. Precise answers are not required, any information is appreciated. If necessary, please add space between questions to fully answer questions.

1. Please indicate, with an "X", the **most** important crash type to your customers and your business?

_____ Lane Change
_____ Junction Crossing
_____ Opposite Direction
_____ Rear End
_____ Left Turn Across Path, Opposite Direction
_____ Traffic Control Device Violation

2. Please explain the importance of your **top** ranking from question 1.

3. Address the following questions for each crash type
    a. *Crash Type:* ***Lane Change***
        i. What general performance requirements are needed to address crashes involving lane changes?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –

2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address crashes involving lane changes?

iii. What technologies are emerging to address crashes involving lane changes?

b. Crash Type: ***Rear-End***

i. What general performance requirements are needed to address rear-end crashes?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –

2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address rear-end crashes?

iii. What technologies are emerging to address rear-end crashes?

c. Crash Type: ***Junction Crossing***

i. What general performance requirements are needed to address junction crossing crashes?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –

2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address junction crossing crashes?

iii. What technologies are emerging to address junction crossing crashes?

d. Crash Type: ***Left Turn Across Path, Opposite Direction***

i. What general performance requirements are needed to address left turn across path crashes involving vehicles from opposite directions?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –

2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address left turn across path crashes involving vehicles from opposite directions?

iii. What technologies are emerging to address this crash type?

e. Crash Type: ***Opposite Direction***

i. What general performance requirements are needed to address crashes involving vehicles from opposite directions?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –
2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address crashes involving vehicles from opposite directions?

iii. What technologies are emerging to address crashes involving vehicles from opposite directions?

f. Crash Type: ***Traffic Control Device Violation***

i. What general performance requirements are needed to address crashes involving traffic control device violations?

1. From the subject vehicle perspective (e.g., subject vehicle speed) –

2. From the roadway perspective (e.g., roadway heading relative to the vehicle axes and road curvature) –

3. From the adjacent objects perspective (e.g., kinematics of adjacent traffic) –

ii. What technologies currently exist to address crashes involving traffic control device violations?

4. What technologies are emerging to address crashes involving traffic control device violations?

5. It is foreseeable that vehicles will eventually be equipped with dedicated short range communications (DSRC) that will wirelessly communicate their precise location and trajectory to other vehicles and infrastructure. Please respond to the following questions with the assumptions that DSRC has become widely deployed among all vehicles on the roadway.
   a. Would you consider moving away from the current onboard sensors and using data from the wireless vehicle network?

   b. What potential problems do you envision with using DSRC to replace the current sensor suite?

   c. Would DSRC technology provide novel data to improve the effectiveness of crash avoidance technologies? If so, what novel data might that be?

6. Please share any additional thoughts or comments you have in the space below:

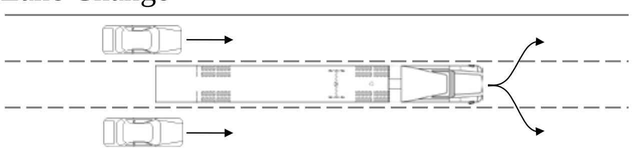
Commercial Vehicle Manufacturer –

Crash Avoidance Technology Questionnaire

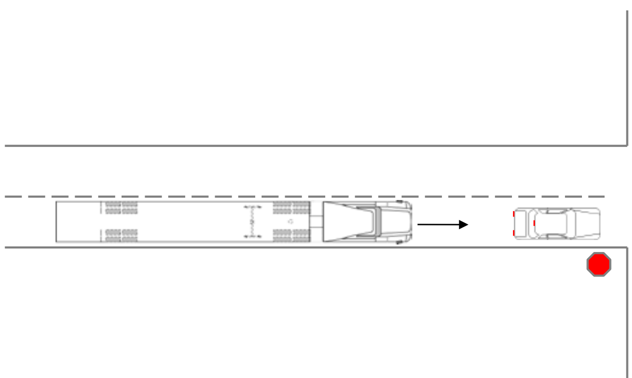
BACKGROUND

The U.S. Department of Transportation has a high interest in accelerating the widespread deployment of connected commercial vehicles (e.g., trucks, buses, transit). The DOT's Motivation for widespread deployment of connected vehicle safety is dependent on understanding the effectiveness of safety applications in commercial vehicles. Within this context, the DOT has contracted the Virginia Tech Transportation Institute to obtain industry input; specifically with regard to current and upcoming crash avoidance technologies.
The following questions are focused around the six crash types DOT has identified for further research. The crash types include:

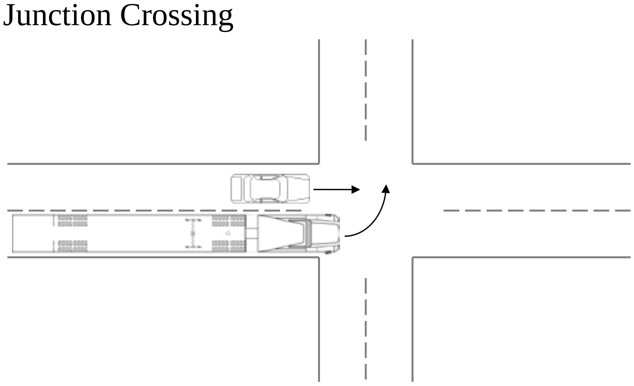
1. Lane Change



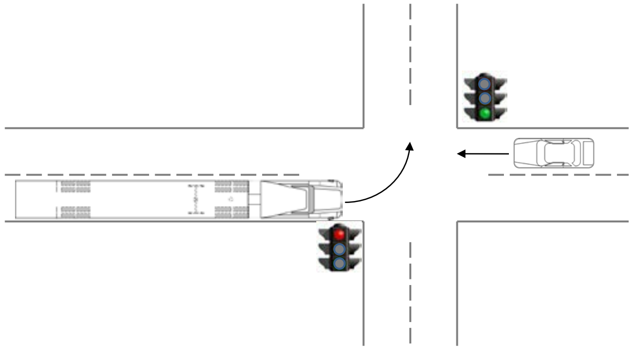
2. Rear-End



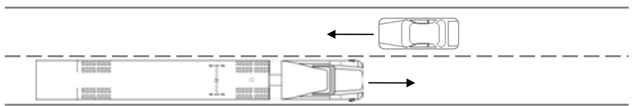
3. Junction Crossing



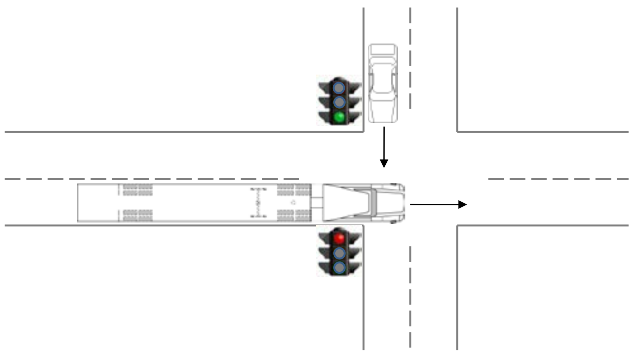
4. Left Turn Across Path, Opposite Direction



5. Opposite Direction



6. Traffic Control Device Violation



It is expected that industry currently has existing, emerging, or theoretical technologies to address most of the crash types. VTTI has assembled the following questions to capture the current state of technology and knowledge within the industry. The questions provide an opportunity for industry to provide the DOT background information that will aid in the development of research programs to accelerate widespread deployment of accident avoidance technologies. Precise answers are not required, any information is appreciated. If necessary, please add space between questions to fully answer questions.

1. Please indicate, with an "X", the **most** important crash type to your customers and your business?

_____ Lane Change
_____ Junction Crossing
_____ Opposite Direction
_____ Rear End
_____ Left Turn Across Path, Opposite Direction
_____ Traffic Control Device Violation

2. Please explain the importance of your **top** ranking from question 1.

3. Address the following questions for each crash type
   a. *Crash Type:* ***Lane Change***
      i. What technologies are you currently implementing in your vehicles to address crashes involving lane changes?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate crashes involving lane changes?

iii. Are there technologies to address this crash type that you do not implement?

b. *Crash Type:* ***Rear-End***

i. What technologies are you currently implementing in your vehicles to address rear-end crashes?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate rear-end crashes?

iii. Are there technologies to address this crash type that you do not implement?

c. *Crash Type:* ***Junction Crossing***

i. What technologies are you currently implementing in your vehicles to address junction crossing crashes?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate junction crossing crashes?

iii. Are there technologies to address this crash type that you do not implement?

d. *Crash Type:* ***Left Turn Across Path, Opposite Direction***

i. What technologies are you currently implementing in your vehicles to address left turn across path crashes involving vehicles from opposite directions?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate this crash type?

iii. Are there technologies to address this crash type that you do not implement?

e. *Crash Type:* ***Opposite Direction***

i. What technologies are you currently implementing in your vehicle to address crashes involving vehicles from opposite directions?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate this crash type?

iii. Are there technologies to address this crash type that you do not implement?

f. *Crash Type:* ***Traffic Control Device Violation***

i. What technologies are you currently implementing in your vehicles to address crashes involving traffic control device violations?

ii. What are the general vehicle-level requirements to be considered when integrating technologies that mitigate this crash type?

iii. Are there technologies to address this crash type that you do not implement?

4. It is foreseeable that vehicles will eventually be equipped with dedicated short range communications (DSRC) that will wirelessly communicate their precise location and trajectory to other vehicles and infrastructure. Please respond to the following questions with the assumptions that DSRC has become widely deployed among all vehicles on the roadway.

   a. Would you consider voluntarily implementing DSRC for enabling crash avoidance systems on your product line?

   b. What potential problems do you envision with using DSRC to replace the current sensor suite?

5. Please share any additional thoughts or comments you have in the space below:

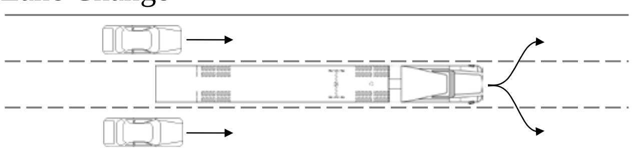
Commercial Vehicle Fleet –

Crash Avoidance Technology Questionnaire

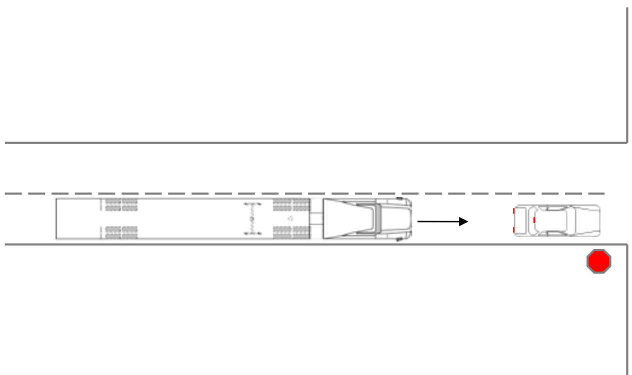
BACKGROUND

The U.S. Department of Transportation has a high interest in accelerating the widespread deployment of connected commercial vehicles (e.g., trucks, buses, transit). The DOT's Motivation for widespread deployment of connected vehicle safety is dependent on understanding the effectiveness of safety applications in commercial vehicles. Within this context, the DOT has contracted the Virginia Tech Transportation Institute to obtain industry input; specifically with regard to current and upcoming crash avoidance technologies.
The following questions are focused around the six crash types DOT has identified for further research. The crash types include:

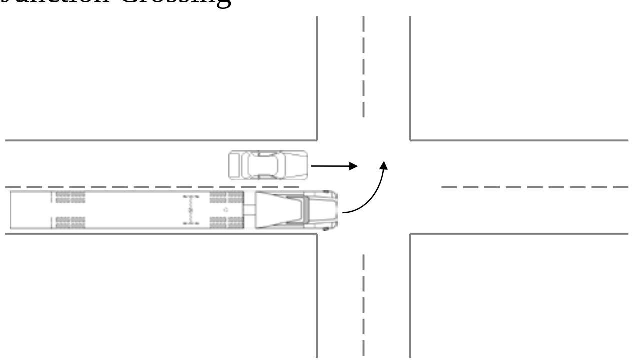
1. Lane Change



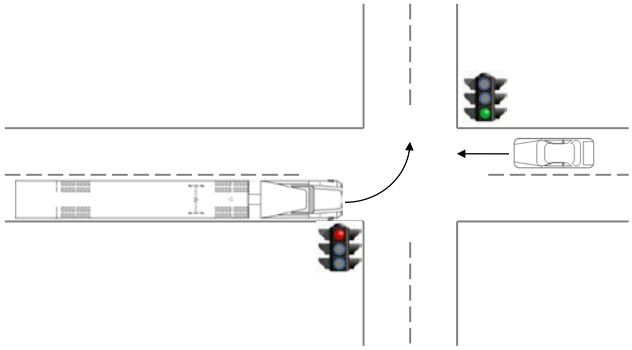
2. Rear-End



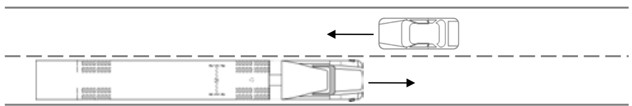
3. Junction Crossing



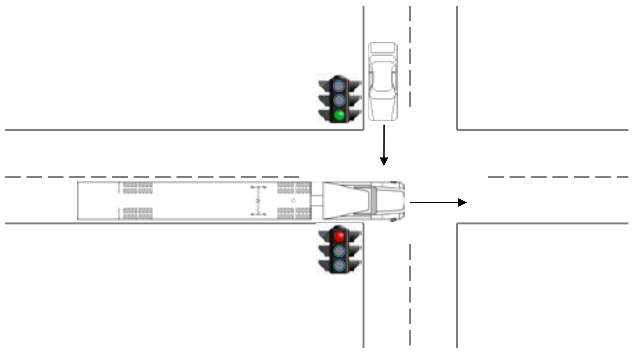
4. Left Turn Across Path, Opposite Direction



5. Opposite Direction



6. Traffic Control Device Violation



It is expected that industry currently has existing, emerging, or theoretical technologies to address most of the crash types. VTTI has assembled the following questions to capture the current state of technology and knowledge within the industry. The questions provide an opportunity for industry to provide the DOT background information that will aid in the development of research programs to accelerate widespread deployment of accident avoidance technologies. Precise answers are not required, any information is appreciated. If necessary, please add space between questions to fully answer questions.

1. Please indicate, with an "X", the **most** important crash type to your customers and your business?

_____ Lane Change
_____ Junction Crossing
_____ Opposite Direction
_____ Rear End
_____ Left Turn Across Path, Opposite Direction
_____ Traffic Control Device Violation

2. Please explain the importance of your **top** ranking from question 1.

3. Address the following questions for each crash type
   a. Crash Type: ***Lane Change***

i. What technologies are you currently implementing in your fleet to address lane change crashes?

ii. What fleet implementation issues have you encountered with these technologies?

iii. Are you aware of other technologies to address lane change crashes that you do not implement?

b. *Crash Type:* ***Rear-End***

i. What technologies are you currently implementing in your fleet to address rear-end crashes?

ii. What fleet implementation issues have you encountered with these technologies?

iii. Are you aware of other technologies to address rear-end crashes that you do not implement?

c. *Crash Type:* ***Junction Crossing***

i. What technologies are you currently implementing in your fleet to address junction crossing crashes?

ii. What fleet implementation issues have you encountered with these technologies?

iii. Are you aware of other technologies to address junction crossing crashes that you do not implement?

d. *Crash Type:* ***Left Turn Across Path, Opposite Direction***

i. What technologies are you currently implementing in your fleet to address left turn across path crashes involving vehicles from opposite directions?

ii. What fleet implementation issues have you encountered with these technologies?

iii. Are you aware of other technologies to address left turn across path crashes involving vehicles from opposite directions that you do not implement?

e. *Crash Type:* ***Opposite Direction***
    i. What technologies are you currently implementing in your fleet to address crashes involving vehicles from opposite directions?

    ii. What fleet implementation issues have you encountered with these technologies?

    iii. Are you aware of other technologies to address crashes involving vehicles from opposite directions that you do not implement?

f. *Crash Type:* ***Traffic Control Device Violation***
    i. What technologies are you currently implementing in your fleet to address crashes involving traffic control device violations?

    ii. What fleet implementation issues have you encountered with these technologies?

    iii. Are you aware of other technologies to address crashes involving traffic control device violations that you do not implement?

4. It is foreseeable that vehicles will eventually be equipped with dedicated short range communications (DSRC) that will wirelessly communicate their precise location and trajectory to other vehicles and infrastructure. Please respond to the following questions with the assumptions that DSRC has become widely deployed among all vehicles on the roadway.
    a. Would you consider voluntarily implementing DSRC in your fleet so that crash avoidance systems can communicate with other vehicles and roadway infrastructure?

    b. What potential problems do you envision with using DSRC to replace the current sensor suite?

5. Please share any additional thoughts or comments you have in the space below:

DOT HS 811 772
May 2013

U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov

9149-051713-v2