The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes

Special Investigation Report

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The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes

National Transportation Safety Board

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National Transportation Safety Board. 2015. ***The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes*****. Special Investigation Report NTSB/SIR-15-01. Washington, DC.**

Abstract: Over the past 3 years, the National Transportation Safety Board (NTSB) has investigated nine rear-end accidents involving passenger or commercial vehicles striking the rear of another vehicle—the result of which was 28 fatalities and 90 injured people. In 2012, rear-end crashes resulted in 1,705 fatalities and represented almost half of all two-vehicle crashes. This Special Investigation Report reviews the previous recommendations made by the NTSB pertaining to the reduction of rear-end crashes and examines recent collision avoidance technologies that would aid in their prevention. The report concludes that collision warning systems, particularly when paired with active braking, could significantly reduce the frequency and severity of rear-end crashes. The report issues six new recommendations—four to the National Highway Traffic Safety Administration (NHTSA) and two to vehicle manufacturers, both passenger and commercial. In addition, it reiterates two recommendations to NHTSA and reclassifies four recommendations previously issued to NHTSA.

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Acronyms and Abbreviations

ACC	adaptive cruise control
ADAC	Allgemeiner Deutscher Automobil Club
AEB	autonomous emergency braking
CAS	collision avoidance system(s)
CV	connected vehicle
CWS	collision warning system(s)
DBS	dynamic brake support
DOT	US Department of Transportation
ESC	electronic stability control
FARS	Fatality Analysis Reporting System
GES	General Estimates System
HLDI	Highway Loss Data Institute
I-65	Interstate 65
IIHS	Insurance Institute for Highway Safety
ISO	International Standardization Organization
NCAP	New Car Assessment Program (Euro/Australia/US)
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SUV	sport utility vehicle
TTC	time-to-contact
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VIN	vehicle identification number

Executive Summary

In 2012 alone, more than 1.7 million rear-end crashes occurred on our nation's highways, resulting in more than 1,700 fatalities and 500,000 injured people. Many of these crashes could have been mitigated, or possibly even prevented, had rear-end collision avoidance technologies been in place. However, slow and insufficient action on the part of the National Highway Traffic Safety Administration (NHTSA) to develop performance standards for these technologies and require them in passenger and commercial vehicles, as well as a lack of incentives for manufacturers, has contributed to the ongoing and unacceptable frequency of rear-end crashes.

The National Transportation Safety Board (NTSB) has an extensive history of investigating rear-end crashes and has encouraged technological countermeasures since 1995. To date, the NTSB has issued 12 recommendations pertaining to this safety issue.

In 2001, the NTSB released a Special Investigation Report on rear-end crashes that focused on technology as a potential countermeasure and made several recommendations to federal agencies and vehicle manufacturers (NTSB 2001). Due to a lack of progress in the implementation of NTSB recommendations intended to mitigate or prevent rear-end crashes, the recent technological advancements in collision avoidance technologies, and the continued prevalence of rear-end crashes, the NTSB is revisiting the topic of rear-end crash prevention.

This report describes the common causes of rear-end crashes, considers some of the latest potential solutions and countermeasures, reiterates and reclassifies previous recommendations, and issues new recommendations aimed at reducing the number and severity of such crashes. Specifically, the main goals of this report include the following:

- Reviewing the progress of the implementation of previous recommendations related to rear-end crash mitigation,
- Examining the real-world and predicted efficacy of currently available collision avoidance technologies and the potential for such technologies to mitigate or prevent rear-end crashes,
- Examining current methods of assessment and rating systems for collision avoidance technologies, and
- Exploring options for increasing the presence of such technologies in newly manufactured vehicles.

Ultimately, the NTSB's investigation found that currently available forward collision avoidance technologies for passenger and commercial vehicles still show clear benefits that could reduce rear-end crash fatalities. However, more must be done to speed up deployment of these technologies in all vehicle types. As a result of these findings, the NTSB makes six new recommendations in this report in the following areas:

- For manufacturers to install forward collision avoidance systems as standard features on all newly manufactured passenger and commercial motor vehicles,

- For NHTSA to expand the New Car Assessment Program to include a graded rating to assess the performance of forward collision avoidance systems, and

- For NHTSA to expand or develop protocols for the assessment of forward collision avoidance systems in passenger and commercial vehicles.

The NTSB is also reiterating two recommendations to NHTSA and reclassifying four previous recommendations.

1. Background

The National Transportation Safety Board (NTSB) has an extensive history of investigating rear-end crashes, particularly catastrophic rear-end crashes with multiple fatalities.[1] Those investigations have resulted in the NTSB making several recommendations aimed at reducing or mitigating the occurrence of such crashes; however, potentially preventable fatal rear-end crashes continue to occur. Technological improvements in recent years have partly motivated the re-examination of this safety issue, with the objective of reducing the overall number of rear-end crashes, including some of the catastrophic ones that the NTSB typically investigates. The NTSB investigated one such crash in Elizabethtown, Kentucky, in 2013.[2]

Elizabethtown, Kentucky. On March 3, 2013, approximately 11:10 a.m., a collision occurred in the northbound lanes of Interstate 65 (I-65), near Elizabethtown, Kentucky, resulting in multiple fatalities. A 2012 Kenworth truck-tractor in combination with a semitrailer was traveling northbound in the right lane of I-65. A 1999 Ford Expedition sport utility vehicle (SUV), occupied by a 62-year-old driver and seven passengers, was also traveling northbound in the right lane in front of the combination vehicle. In response to a disabled vehicle broken down in the right shoulder, vehicles ahead of the Ford had slowed and a traffic queue had formed in the right lane of I-65. The Ford was at the rear of that traffic queue. The combination vehicle struck the rear of the Ford, pushing it into another passenger vehicle. A postcrash fire ensued, killing six of the Ford's eight occupants (see figure 1).

Figure 1. View of the Kenworth truck-tractor combination and Ford Expedition at final rest positions in the crash site near Elizabethtown, Kentucky.

There were no mechanical issues with the truck-tractor. The Kenworth driver was not driving under the influence of drugs or alcohol and was not using a cell phone at the time of the

[1] A rear-end crash is one in which the front of one vehicle strikes the rear of a moving or stationary vehicle; however, it does not necessarily have to involve the front structure of a vehicle impacting the rear of another. For example, if a vehicle approaching the rear of another skids sideways due to braking and its side collides with the vehicle ahead, the crash would still be classified as a rear-end collision.

[2] See the NTSB public docket (HWY13FH008).

crash. The weather conditions were clear and not a factor. A review of the accident driver's logbook indicated that he had driven beyond the legal hours of service and was likely fatigued at the time of the crash. The driver of the Kenworth truck-tractor reported to police that he "didn't hit the brakes in time."

The speed limit at this section of I-65 was 70 mph. Information from the Kenworth truck-tractor's engine control module revealed that the combination vehicle was traveling between 66 and 68 mph for the 60 seconds leading up to the impact with the Ford SUV. Due to the ensuing fire, recovering data from the Ford was not possible, although the investigation revealed that the Ford was moving very slowly or was stopped at the time of the collision.

Other Rear-End Crashes. From 2012 to 2014, the NTSB investigated nine rear-end accidents, including Elizabethtown, involving passenger or commercial vehicles striking the rear of another vehicle, which resulted in 28 fatalities and 90 injured people (see table 1). It is worth noting that these collisions do not represent the typical rear-end crash scenario; rather, they represent more catastrophic crashes.

Table 1. Summary of nine rear-end crashes investigated by the NTSB (2012–2014).

Accident Location[a]	Date	Initial Striking Vehicle	Fatalities	Injured People	Vehicles Involved
Paynes Prairie, FL	1/29/12	Honda Accord (northbound); Dodge Dakota (southbound)	11	29	16
Springfield, VA	12/27/12	Ford Ranger	3	1	2
Elizabethtown, KY	3/3/13	Kenworth truck-tractor	6	2	3
Murfreesboro, TN	6/13/13	Kenworth truck-tractor	2	6	9
Annapolis, MD	7/19/13	International truck-tractor	0	1	3
White Deer Township, PA	10/9/13	Greyhound motorcoach	1	37	2
Naperville, IL	1/27/14	International truck-tractor	1	2	5
Three Rivers, TX	1/30/14	Ford E-350 van	3	4	2
Cranbury, NJ	6/7/14	Peterbilt truck-tractor	1	8	6
		TOTAL	28	90	48

[a] See the NTSB public docket for more information on the following crashes: Paynes Prairie, FL (HWY12FH006); Springfield, VA (HWY13SH001); Elizabethtown, KY (HWY13FH008); Murfreesboro, TN (HWY13FH015); Annapolis, MD (HWY13FH018); White Deer, PA (HWY14IH001); Naperville, IL (HWY14FH002); Three Rivers, TX (HWY14IH003); and Cranbury, NJ (HWY14MH012).

Although rear-end crashes are rarely fatal—approximately 1 in 1,000 results in a fatality—the statistics reveal the prevalence of rear-end crashes. In 2012, there were 1.7 million rear-end crashes, representing almost half of all two-vehicle crashes. The data for the last two available years—2011 and 2012—show that rear-end crashes killed 3,491 people and injured more than 1 million others (see table 2).

Table 2. Statistics for rear-end crashes, including number of crashes, fatalities, and injured people (2011 and 2012).

	Crashes	Fatalities	Injured People
2011	1,630,918	1,786	527,572
2012	1,742,413	1,705	547,443

Source: National Highway Traffic Safety Administration's Fatality Analysis Reporting System and General Estimates System

These numbers illustrate the frequent occurrence of rear-end crashes on roadways—more than 4,500 rear-end crashes each day.

1.1 Rear-End Crash Causes

In each of the NTSB-investigated rear-end collisions from table 1, the drivers of the striking vehicles were not able to detect the slowed or stopped traffic and stop their vehicle in time. The reasons for their failure to stop varied—from driver inattentiveness and violations of driver expectancy to unsafe speed, fatigue, and reduced visibility.[3]

Driver failure to orient attention to critical situations is a common cause of rear-end crashes. For example, a 100-car naturalistic study, sponsored by the National Highway Traffic Safety Administration (NHTSA), found that driver inattention contributed to 78 percent of all crashes (Klauer and others 2006), while 87 percent of rear-end crashes involved some degree of driver inattention (Lee and others 2007).[4]

The primary detriment of driver inattention is an increased response time to a potential collision. When inattentive, drivers take longer to perceive a danger and subsequently take longer to initiate an avoidance maneuver. The prevalence of portable electronic devices and in-vehicle systems designed to assist a driver with tasks unrelated to driving, such as music and

[3] Driver expectancy is a condition in which drivers expect situations, events, and information to operate in certain ways; expectancies relate to a driver's readiness to respond to them in successful ways. Aspects of the highway situation that violate prevalent expectancies lead to longer reaction times, confusion, and driver error. Such situations include suddenly stopped or slowed traffic on a highway, particularly outside areas (for example, a work zone) in which such traffic may occur.

[4] In naturalistic driving research, driving behavior is observed in a natural, real-world setting through unobtrusive means.

communication, increases the potential for driver distraction and, as such, contributes further to driver inattention.

In addition to driver inattention, other factors can increase a driver's response time to a potential collision. In many crashes investigated by the NTSB, particularly in the highway environment, a violation of driver expectancy occurred when a driver encountered slowed or stopped traffic due to congestion, a work zone, or a crash. In those crashes, the driver of a striking vehicle was unprepared for the slowed or stopped vehicle ahead, resulting in a rear-end collision. Fatigue, road conditions (icy/wet roadway), and reduced visibility (due to fog, sun glare, smoke, or fire) are also frequently cited as contributing factors in rear-end crashes. These conditions, coupled with unsafe driving behaviors, such as speeding and following too closely, often result in rear-end collisions.

1.2 NTSB Recommendations History

Over the last 2 decades, the NTSB has examined various collision avoidance technologies, such as collision warning systems (CWS), and has made 12 safety recommendations to the US Department of Transportation (DOT) and vehicle manufacturers regarding the need to develop performance standards for these technologies and to promote their utilization in vehicles. The NTSB believes such technologies could prevent or mitigate a crash; however, many of the NTSB's recommendations in this area have not been addressed in a satisfactory manner. (A complete list of these safety recommendations is presented in appendix A.)

The NTSB made its first recommendation pertaining to collision avoidance technology in 1995 (Safety Recommendation H-95-44), when it asked the DOT to begin testing CWS within commercial fleets. Due to a lack of progress in addressing this issue, this recommendation was classified "Closed—Unacceptable Action" in 1999.

The NTSB again addressed the technological solutions for rear-end collisions in a 2001 Special Investigation Report (NTSB 2001). In this report, the NTSB issued 10 recommendations pertaining to collision avoidance technology. Two recommendations (H-01-6 and -8) asked NHTSA to develop performance standards for CWS and adaptive cruise control (ACC) for new commercial and passenger vehicles, and one recommendation (H-01-7) asked NHTSA to require that all new commercial vehicles be equipped with such a system. NHTSA expressed its concern about the difficulty in differentiating the effect of ACC and CWS and, while acknowledging the potential safety benefit of CWS in commercial vehicles, stated that more data were required. The NTSB acknowledges that parsing the potential benefits of ACC and CWS is challenging and that, in the current generation of collision avoidance systems (CAS), ACC should be viewed as a secondary component of a CAS, which is overridden when a warning or autonomous emergency braking (AEB) is required. However, progress on the implementation of these recommendations has been limited, particularly for the recommendations pertaining to commercial vehicles. While NHTSA has made some progress on the development of performance standards for CWS in passenger vehicles (H-01-8), and is currently developing performance standards for the assessment of AEB systems in heavy trucks, collision avoidance technologies are still not required on new commercial vehicles.[5] Therefore, these recommendations were classified "Open—Unacceptable Response."

In 2008, the NTSB issued a recommendation to NHTSA (H-08-15) to determine whether equipping commercial vehicles with AEB and electronic stability control (ESC) would reduce commercial vehicle accidents and, if so, to require these technologies to be installed on new commercial vehicles. In its response in December 2014, NHTSA reported that it was in the process of conducting research examining this question and would make a decision regarding the implementation of these systems in 2015.

The NTSB concludes that the slow development of performance standards and the lack of regulatory action have delayed deployment of collision avoidance technologies that could prevent or mitigate rear-end crashes.

[5] This information was obtained from NTSB e-mail correspondence with the associate administrator for Vehicle Safety Research at NHTSA in January 2015.

2. Technologies and Research for the Prevention of Rear-End Crashes

2.1 Collision Avoidance Systems

2.1.1 Overview

The primary goal of any CAS technology is to prevent crashes by detecting a conflict and alerting the driver, and, in many systems, also aiding in brake application or automatically applying brakes. For the purposes of this report, a *complete* forward CAS is defined as a suite of technologies that accomplishes all those goals. The complete forward CAS in passenger vehicles typically includes CWS, dynamic brake support (DBS), and AEB; in commercial vehicles, the DBS system is limited or absent. (See figure 2 below. These components are also discussed in more depth in the following sections.)

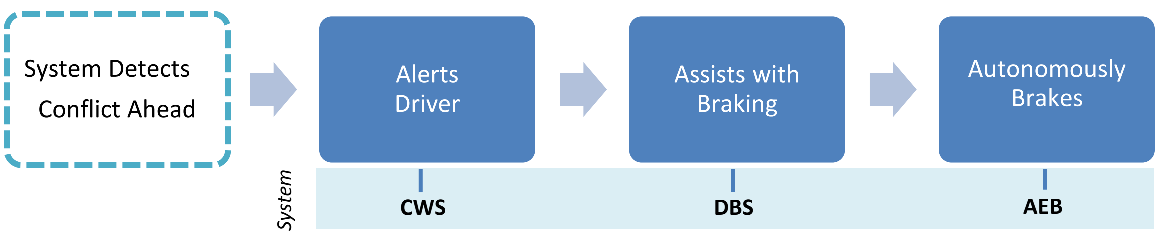

Figure 2. Steps and system components associated with the complete forward CAS.

A complete forward CAS works by monitoring the environment—either via lidar (light detection and ranging), radar, camera, or a fusion of different technologies[6]—for potential conflicts, such as a slow moving or stopped vehicle. Then, when it detects a conflict, it begins the process of alerting the driver by initially preparing the brakes in anticipation of braking and alerting a driver through different warning cues. If the conflict persists, the system initiates AEB or provides additional braking force if the driver brakes too late or not strongly enough. The effectiveness of the forward CAS (complete or its components) depends heavily on the accuracy and timeliness of detection, which relies on the quality of the installed sensor, camera, or vision algorithm detecting targets. (See appendix B and Glossary of Terms for additional description of forward CAS components.)

While forward CAS for passenger and commercial vehicles operate similarly, differences in vehicle size and weight require the manufacturers of AEB components to consider differences in vehicle stopping distances.

[6] A fusion system is any system that combines two or more types of CAS technologies, such as lidar, radar, and camera.

2.1.2 Collision Warning Systems

A CWS assists a driver in preventing or mitigating a rear-end collision by presenting auditory, visual, and/or haptic warnings.[7] The current human-machine interfaces—the manner in which a CWS alerts a driver—are consistent with the key findings of the research on CWS development. This research has examined the extent to which various warning alerts aid drivers in a variety of potentially dangerous situations, including frontal collision, blind spot detection, and lane departure. Researchers consistently reported faster response times to sudden events when drivers were alerted by multi-modal signals, such as an auditory/visual or auditory/haptic, rather than a single sensory cue (Kramer and others 2007; Forkenbrock and others 2011).

The findings of the research into the efficacy of different warning cues to alert a driver to a potential collision, although conducted with passenger vehicles, also apply to commercial vehicles. While the timing of the warnings presented to a heavy truck driver may differ from the timing posed to a driver in a passenger vehicle, the basic findings of the benefits of multi-modal cues remain.

2.1.3 Dynamic Brake Support

Various versions of a DBS system exist, but they all share a common purpose: to assist when a driver brakes in response to a sudden emergency situation.[8] A DBS system uses information from forward-looking sensors/cameras to ascertain driving situations and potential conflicts. One function includes pre-charging brakes in anticipation of the driver's braking response. As part of this function, the system builds up preventive brake pressure by placing the braking pads on the brake disks and putting the hydraulic brake assist into an alert state. When a driver actually brakes, the fastest braking response time is achieved. The pre-charging of the brake system, which can save about 30 milliseconds in passenger vehicles, may result in a reduction of impact velocity but is unlikely to actually prevent a collision.

Some DBS systems can aid a driver by delivering a predetermined braking force when a driver initiates a sudden braking response to avoid an imminent collision. This braking assistance is particularly useful because most drivers do not apply sufficient pressure when braking in emergency situations (Page and others 2005). A DBS system can also measure the speed at which the brake pedal is applied, as well as the braking force, differentiating braking in response to a sudden emergency event from controlled deceleration. When a certain threshold is reached, the system can apply full braking pressure, assisting the driver in achieving the shortest stopping distance.

Most passenger vehicle manufacturers in the United States that offer forward CAS offer some version of a DBS system in their vehicles. The functionalities of a DBS system, described above, are more limited in truck-tractors and motorcoaches. Due to the current design of brakes on such vehicles—in particular, air brake systems—pre-charging of brakes is not feasible.

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[7] A haptic alert involves providing tactile sensations to a driver, in the form of pressure, vibrations, or motion.

[8] DBS is also known as dynamic braking assist system.

2.1.4 Autonomous Emergency Braking

AEB refers to a component of forward CAS that autonomously applies brakes in order to prevent or mitigate a collision. AEB is typically activated after a warning system alerts a driver about a potential rear-end collision and the driver fails to respond. The AEB may apply either partial or full braking force, or cascaded braking, which is the application of partial braking followed by full braking force.[9]

AEB systems designed to work at high speeds require different types of sensors, such as mid- or long-range sensors, while those designed for lower speeds use short-range sensors. Some of the current AEB systems are designed to prevent collisions (up to certain speeds), while others may be capable only of collision mitigation.

2.2 Research on the Efficacy of Forward CAS

2.2.1 Overview

In the NTSB's 2001 report examining CWS technology, the NTSB presented research showing the potential for CWS to reduce the frequency of rear-end crashes (NTSB 2001). In the last decade, however, new research examining the efficacy of CWS in both passenger and commercial vehicles, and newer technology, such as AEB, has emerged. In the next few sections, we present the latest research examining (1) the predicted benefits of such systems, (2) insurance claim studies, and (3) available field operational tests.[10]

2.2.2 Predicted Benefits Research

One method of determining the potential value of the wide-scale implementation of a certain technology is through predicted benefits research. Such research typically utilizes data from various crash databases or naturalistic research—and applies excluding variables—to determine the number of crashes that could have been prevented had such technology been deployed.[11]

The NTSB used 2011–2012 crash data from the Fatality Analysis Reporting System (FARS) database to determine the number of fatalities that resulted from rear-end crashes and then evaluated those crashes to determine which could potentially have been prevented or mitigated by the implementation of forward CAS technology in all vehicles.[12] Using the 2011–

[9] Cascaded braking serves a dual purpose: (1) to act as another cue to a driver regarding the potential conflict and (2) to provide the system additional time in which to determine the imminence of the collision and whether the full braking is required. The additional time to determine the need for full braking can reduce the incidence of false alarms—for example, initiating full braking when a conflict does not exist.

[10] Field operational tests involve naturalistic examination of the effectiveness of the tested technology, such as forward CAS. The optimal research design involves a field operational test in which the same vehicle models with and without a forward CAS are compared, while controlling for environmental and driver characteristics.

[11] This past research excluded those crashes that a forward CAS may not prevent, such as those occurring in inclement weather (for earlier generations of CAS technologies) or those in which another vehicle cuts in front.

[12] FARS is a nationwide census of fatal motor vehicle crashes on public roads in which a death occurred within 30 days. (See http://www.nhtsa.gov/FARS.)

2012 crash data from the General Estimates System (GES) database, the NTSB also examined the number of injuries that could have been prevented, or the number of crashes in which the severity might have been mitigated, had the vehicles been equipped with a forward CAS.[13] The full report is available in the NTSB public docket (DCA14SS001).[14]

Specifically, the NTSB looked at the number of rear-end crashes that resulted in fatalities and injuries from three categories of striking vehicles: passenger vehicles, truck-tractors, and single-unit trucks. The NTSB examined factors such as road characteristics, time of day, and precrash maneuvers to determine whether the current generation of CAS would have prevented a crash. Potentially preventable collisions included those that occurred during inclement weather or in poor visibility conditions, and those that resulted from driver error.[15] These are the specific conditions that can be best addressed by a forward CAS.

During 2011–2012, two-vehicle rear-end crashes resulted in 3,491 fatalities—2,700 of which were attributed to crashes in which a passenger vehicle, truck-tractor, or single-unit truck struck the rear of another vehicle.[16] The results of NTSB analysis of these data showed that, during those 2 years, up to 2,220 lives might have been saved, had the vehicles been equipped with forward CAS. This analysis assumes a perfect system capable of providing sufficiently early warnings or initiation of the AEB.

A forward CAS would also have been effective in reducing the number of injured people and the severity of injuries. When specifically considering the rear-end crashes in which a passenger vehicle was the striking vehicle, a forward CAS might have prevented or lessened the severity of injuries in 93.7 percent of those crashes. This is compared to 87.1 and 79.0 percent when the striking vehicle was a single-unit truck or a tractor-trailer, respectively. Tables 3 and 4 outline the results of the NTSB's study of crash data.[17]

Table 3. Fatalities resulting from rear-end crashes by vehicle class.

	2011		2012		
Vehicle Class	**Total**	**Potentially Preventable**	**Total**	**Potentially Preventable**	**TOTAL Potentially Preventable**
Passenger (1-2)	1,165	950	1,127	934	1,884
Commercial (3-7)	55	48	54	41	89
Commercial (8)	169	139	130	108	247
				TOTAL	**2,220 (82.2%)**

[13] Data within the GES come from a nationally representative sample of police-reported motor vehicle crashes—from minor to fatal. (See http://www.nhtsa.gov/NASS.)

[14] See docket location at http://tinyurl.com/m63wyeg.

[15] Crashes considered potentially preventable did not include those in which (1) the driver had been asleep or unconscious, (2) drivers were changing lanes or merging, (3) drivers were reported as swerving to avoid an object or other vehicle prior to the collision, or (4) vehicle defects were reported. However, the reporting for these factors may be incomplete.

[16] The rest of the fatalities occurred in rear-end crashes in which the vehicle identification number (VIN) of the striking vehicle was not reported, or those in which the striking vehicle had an invalid VIN, was a motorcycle, or was a bus.

[17] The NTSB used VIN-based methods to identify large trucks in weight classes 3–7 and class 8 in FARS. However, GES did not provide VIN-based weight classes, so we relied solely on police-reported vehicle body type to identify large trucks. For this reason, NTSB presents the data for fatalities and injuries for non-passenger vehicles in different tables.

Table 4. Injured people resulting from rear-end crashes by vehicle type.

Vehicle Class	2011 Total	2011 Potentially Preventable	2012 Total	2012 Potentially Preventable	TOTAL Potentially Preventable
Passenger	504,838	473,298	522,918	489,580	962,878
Commercial Single-Unit	4,909	4,205	7,177	6,324	10,529
Commercial Tractor-Trailer	4,722	4,149	5,841	4,195	8,344
				TOTAL	**981,751 (93.5%)**

The results of the research carried out by the NTSB is consistent with the predicted benefits research performed by the Insurance Institute for Highway Safety (IIHS), which used 2004–2008 crash data for passenger vehicles (Jermakian 2011) and medium- and heavy-duty trucks (Jermakian 2012).

2.2.3 Insurance Claim Research

Studies using insurance claim data offer another method of estimating the real-world impact of collision avoidance technologies on rear-end crashes involving passenger vehicles. The IIHS used insurance data from the database of its sister institute, the Highway Loss Data Institute (HLDI), to examine insurance claims for three passenger vehicle manufacturers—Acura, Mercedes-Benz, and Volvo—all of which offered models with a CAS, with or without an AEB component (Moore and Zuby 2013).[18] With certain limitations, the IIHS study examined the insurance claim rates of the vehicles equipped with a forward CAS and compared them to the same year and model of vehicles not equipped with such systems.[19] It is important to note that each claim indicated only an occurrence of a crash and not the extent of it, and did not report whether any injuries or fatalities resulted from the crash.

While the study examined different types of insurance claims, the most relevant was property damage liability, which covers damage that at-fault drivers cause to other people's vehicles and property, including in rear-end crashes. The results showed a lower property damage liability claim frequency across all vehicles equipped with any type of forward CAS, compared to the same or similar vehicles without a forward CAS. Mercedes-Benz and Volvo vehicles equipped only with a CWS had a 7 percent lower claim frequency, compared to the same vehicles without CWS. Vehicles equipped with CWS with AEB showed a further reduction in claim frequency. Specifically, Acura and Mercedes-Benz vehicles had about a 14 percent lower claim frequency compared to the same vehicles without these systems, while Volvo had a 10 percent lower claim frequency (Moore and Zuby 2013).

[18] The insurance data accessible to the HLDI covered more than 80 percent of all passenger vehicles in the insurance market.

[19] Since all Volvo models S60 and XC60 were equipped with a forward CAS, they were compared to similar Volvo models without a forward CAS, as well as the same year vehicles from other passenger vehicle manufacturers in the same category.

2.2.4 Field Research

Field testing can yield valuable data when examining the efficacy of a safety system. Continued observation and data collection on vehicles equipped with such systems to determine their long-term effectiveness are critical. The following sections discuss two such field tests of commercial vehicles—one performed by Volvo and DOT, and another performed by Con-way.

Volvo and DOT. Starting in 2001, Volvo Trucks, in cooperation with the DOT, conducted field research examining the potential safety benefits of advanced safety systems, including CWS, for truck-tractors (US DOT 2007). As part of this research, 100 truck-tractors were tracked and their data were collected over a period of 3 years. The full test group comprised 50 truck-tractors equipped with CWS, ACC, and ESC systems. The other 50 truck-tractors were equipped only with a CWS, although a subset of this group (20 trucks) had their CWS disabled for the first 18 months, serving as the baseline group to which the treatment conditions were compared (see figure 3).

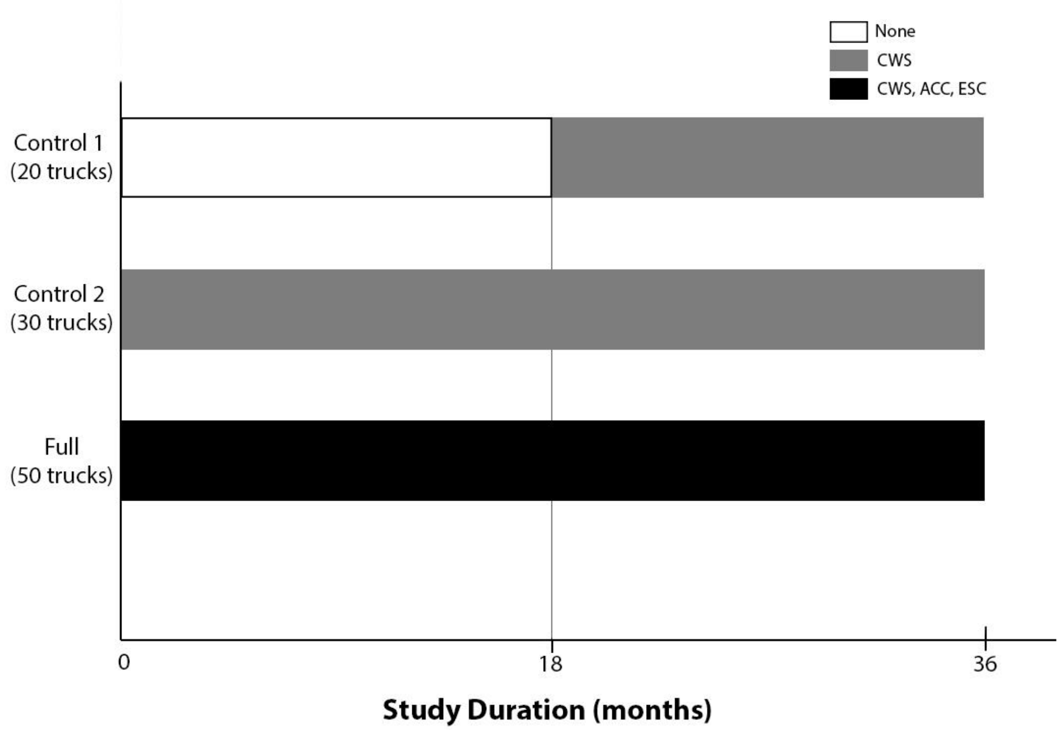

Figure 3. Design of the DOT and Volvo study showing three groups testing different forward CAS technologies (key at top right of graphic) over various time frames.

The trucks in this study were equipped with an Eaton Vorad CWS, which was able to detect vehicles up to 350 feet forward of the truck. The Eaton Vorad system did not include AEB.

From the collected data, the researchers calculated the frequency of conflicts (driving situations that resulted, or could have resulted, in a rear-end crash), the threshold of which was based on the time required to initiate braking or conduct another avoidance maneuver. The conflicts were further categorized based on their severity—from the least severe (allowing a driver up to 1.5 seconds to begin braking) to the most severe (requiring a driver to brake hard within 0.5 seconds). So, the primary measure included the frequency of conflicts at different severity levels.

When examining the frequency of the conflicts—while taking into account the miles traveled—the results showed that, for every 10 conflicts that occurred for a truck-tractor without any safety systems, 7.2 conflicts occurred for a truck-tractor equipped with only a CWS and 6.3 conflicts occurred for a truck-tractor equipped with CWS, ACC, and ESC systems. The results clearly showed that truck-tractors equipped with CWS alone, or in combination with other safety components, were less frequently (by 37 percent) involved in situations that had a potential to result in a rear-end collision.

In driver debriefings and surveys, more than 80 percent of drivers reported that they preferred driving truck-tractors equipped with a CWS. Drivers reported that the systems made them more vigilant and improved their following distances. The improvement in following distance is supported by the data showing that, in the baseline condition, the average following distance was 149 feet, which was 15 feet shorter than when assisted with a CWS.

Con-way. Con-way performed an internal study to determine the extent to which a suite of safety technologies (forward CAS with AEB, ESC, and lane departure warning) installed on the truck-tractors in its fleet reduced the frequency of various types of crashes. This study collected data over a 30-month period on approximately 12,600 truck-tractors. Researchers compared the crash rate and frequency of engagement in risky driving behavior, such as driving at an unsafe speed, in truck-tractors equipped with the suite of safety systems to those truck-tractors without such systems. The results were uniformly positive: drivers operating truck-tractors equipped with the safety systems exhibited a decreased crash rate for different types of crashes, as well as a decline in risky driving behavior. For example, there was a 71 percent reduction in rear-end collisions and a 63 percent decline in unsafe following behaviors (see figure 4).

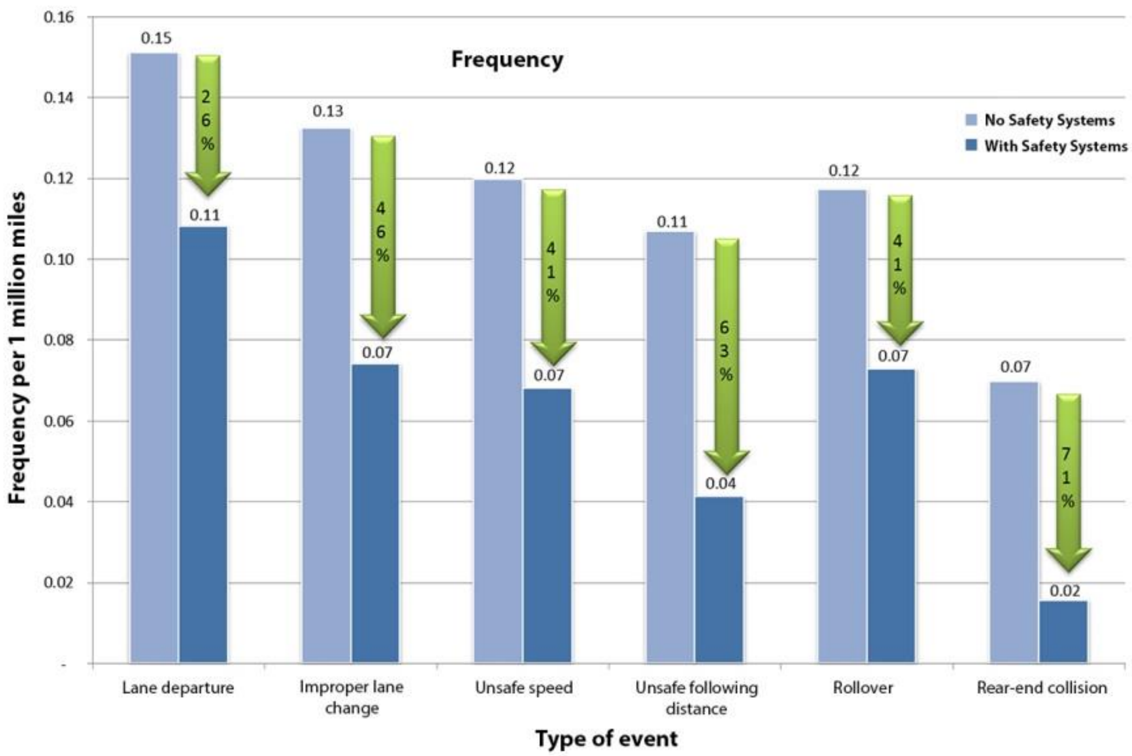

Figure 4. Crash rates of different types of crashes and frequency of engagement in risky driving behaviors in vehicles with and without safety systems. Data were collected between January 2011 and September 2013. (Source: Con-way)

2.2.5 Summary of the Research

Predicted benefits research, insurance claim data, and field research by various private entities, government agencies, and universities showed a significant benefit from the use of forward CAS. It is worth noting that the research on the efficacy of forward CAS in highway—especially, commercial—vehicles has largely focused on the capacity of those systems to *prevent* rear-end crashes. However, *mitigating* the impact of a crash can also prevent fatalities. Therefore, the NTSB concludes that, while focusing research on how forward CAS can prevent rear-end crashes is important, mitigating a crash is similarly important.

The NTSB's predicted benefits research showed that a substantial proportion of fatalities and injuries resulting from rear-end crashes might have been prevented had the vehicles been equipped with a forward CAS. The insurance claim research showed that the predicted benefits are realized in the real world. Finally, considerable field research showed that forward CAS are effective in significantly reducing the frequency and the severity of rear-end crashes. Therefore, the NTSB concludes that a CWS, particularly when paired with active braking, such as DBS and AEB, could significantly reduce the frequency and severity of rear-end crashes.

The benefits of a forward CAS would apply, regardless of the driver's level of vigilance. Although drowsy, distracted, and impaired drivers may require more time to detect a potential conflict and initiate an avoidance maneuver, a CWS may, at the very least, mitigate the cost of inattentiveness. Furthermore, AEB would initiate, even if a driver were asleep or otherwise incapacitated.

The benefits of a forward CAS are considerable for all highway vehicles; however, most research examining the benefits in commercial vehicles assumed the presence of ESC when assessing the benefits of AEB systems. When an AEB system applies considerable braking force, the system relies on a vehicle's ESC to provide stabilization, particularly to prevent jack-knifing, making ESC a necessary component to ensure the full benefits of AEB.[20] ESC is standard equipment on new passenger vehicles but not on commercial vehicles. The NTSB, therefore, concludes that the full benefits of AEB for commercial vehicles can be achieved only when such a braking system is installed on vehicles also equipped with ESC.

The NTSB continues to be concerned with the issue of stability control for commercial vehicles and has made seven recommendations pertaining to ESC technology since 2002 (see appendix A for recent recommendations pertaining to ESC). In its most recent recommendation (H-11-8), the NTSB asked NHTSA to require all new commercial vehicles to be equipped with such systems. In its most recent correspondence on this recommendation, dated December 2014, NHTSA responded that it was preparing a final notice to consider mandating stability control systems in truck-tractors and motorcoaches. This recommendation, as well as the accompanying recommendation to NHTSA to develop ESC performance standards for commercial vehicles (H-11-7), is currently classified "Open—Acceptable Response." Because of the importance of ESC in the application of forward CAS with AEB, the NTSB reiterates Safety Recommendations H-11-7 and -8.

[20] In the case of a truck-tractor combination vehicle, jack-knifing refers to the folding of a trailer, such that it pushes from behind until it spins around.

3. Deployment of Forward CAS

3.1 Overview

The development of performance standards, which define minimum performance requirements, and assessment protocols, which allow for testing and comparing of systems, can aid in the successful and rapid deployment of forward CAS into all passenger and commercial vehicles. Also important is the development of incentives for manufacturers and consumers. Ultimately, a forward CAS should be compatible with—and even a necessary component of—any future collision avoidance technology to ensure its greatest potential for reducing the frequency and severity of crashes.

In this section, we examine the current performance standards for forward CAS, the prevalence of these systems in passenger and commercial fleets, and the methods and incentives that could expedite deployment of these systems in all vehicles.

3.2 Performance Standards, Assessment Protocols, and Testing

Although more collision avoidance technologies have been deployed into new vehicles over the last decade, NHTSA and standard-producing organizations have been slow to develop established comprehensive standards and criteria for the assessment of these systems. Performance standards specify the minimum level of performance a system, such as a forward CAS, should meet. Performance standards for these systems are typically developed by government agencies, such as NHTSA, or organizations that specialize in the development of performance standards, such as the International Standardization Organization (ISO) or SAE International. These agencies typically also develop assessment protocols—an evaluation process critical to ensuring the efficacy of such systems prior to their deployment in vehicles. Once the assessment protocols are established, the systems can be tested. Manufacturers conduct their own internal tests during the development of systems and typically utilize the established assessment protocols as an additional method to test system effectiveness. An agency such as NHTSA can perform those tests, but transportation safety organizations such as the IIHS or the Allgemeiner Deutscher Automobil Club (ADAC) in Europe also conduct such testing. Those results are made available to the public consumer.

Only one international standard pertaining to forward CAS technologies currently exists. The ISO has developed a standard for CWS that specifies performance requirements and provides limited test procedures.[21] SAE International is in the process of developing standards for multiple aspects of forward CAS. These standards are expected to address interface design, such as the modality and timing of a warning, as well as the performance threshold, such as miss rate and false alarm rate.[22]

[21] See ISO 15623:2013, "Intelligent Transport Systems—Forward Vehicle Collision Warning Systems—Performance Requirements and Test Procedures."

[22] Miss rate indicates a failure to detect a conflict; the false alarm rate indicates the detection of a conflict when none is present.

In 2010, nine years after the NTSB made the majority of its recommendations pertaining to collision avoidance technologies (NTSB 2001), NHTSA developed partial performance standards and assessment protocols for the evaluation of forward CWS for passenger vehicles (addressing Safety Recommendation H-01-8). The assessment protocols (www.regulations.gov; NHTSA-2006-26555-0128) cover the evaluation of the CWS only, not the complete forward CAS. These performance tests are intended to measure the system's ability to detect a conflict and warn a driver, as well as to evaluate the timing of an alert. However, aspects of Safety Recommendation H-01-8 that pertain to human factors guidelines, such as the modalities of a warning, have not been addressed.

While some performance standards and assessment protocols for the forward CAS (specifically CWS) exist for passenger vehicles, NHTSA has not developed any similar standards for commercial vehicles. Despite the lack of any performance standards and assessment protocols, commercial fleets are, nevertheless, adopting forward CAS.

3.2.1 Collision Warning

3.2.1.1 Assessment Protocols

The testing protocols established by NHTSA require forward CWS to be tested under three specific scenarios involving a (1) stopped lead vehicle, (2) suddenly decelerating lead vehicle, and (3) slower-moving lead vehicle. To be effective, warnings must occur sufficiently early; the time of the warning onset has been determined by NHTSA's regulations.[23] The test scenario determines the minimum time of the warning onset a system must achieve. The requirement in each of the three testing scenarios specifies that the test vehicle must travel at 45 mph.

The timing of a warning in rear-end crashes is based on time-to-contact (TTC) with the lead vehicle, provided that both vehicles (lead and striking) remain on the current path and retain the current velocity. A stopped lead vehicle scenario requires a warning to onset, at the latest, at 2.1 seconds TTC. The minimum timing of a warning for a decelerating lead vehicle scenario is 2.4 seconds TTC, and for a slower- moving lead vehicle scenario is 1.8 seconds TTC. To receive a passing grade, a system must recognize a conflict and produce a timely warning in five out of seven trials in each of the three test scenarios. These tests evaluate the system's capacity to detect a conflict but do not evaluate false alarms.

Established protocols for the assessment of CWS for passenger vehicles also exist elsewhere. For example, the European New Car Assessment Programme (Euro NCAP) has developed procedures for the testing of CWS that include the same type of scenarios as those of NHTSA.[24] However, Euro NCAP's protocols include a broader range of velocities—ranging from 12 to 62 mph, depending on the scenario.

[23] See NHTSA-2006-26555-0120.

[24] Euro NCAP, established in 1997, organizes crash tests and provides motoring consumers with an independent assessment of the safety performance of some of the most popular cars sold in Europe. Seven European governments, as well as motoring and consumer organizations in every European country, comprise Euro NCAP.

3.2.1.2 Testing in Passenger Vehicles

NHTSA conducted one of the early on-road tests of vehicles with CWS sold in the United States. Its researchers compared the presence and timing of warning alerts of three passenger vehicles in various testing scenarios (Forkenbrock and O'Harra 2009). In this study, NHTSA tested a vehicle traveling at 45 mph in two different scenarios: (1) as it approached a slow-moving vehicle traveling at 20 mph and (2) as it approached a stopped vehicle. The researchers measured the TTC at which a warning alert was initiated. The timing of an alert when approaching a stopped vehicle differed among passenger vehicle manufacturers, as well as between different scenarios (see table 5). The Mercedes Benz model retained the same timing regardless of the scenario, while the Volvo and Acura vehicles showed a delayed warning when approaching a stopped vehicle. This could indicate differences in the sensitivity of the sensors—such as the delayed detection of the stopped vehicle—or possibly a manufacturer's preference for delaying a warning to a driver about a stopped vehicle ahead.[25]

Table 5. Comparison of average activation times of the collision warning, measured in seconds before contact, among different passenger vehicles and testing scenarios; testing conducted by NHTSA.

Vehicles	Slow-Moving Lead Vehicle	Stationary Lead Vehicle
2009 Acura RL	2.3	1.7
2009 Mercedes-Benz S600	2.3	2.3
2008 Volvo S80	3.1	2.4

In 2011, ADAC compared different vehicles equipped with forward CAS sold in Europe (ADAC 2011). The ADAC conducted tests under the same driving scenarios as NHTSA's study, although at varying speeds (see table 6).

Table 6. Comparison of average activation times of the CWS, measured in seconds before contact, among different passenger vehicles and testing scenarios; testing conducted by ADAC.

Vehicles	Slow-Moving Lead Vehicle		Stationary Lead Vehicle		
	T: 31, L: 13	T: 62, L: 37	T: 12	T: 25	T: 44
Audi A7	1.4	2.1	warning did not activate	1.4	1.9
BMW 530	2.8	3.4	1.8	1.8	2.2
Mercedes-Benz CLS	2.2	2.7	warning did not activate	2.2	2.5
Infiniti M	3.2	4.0	1.7	2.3	2.5
Volvo V60	1.9	2.3	1.6	2.4	3.0
VW Passat	2.7	2.8	.8	warning did not activate	warning did not activate

T = Test vehicle speed (mph)
L = Lead (dummy) vehicle speed (mph)

[25] This would likely be a consequence of minimizing the instances of false alarms.

In both scenarios, the warning was presented earlier in the high-velocity condition, as compared to the low-velocity condition. Vehicles traveling at a higher velocity required a greater stopping distance and, as such, an earlier warning. However, a warning may also be presented too early, potentially being interpreted as a false alarm by a driver. For example, the ADAC considered the warning presented by the Infiniti at 4 seconds as too early, outside the optimal window of alert, as determined by ADAC. It is worth noting that the Audi, Mercedes-Benz, and Volkswagen models did not provide a warning in certain velocity conditions.

As can be seen from the testing conducted in the United States and Europe, the timing of a warning can vary among passenger vehicle manufacturers, as well as within the same manufacturer's products from one year or vehicle model to another. Timing also depends on other factors, such as the vehicle's own speed and the speed of the vehicle in front.

3.2.2 Autonomous Emergency Braking

3.2.2.1 Assessment Protocols

As of the release of this report, NHTSA is still working to finalize performance standards and assessment protocols for testing the efficacy of AEB systems in passenger vehicles; the development of an assessment protocol has gone through several iterations.[26] NHTSA's latest research report regarding AEB systems in passenger vehicles presents the current protocols for the assessment of AEB and DBS; it also presents the results of testing on several vehicles (NHTSA 2014). NHTSA expects to finalize the assessment protocols for AEB and DBS by the end of 2015. Performance standards and protocols for the assessment of AEB in commercial vehicles are also not finalized. These testing procedures are expected to largely mirror those eventually developed and released for passenger vehicles.[27]

The IIHS has developed protocols for the assessment of AEB for passenger vehicles, and, although they represent the first such protocols in the United States, they cover only a single rear-end crash scenario (encountering a stationary vehicle). Moreover, the protocol includes only low-velocity conditions (up to 25 mph). Although these assessment protocols do not cover a wide range of conflict situations, the IIHS has taken an important step toward the evaluation of AEB.

The Euro NCAP's protocols for the assessment of AEB in passenger vehicles include the same scenarios and velocity ranges as those for the assessment of CWS. Furthermore, the Euro NCAP has developed separate assessment protocols for low- and high-velocity scenarios (Euro NCAP 2013a, Euro NCAP 2013b).

[26] See NHTSA docket #2012-0057.

[27] This information was obtained from an NTSB e-mail correspondence with the associate administrator for Vehicle Safety Research at NHTSA in January 2015.

3.2.2.2 Testing in Passenger Vehicles

In September 2013, the IIHS published the testing results of 13 passenger vehicles equipped with AEB (IIHS 2013). (See table 7.) This represented the first such testing in the United States. The testing was performed on vehicles traveling at low speeds, of 12 and 25 mph, encountering a stationary object. One of the tested vehicles avoided the collision at both velocities. Several other vehicles avoided a collision in a low-velocity condition but only mitigated the collision in the higher-velocity condition. The testing revealed that several test vehicles exhibited limited or no reduction in impact velocity in the 25 mph test (see bottom half of table 7). However, more than half of the tested vehicles were able to completely avoid a collision at 12 mph.

Table 7. Comparison of AEB performance (measuring reduction in velocity) across different passenger vehicles and two test velocities in a stationary vehicle scenario; testing performed by the IIHS.

Tested Vehicles	Velocity Reduction (in mph)	
	12 mph test	25 mph test
Subaru Legacy	12[a]	25[a]
Subaru Outback	12[a]	25[a]
Cadillac ATS	12[a]	15
Cadillac SRX	12[a]	19
Mercedes-Benz C-class	11	13
Volvo S60[b]	12[a]	14
Volvo XC60[b]	12[a]	11
Acura MDX	7	6
Audi A4	11	did not activate
Audi Q5	11	did not activate
Jeep Grand Cherokee	4	7
Lexus ES	6	4
Mazda 6	12[a]	did not activate
Volvo S60[c]	12[a]	2
Volvo XC60[c]	12[a]	1

[a] Test vehicle stopped before impacting the target.
[b] Includes CWS with full auto brake.
[c] Includes City Safety system.

These results showed that AEB capabilities also vary significantly among passenger vehicle manufacturers and models. The testing the IIHS performed examined a system's effectiveness in preventing rear-end crashes in low-velocity conditions only, and only when encountering a stationary vehicle. Although this is an important initial step, this test cannot assess the effectiveness of different systems to prevent fatalities, which typically occur in high-speed collisions. ADAC in Europe conducted additional testing of vehicles with AEB. The testing occurred in medium- and high-velocity conditions, and showed considerable performance differences among AEB (see appendix C).

3.2.3 Summary of Assessment Protocols and Testing

3.2.3.1 Passenger Vehicles

Testing of CWS and AEB in the United States has primarily been conducted in low- to medium-velocity conditions, leaving an information gap about how they would operate under high-velocity conditions. The IIHS testing protocols for the AEB component included only low-velocity scenarios, and NHTSA's testing scenarios for a CWS are based on a single velocity of the test vehicle (45 mph). The predicted benefits research presented earlier in the report showed that forward CAS have the potential to save hundreds of lives each year. The NTSB believes that the ultimate goal of these systems should include the reduction of fatalities, necessitating testing of their effectiveness in conditions resembling highway crashes. Testing conducted by the ADAC shows that at least some systems are capable of mitigating high-velocity crashes.

The crash in Elizabethtown, discussed in section 1, involved a striking vehicle traveling at a speed greater than 60 mph shortly before impacting a very slow-moving vehicle—velocity parameters that far exceed NHTSA's current test scenarios for the assessment of CWS. These parameters would not be covered by ADAC's test scenarios either. Although ADAC's scenarios include a test vehicle traveling at highway velocities (for example, 62 mph), the velocity differential (difference in the velocity between the test and the lead vehicle) is only 25 mph.[28] Although the velocity differential in NHTSA's test protocols approaches the observed differences in the Elizabethtown crash, the velocity of the test vehicle does not. The available energy of a vehicle in a 65 mph test is twice that of the same vehicle in a 45 mph test, and the stopping distance is almost double.[29] So, neither NHTSA's nor ADAC's testing scenarios would fully account for the conditions present in the Elizabethtown crash.

The NTSB, therefore, concludes that NHTSA's existing testing scenarios and protocols for the assessment of forward CAS in passenger vehicles do not adequately represent the wide range of velocity conditions seen in crashes, particularly high-speed crashes. Because of this deficiency, the NTSB recommends that NHTSA develop and apply testing protocols to assess the performance of forward CAS in passenger vehicles at various velocities, including high speed and high velocity-differential.

This new recommendation necessitates a review of the recommendation the NTSB issued to NHTSA to develop performance standards for CWS in passenger vehicles (H-01-8). While NHTSA has developed these performance standards, they do not address adherence to human factors guidelines. However, NHTSA has funded and conducted considerable research into the development of human factors guidelines for forward CAS—the findings of which the auto manufacturers, in conjunction with their own research, now use to develop their systems. As such, the evaluation of the adherence to human factors guidelines has been addressed in an acceptable alternate manner. Therefore, Safety Recommendation H-01-8 is classified "Closed—Acceptable Alternate Action."

[28] See section 3.2.1.2 for more detail.

[29] The energy of a vehicle is proportional to that vehicle's velocity squared. Applying this formula shows that a vehicle's energy at 65 mph is double compared to 45 mph ($65^2 / 45^2 = 2.08$).

3.2.3.2 Commercial Vehicles

The NTSB is disappointed with the lack of progress in the development of performance standards and assessment protocols for forward CAS in commercial vehicles. This lack of progress, however, should not preclude the use of such systems in these vehicle types. Currently available CWS and AEB provide clear benefits, meriting a consideration for their deployment, even without the existence of published performance standards. While the NTSB acknowledges the initial steps NHTSA has taken in the development of performance standards for AEB in heavy trucks, progress has been slow. Performance standards and assessment protocols would further advance these technologies, partly by allowing comparisons between systems. The NTSB, therefore, concludes that performance standards and protocols for the assessment of forward CAS in commercial vehicles would provide an impetus for the advancement of the systems and speed their deployment in commercial fleets. Because of the lack of finalized performance requirements, standards, and testing procedures, the NTSB recommends that NHTSA complete, as soon as possible, the development and application of performance standards and protocols for the assessment of forward CAS in commercial vehicles.

Due to the insufficient progress on NTSB's recommendations pertaining to the development of performance standards for CWS in commercial vehicles, and the new recommendations issued in this report instructing NHTSA to develop performance standards and assessment protocols for forward CAS, Safety Recommendation H-01-6 is classified "Closed—Unacceptable Action/Superseded" (superseded by new Safety Recommendation H-15-5). Furthermore, due to NHTSA's lack of progress in requiring CWS on new commercial vehicles, Safety Recommendation H-01-7 is classified "Closed—Unacceptable Action."

The 2008 recommendation to NHTSA pertaining to AEB in commercial vehicles (H-08-15) also merits reconsideration. In this report, the NTSB addressed the first half of this recommendation, which asked NHTSA to determine whether adding AEB and ESC to CWS-equipped vehicles would reduce commercial vehicle accidents. The research findings show that equipping commercial vehicles with AEB and ESC would be an effective countermeasure in reducing the frequency of rear-end collisions or mitigating their severity. Due to NHTSA's lack of progress on this recommendation and the reiterated recommendation to install ESC in new commercial vehicles, Safety Recommendation H-08-15 is classified "Closed—Unacceptable Action."

3.3 Prevalence of Forward CAS

3.3.1 Passenger Vehicles

Currently, there is no reliable estimate of the number of passenger vehicles already deployed on US roadways equipped with a CWS or a complete forward CAS. A review of the features of the current vehicle models, however, provides an indication of the availability of forward CAS. (See appendix D for a listing of forward CAS availability in passenger vehicles.) As of late 2014, 41.2 percent of new 2014 models were offered with an *optional* CWS or complete forward CAS.[30] Although this may appear to be a significant proportion of new vehicle models, only 3.8 percent of new vehicle models included a CWS or a complete forward CAS as a *standard* feature. Specifically, only 4 out of 684 vehicle models in 2014 included a complete forward CAS as a standard feature, which represented less than 1 percent of all 2014 passenger vehicle models (see figure 5).

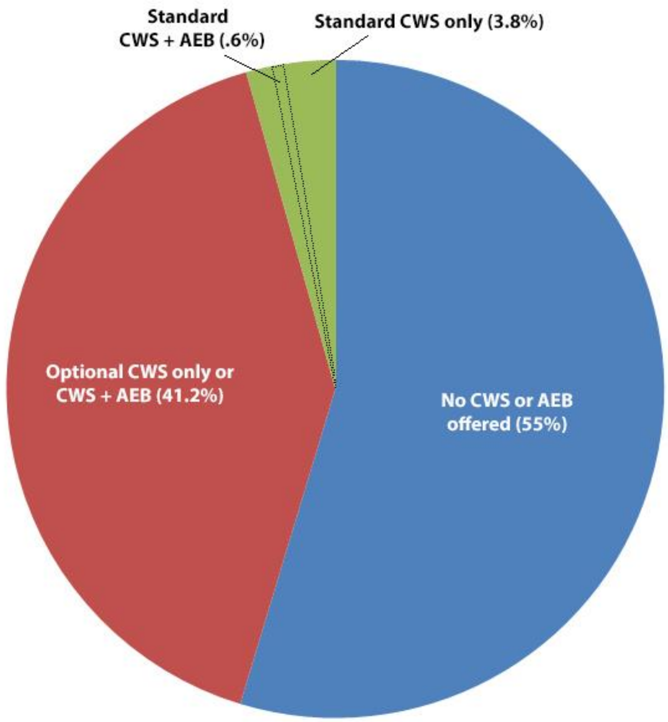

Figure 5. Chart depicting rear-end CAS offered as a standard or optional feature in new 2014 passenger vehicle models.

The proportion of new vehicles offering CAS technologies has, however, greatly increased since 2010, when only 11 percent of new vehicles offered a CWS (HLDI 2012).

Market penetration of forward CAS differs between the American and European markets. As a comparison, Volkswagen offers a complete forward CAS in almost all its vehicles in Europe; however, none of the models sold in the United States, as of 2014, offered a complete forward CAS or CWS only, even as an optional feature. (For the 2014 models, Volvo is the only manufacturer currently offering US consumers a forward CAS as part of the standard equipment.) Thatcham Research estimated that, in 2013 in the United Kingdom, 4 percent of new vehicle models were fitted with a complete forward CAS (Thatcham 2013).

[30] The NTSB received this information via e-mail from the IIHS chief research officer in July 2014.

3.3.2 Commercial Vehicles

Estimates for the number of commercial vehicles in the United States equipped with forward CAS are more readily available. According to one industry estimate, 8–10 percent of class 8 truck-tractors in the United States in 2013 were equipped with a forward CAS.[31] Many commercial fleet owners have made a decision to equip new truck-tractors with a forward CAS. Con-way, for example, started using Meritor WABCO's OnGuard system (CWS and AEB) on its truck-tractors in 2010, and, since then, all new truck-tractors introduced into the fleet have been equipped with that system. This implementation included a complete forward CAS with ESC and lane departure warning. According to Con-way, the company expects that, by the first half of 2015, about half its fleet (approximately 8,000 truck-tractors) will be equipped with this technology.

3.3.3 A Case for Broader Deployment

Research on the effectiveness of forward CAS to mitigate or reduce the frequency of rear-end crashes shows that these systems can offer clear benefits, and these benefits will grow as manufacturers equip more vehicles with this technology. Therefore, the NTSB concludes that broad deployment of forward CAS into passenger vehicles, motorcoaches, single-unit trucks, and truck-tractors would considerably reduce the frequency and severity of rear-end crashes.

Based on the available research evidence and testing that support the benefits of forward CAS, and the established performance standards for CWS, the NTSB recommends that passenger vehicle, truck-tractor, motorcoach, and single-unit truck manufacturers install forward CAS that include, at a minimum, a forward collision warning component, as standard equipment on all new vehicles.

The research has shown considerable benefits of CWS—and even greater benefits when a CWS is accompanied by AEB or is part of a complete forward CAS. These benefits are evident in research examining insurance claims, as well as in field studies. While NHTSA currently does not have finalized performance standards for AEB, the agency is nearing the completion of those standards. Furthermore, NHTSA acknowledges the benefits of these systems and has recently announced a plan to add AEB and DBS systems to the list of recommended features for passenger vehicles.[32] Based on the research evidence supporting the benefits of AEB, as well as the performance standards for active braking soon to be finalized by NHTSA, the NTSB recommends to passenger vehicle, truck-tractor, motorcoach, and single-unit truck manufacturers that, once NHTSA publishes performance standards for AEB, install systems meeting those standards on all new vehicles.

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[31] This information was reported to the NTSB in a phone conversation with the director of Advanced Brake Systems Integration at Meritor WABCO in October 2013.

[32] See NHTSA press release issued on January 22, 2015, http://tinyurl.com/p5gp4z9.

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3.4 Ratings of Forward CAS

3.4.1 United States

NHTSA's protocols for the assessment of a CWS (see section 3.2.1.1) not only establish minimum performance guidelines but also identify the presence of a CWS in passenger vehicles. CWS that meet the minimum performance specifications are recognized on NHTSA's NCAP website (www.safercar.gov). The NCAP consists of a 5-star safety ratings program that provides consumers with information regarding passenger vehicle crashworthiness and rollover safety.[33] CAS technologies are not included in the 5-star rating. A CWS recognition comes in the form of an icon indicating the presence of certain safety technologies, located next to the vehicle's star rating (see figure 6); however, this icon is present only on the NCAP website, not on the vehicle's Monroney label.[34] In January 2015, NHTSA announced plans to add AEB and DBS to the list of recommended technologies for passenger vehicles.[35] Once the performance standards are finalized, vehicles meeting those standards will receive an icon on the NCAP website. While the website includes information about safety technologies, such information will still be absent from the Monroney label.

Figure 6. Example of an NCAP rating showing the 5-star crashworthiness score and an icon indicating a presence of a particular safety technology. Buick shows optional forward collision (in red) and lane departure (in blue) warning systems. Note: red and blue frames were added by the NTSB. (Source: NHTSA's NCAP website)

To date, the IIHS is the only organization in the United States that has published ratings of forward CAS available on passenger vehicles. These ratings supplement the IIHS crashworthiness rating and are based on the availability and performance of CWS and AEB components. The maximum score is 6 points; a vehicle requires a minimum of 5 points to receive the top rating. The IIHS conducts testing only on AEB, and, based off the results of these tests, a vehicle can receive up to 5 points. Vehicles can receive an additional 1 point if equipped with CWS. The IIHS does not conduct tests for the CWS component; rather, the rating for CWS is based on either NHTSA's posting that the system has met the criteria or the auto manufacturer's response as to whether the system has met NHTSA criteria (only if NHTSA has not yet published the rating).

[33] Crashworthiness is the capacity of a vehicle to protect its occupants during a crash.

[34] This window sticker is displayed on all new vehicles and includes a list of certain information about the vehicle.

[35] See NHTSA press release issued on January 22, 2015, http://tinyurl.com/p5gp4z9.

3.4.2 International[36]

Australia's NCAP rating considers both a vehicle's crashworthiness results and the presence and performance of safety assist systems.[37] To be awarded the top 5-star safety rating, a vehicle must have a minimum number of safety assist technologies and have successfully passed crashworthiness tests. The vehicles are scored based on their performance in various scenarios, which carry different weights based on the risk. The Australian NCAP is currently examining ways to encourage passenger vehicle manufacturers to incorporate AEB technologies, either by making their inclusion mandatory in new vehicles or by awarding additional points for vehicles that include well-performing AEB systems. Further concessions are available for vehicles equipped with pedestrian detection systems.[38]

In 2014, the Euro NCAP began rating AEB safety components. Due to more stringent requirements, a vehicle without a forward CAS that received a top rating in 2013 may not achieve a top rating in 2014. The 2014 ratings are based on the performance of a vehicle's forward CAS in both low- and high-velocity scenarios. Starting in 2016, the Euro NCAP plans to include an AEB pedestrian component in its rating system, making it even more challenging for vehicle manufacturers to achieve a top safety grade (Schram, Williams, and Van Ratingen 2013).

3.5 Incentives for Deployment

Providing incentives to vehicle manufacturers to equip new vehicles with forward CAS—the complete forward CAS or its components—would speed up deployment of such systems into all vehicles, resulting in a quicker reduction in rear-end crashes. Federal transportation agencies have an opportunity to promote and implement incentives for the inclusion of forward CAS.[39] NCAP ratings can promote the use of, as well as provide incentives for, forward CAS. These ratings have been effective in informing the public about vehicle crashworthiness, and a similar method of rating the efficacy of forward CAS would inform the public about a vehicle's capacity to prevent rear-end crashes, as well as differentiate these safety systems based on their performance.

The current structure of the NCAP could be improved to provide additional incentives for consumers to buy and manufacturers to deploy vehicles with forward CAS. Based on the current structure of the NCAP 5-star rating, two vehicles can receive the same NCAP star rating, even if one vehicle is equipped with a highly effective forward CAS—as well as other safety features, such as lane departure warning and blind spot assist—and the other vehicle lacks any such

[36] There are several international NCAP agencies. Some are specific to a country, such as JNCAP for Japan, while others are region-based, such as Latin NCAP, operating within Latin America and the Caribbean. Some conduct testing on collision avoidance technologies. More information on international NCAP agencies is available at the Global NCAP website: http://www.globalncap.org/ncap-programmes/.

[37] A safety assist system can include a forward CAS, lane departure warning, blind spot detection, pedestrian collision warning, or other systems that aid in safe driving.

[38] The NTSB received this information via email from the technical manager of the Australian New Car Assessment Program in September 2013.

[39] The NTSB developed a Safety Alert (see appendix E) to increase consumer awareness and promote the use of this technology.

systems. Such a method of evaluating vehicle safety provides very little incentive to vehicle manufacturers to include other safety features, as the manufacturers cannot use the NCAP 5-star rating to differentiate to consumers their safety-feature-laden vehicles from those without such safety systems. Icons indicating the presence of certain safety technologies are located only on the NCAP website (safercar.org) and do not appear on the specification sheet in a dealer showroom. However, even if the public were presented with such icons alongside the 5-star rating score, the icons only indicate whether the vehicle has a safety system. A system meeting only the minimum requirements in the currently available CWS testing—for example, if it detects the lead vehicle in five out of seven trials—would be rated the same as one with a forward CAS with a perfect test score. This lack of information is potentially misleading to consumers and further indicates a need for a graded rating. As can be seen from the testing on CWS and AEB conducted in the United States and in Europe, some forward CAS perform better than others, a distinction the NTSB believes should be recognized.

There is a growing movement to include various CAS technologies in rating systems in vehicles sold outside the United States. It is unclear whether these rating systems have had success in motivating manufacturers to offer these technologies, but there is evidence that the public considers such ratings when purchasing a vehicle. Drivers in Europe have reported safety-related factors, such as the Euro NCAP ratings, as more important than price when purchasing a new vehicle (Koppel and others 2008).

Similar findings have been reported in the United States. A survey conducted by the IIHS showed that three out of four respondents reported having seen a safety rating, and indicated that it would be very useful when making a decision to purchase a new vehicle (McCartt and Wells 2010). Therefore, because rating systems appear to influence purchasing decisions, the NTSB concludes that the incorporation of forward CAS technologies into the 5-star NCAP rating in the United States would provide an incentive to consumers to purchase vehicles with such systems and would likely encourage passenger vehicle manufacturers to include these systems in their vehicles as standard features. Furthermore, because some forward CAS perform better than others, the NTSB concludes that a graded rating that compares the performance of forward CAS across vehicle models would help consumers differentiate the effectiveness of the available systems. The NTSB recommends that NHTSA expand the NCAP 5-star rating system to include a scale that rates the performance of forward CAS. This expansion could take the form of a separate rating system or involve the reorganization of the current 5-star NCAP rating to include forward CAS. Furthermore, the NTSB recommends that, once the rating scale, described in new Safety Recommendation H-15-6, is established, NHTSA include the ratings of forward CAS on vehicle Monroney labels.

3.6 The Forward CAS of Tomorrow

While the primary goal of this report is to examine current research, identify optimal solutions for the prevention and mitigation of rear-end crashes, and make or reiterate recommendations to government agencies and the manufacturers of highway vehicles that will address the immediate need for the reduction of preventable rear-end crashes, the NTSB recognizes the value of keeping an eye toward future safety technologies that could also prevent or mitigate crashes.

Connected vehicle (CV) technology—a possible next step in the evolution of safety systems—represents another method for detecting a conflict. CV technology currently under development does not rely on radar or camera but on communication between vehicles—vehicle-to-vehicle (V2V)—or between vehicles and infrastructure—vehicle-to-infrastructure. (See figure 7.)

Figure 7. Visual representation of wireless communications among vehicles in the application of connected vehicle technology. (Source: NHTSA website)

CV technology's initial introduction is expected to begin in the early part of the 2020s, with the instrumenting of signalized intersections to allow those "connected intersections" to receive information regarding the locations of vehicles in the vicinity and relay information regarding potential conflicts. DOT predicts that, by the year 2040, about 80 percent of signalized intersections will be connected (US DOT 2014).

CV technology is expected to provide better accuracy and faster detection of a conflict. For the V2V-only technology to be effective, however, a significant portion of a fleet would need to be connected; this requirement currently poses the greatest limitation.

Vehicle-based CAS would be essential in the early stages of CV deployment, in which only a small proportion of vehicles would be connected. In the early stages, a vehicle equipped with only CV technology would, therefore, have a low detection rate of forward conflicts, as it would detect conflicts only with other connected vehicles. A safety system that frequently fails to detect a conflict (even if such a limitation is by design) could easily become an unreliable system in the eyes of the driver, further necessitating the need for the comprehensive active safety system offered by a vehicle-based CAS. A connected vehicle, however, that is also equipped with a vehicle-based CAS would be able to detect conflicts with non-connected vehicles. Furthermore, CV technology is expected to only provide information about the potential conflict. Warning alerts or autonomous braking are additional functions that would have to be integrated within a vehicle—functions that are already part of vehicle-based forward CAS.

It may be an additional two to three decades more before the majority of the passenger and commercial fleets become connected. Given this timeline, an alternative active safety system is necessary until the CV technology matures. Vehicle-based CAS provide just such an alternative for two significant reasons: (1) they are immediately available and can prevent collisions and save lives today; and (2) they address the limitations of the CV technology.

The NTSB concludes that new vehicles equipped with vehicle-based forward CAS would obtain immediate safety benefits and be poised to assume future integration with CV technology, which offers an even broader spectrum of safety coverage for drivers.

4. Conclusions

4.1 Findings

1. The slow development of performance standards and the lack of regulatory action have delayed deployment of collision avoidance technologies that could prevent or mitigate rear-end crashes.

2. While focusing research on how forward collision avoidance systems can prevent rear-end crashes is important, mitigating a crash is similarly important.

3. A collision warning system, particularly when paired with active braking, such as dynamic brake support and autonomous emergency braking, could significantly reduce the frequency and severity of rear-end crashes.

4. The full benefits of autonomous emergency braking for commercial vehicles can be achieved only when such a braking system is installed on vehicles also equipped with electronic stability control.

5. The National Highway Traffic Safety Administration's existing testing scenarios and protocols for the assessment of forward collision avoidance systems in passenger vehicles do not adequately represent the wide range of velocity conditions seen in crashes, particularly high-speed crashes.

6. Performance standards and protocols for the assessment of forward collision avoidance systems in commercial vehicles would provide an impetus for the advancement of the systems and speed their deployment in commercial fleets.

7. Broad deployment of forward collision avoidance systems into passenger vehicles, motorcoaches, single-unit trucks, and truck-tractors would considerably reduce the frequency and severity of rear-end crashes.

8. The incorporation of forward collision avoidance system technologies into the 5-star New Car Assessment Program rating in the United States would provide an incentive to consumers to purchase vehicles with such systems and would likely encourage passenger vehicle manufacturers to include these systems in their vehicles as standard features.

9. A graded rating that compares the performance of forward collision avoidance systems across vehicle models would help consumers differentiate the effectiveness of the available systems.

10. New vehicles equipped with vehicle-based forward collision avoidance systems would obtain immediate safety benefits and be poised to assume future integration with connected-vehicle technology, which offers an even broader spectrum of safety coverage for drivers.

5. Recommendations

5.1 New Recommendations

As a result of this Special Investigation Report, the National Transportation Safety Board makes the following new safety recommendations:

To the National Highway Traffic Safety Administration:

> Develop and apply testing protocols to assess the performance of forward collision avoidance systems in passenger vehicles at various velocities, including high speed and high velocity-differential. (H-15-4)
>
> Complete, as soon as possible, the development and application of performance standards and protocols for the assessment of forward collision avoidance systems in commercial vehicles. (H-15-5)
>
> Expand the New Car Assessment Program 5-star rating system to include a scale that rates the performance of forward collision avoidance systems. (H-15-6)
>
> Once the rating scale, described in Safety Recommendation H-15-6, is established, include the ratings of forward collision avoidance systems on the vehicle Monroney labels. (H-15-7)

To Passenger Vehicle, Truck-Tractor, Motorcoach, and Single-Unit Truck Manufacturers:

> Install forward collision avoidance systems that include, at a minimum, a forward collision warning component, as standard equipment on all new vehicles. (H-15-8)
>
> Once the National Highway Traffic Safety Administration publishes performance standards for autonomous emergency braking, install systems meeting those standards on all new vehicles. (H-15-9)

5.2 Previously Issued Recommendations Reiterated in this Report

To the National Highway Traffic Safety Administration:

> Develop stability control system performance standards for all commercial motor vehicles and buses with a gross vehicle weight rating greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system. (H-11-7)

> Once the performance standards in Safety Recommendation H-11-7 have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-8)

5.3 Previously Issued Recommendations Classified in this Report

To the National Highway Traffic Safety Administration:

Safety Recommendation H-01-6, previously classified *Open—Unacceptable Response*, is now classified *Closed—Unacceptable Action/Superseded*, replaced by new Safety Recommendation H-15-5, in section 3.2.3.2 of this report.

> Complete rulemaking on adaptive cruise control and collision warning system performance standards for new commercial vehicles. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning. (H-01-6)

Safety Recommendation H-01-7, previously classified *Open—Unacceptable Response*, is now classified *Closed—Unacceptable Action* in section 3.2.3.2 of this report.

> After promulgating performance standards for collision warning systems for commercial vehicles, require that all new commercial vehicles be equipped with a collision warning system. (H-01-7)

Safety Recommendation H-01-8, previously classified *Open—Unacceptable Response*, is now classified *Closed—Acceptable Alternate Action* in section 3.2.3.1 of this report.

> Complete rulemaking on adaptive cruise control and collision warning system performance standards for new passenger cars. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning. (H-01-8)

Safety Recommendation H-08-15, previously classified *Open—Acceptable Response*, is now classified *Closed—Unacceptable Action* in section 3.2.3.2 of this report.

> Determine whether equipping commercial vehicles with collision warning systems with active braking and electronic stability control systems will reduce commercial vehicle accidents. If these technologies are determined to be effective in reducing accidents, require their use on commercial vehicles. (H-08-15)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Member

T. BELLA DINH-ZARR
Vice Chairman

EARL F. WEENER
Member

Adopted: May 19, 2015

Appendix A: Past NTSB Recommendations Regarding Forward CAS and ESC

Rec #	Report #	Recipient	Recommendation	Status (as of May 2015)
1995				
H-95-44	HAR-95-03	Department of Transportation	Sponsor, in cooperation with the Intelligent Transportation Society of America, fleet testing of collision warning technology through partnership projects with the commercial carrier industry. Incorporate testing results into demonstration and training programs to educate the potential end-users of the systems.	Closed—Unacceptable Action
2001				
H-01-6	NTSB/SIR-01/01	Department of Transportation (later reissued to National Highway Traffic Safety Administration)	Complete rulemaking on adaptive cruise control and collision warning system performance standards for new commercial vehicles. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning.	Open—Unacceptable Response
H-01-7	NTSB/SIR-01/01	Department of Transportation (later reissued to National Highway Traffic Safety Administration)	After promulgating performance standards for collision warning systems for commercial vehicles, require that all new commercial vehicles be equipped with a collision warning system.	Open—Unacceptable Response
H-01-8	NTSB/SIR-01/01	Department of Transportation (later reissued to National Highway Traffic Safety Administration)	Complete rulemaking on adaptive cruise control and collision warning system performance standards for new passenger cars. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning.	Open—Unacceptable Response

H-01-9	NTSB/SIR-01/01	National Highway Traffic Safety Administration	Develop and implement, in cooperation with the Federal Highway Administration, the Intelligent Transportation Society of America, and the truck, motorcoach, and automobile manufacturers, a program to inform the public and commercial drivers on the benefits, use, and effectiveness of collision warning systems and adaptive cruise controls.	Closed—Acceptable Action
H-01-10	NTSB/SIR-01/01	Federal Highway Administration	Develop and implement, in cooperation with the National Highway Traffic Safety Administration, the Intelligent Transportation Society of America, and the truck, motorcoach, and automobile manufacturers, a program to inform the public and commercial drivers on the benefits, use, and effectiveness of collision warning systems and adaptive cruise controls.	Closed—Acceptable Action
H-01-12	NTSB/SIR-01/01	Truck and motorcoach manufacturers	Develop and implement, in cooperation with the National Highway Traffic Safety Administration, the Federal Highway Administration, the Intelligent Transportation Society of America, and automobile manufacturers, a program to inform the public and commercial drivers on the benefits, use, and effectiveness of collision warning systems and adaptive cruise controls.	Closed—Acceptable Action
H-01-13	NTSB/SIR-01/01	Truck and motorcoach manufacturers	Develop a training program for operators of vehicles equipped with a collision warning system or an adaptive cruise control and provide this training to the vehicle operators.	Closed—Acceptable Action
H-01-14	NTSB/SIR-01/01	Automobile manufacturers	Develop and implement, in cooperation with the National Highway Traffic Safety Administration, the Federal Highway Administration, the Intelligent Transportation Society of America, and the truck and motorcoach manufacturers, a program to inform the public and commercial drivers on the benefits, use, and effectiveness of collision warning systems and adaptive cruise controls.	Closed—Acceptable Action

H-01-15	NTSB/SIR-01/01	Intelligent Transportation Association	Develop and implement, in cooperation with the National Highway Traffic Safety Administration, the Federal Highway Administration, and the truck, motorcoach, and automobile manufacturers, a program to inform the public and commercial drivers on the benefits, use, and effectiveness of collision warning systems and adaptive cruise controls.	Closed—Acceptable Action
H-01-16	NTSB/SIR-01/01	American Trucking Associations, Inc.; the National Private Truck Council; and the Owner-Operator Independent Driver Association	Encourage your members to obtain or provide, or both, training to those drivers who operate collision warning system- or adaptive cruise control-equipped trucks.	Closed—Acceptable Action
2008				
H-08-15	HAR-08-02	National Highway Traffic Safety Administration	Determine whether equipping commercial vehicles with collision warning systems with active braking and electronic stability control systems will reduce commercial vehicle accidents. If these technologies are determined to be effective in reducing accidents, require their use on commercial vehicles.	Open—Acceptable Response
2011				
H-11-7	HAR-11-01	National Highway Traffic Safety Administration	Develop stability control system performance standards for all commercial motor vehicles and buses with a gross vehicle weight rating greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system. This recommendation supersedes Safety Recommendation H-10-5.	Open—Acceptable Response
H-11-8	HAR-11-01	National Highway Traffic Safety Administration	Once the performance standards in Safety Recommendation H-11-7 have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a gross vehicle weight rating greater than 10,000 pounds. This recommendation supersedes Safety Recommendation H-10-6.	Open—Acceptable Response

Appendix B: Detection Technologies for Forward CAS

Lidar-based systems. Lidar (light detection and ranging) is a laser-based scanning system that sends out light waves toward a particular location, for example, forward of a vehicle. Once the waves reach an obstacle, such as a stopped vehicle ahead, they bounce back to the source. The time required for the light to reflect back to the system is then used to calculate the distance between the lidar-system equipped vehicle and the detected target. Typically, due to less interference and the capability to focus more narrowly, lidar sensors can provide a more accurate map of the surrounding environment and could potentially scan longer distances than radar.

Radar-based systems. A radar system sends out radio waves that bounce off objects—for example, a decelerating lead vehicle—and return to the source. The system measures the time it takes for the echo to arrive and then calculates the Doppler effect, providing the radar-based system the means to directly measure velocities. This is one advantage of a radar-based system as compared to a lidar-based system. Radar can also be specialized depending on the specific purpose. Short-range radar sensors with wider coverage (fields of view) are useful when traveling at lower speeds and when detecting vehicles encroaching from adjacent lanes. Long-range sensors are useful at higher speeds when monitoring farther ahead.

Camera-based systems. Camera-based systems use machine vision algorithms to analyze the image of the environment, parsing out relevant targets and detecting conflicts. Camera-based systems require good separation or sufficient contrast between all the objects in the environment and the presence of certain markers—for example, lane markers—to successfully detect conflicts. The quality of the camera and its algorithm affect the level of accuracy and speed of detection, as well as the camera’s range and capability to detect targets at night. (See figure below.)

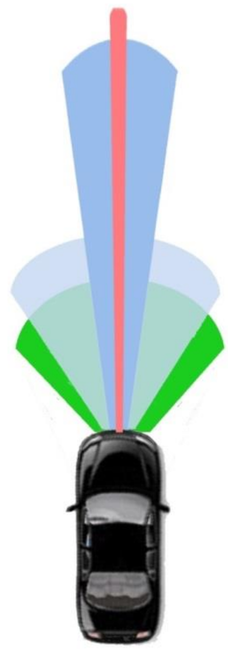

Figure B-1. Portrayal of a typical range of different radar- (in blue), lidar- (in red), and camera-based (in green) CAS.

A summary of some of the advantages and disadvantages of different types of vehicle-based systems is presented in table B-1.

Table B-1. Advantages and limitations of vehicle-based technologies.

Technology Type	Mechanism	Advantages	Limitations
Lidar-based	Uses light waves that reflect off objects to detect and calculate the distance between the source and the detected target	Typically more accurate than radar with fewer misidentifications (i.e., false alarms)	Lack of dynamic information about the detected target
Radar-based	Uses radio waves that bounce off objects and Doppler effect to measure the velocities of the detected target	Can directly measure velocities of the source and the detected target	Increased interference from other sources, resulting in more frequent misidentifications (e.g., identifying a bridge as a conflict vehicle)
Camera-based	Uses machine vision algorithm to analyze the environment and detect conflicts	Easier to install as an aftermarket device	Limitations similar to the limitations of human vision; poorer detection in inclement weather
		Accuracy and speed of detection dependent on the quality of the algorithms	

Appendix C: Testing of AEB in Passenger Vehicles

In 2011, the Allgemeiner Deutscher Automobil Club (ADAC) compared five different vehicles sold in Europe equipped with autonomous emergency braking (AEB) systems. While the Insurance Institute for Highway Safety performed tests only on a stationary vehicle and at low speeds, the ADAC performed tests on three different rear-end crash scenarios at different velocities. Such testing methods produced results that suggested that the efficacy of a particular system may differ substantially depending on the speed of the vehicles involved in the testing (see table C-1).

Table C-1. Comparison of AEB performance (that is, measuring reduction in velocity in mph) among different passenger vehicles, testing scenarios, and test velocities; testing performed by ADAC.

Vehicles	Slow-Moving Lead Vehicle		Stationary Lead Vehicle	
	T: 31, L: 13	T: 62, L: 37	T: 12	T: 25
Audi A7	11	20	did not activate	did not activate
BMW 530	7	7	did not activate	did not activate
Mercedes-Benz CLS	14	14	did not activate	12
Infiniti M	6	7	5	8
Volvo V60	18[a]	12	12[a]	25[a]
VW Passat	18[a]	12	12[a]	did not activate

[a]Test vehicle did not impact the lead vehicle.

T – Velocity (mph) of the test vehicle, L – velocity (mph) of the lead (dummy) vehicle.

For example, the data show that in a low-velocity condition (test vehicle traveling at 31 mph and approaching slow-moving vehicle traveling at 13 mph), AEB systems on the Volvo V60 and VW Passat prevented a collision, while the AEB system on the Audi reduced the velocity of the collision by 11 mph. However, in the high-velocity condition (test vehicle traveling at 62 mph and approaching a slow moving vehicle traveling at 37 mph), the Audi performed better compared to the Volvo. The AEB on the Audi reduced the velocity by 20 mph, while the Volvo reduced the velocity by only 12 mph, a smaller reduction than in the low-velocity condition.

Differences in AEB performance exist not only at different velocities but also depending on the type of the rear-end crash scenario. For example, the Audi AEB system was able to significantly mitigate a collision in both velocity conditions in the slow-moving lead vehicle test, but it was ineffective when encountering a stationary forward vehicle.

Since this testing by the ADAC, passenger vehicle manufacturers have made changes to improve the detection of conflicts under certain scenarios—for example, Audi vehicles are now able to detect stationary vehicles. These results, however, do emphasize the need for expanded testing conditions.

In another study, Thatcham Research conducted AEB testing of several vehicles sold in Europe that offered an AEB component with its complete forward collision avoidance system (CAS) (Hulshof and others 2013). This testing was restricted to examining the efficacy of each of the systems in preventing low-velocity collisions; testing was conducted at velocities up to 31 mph in a stopped lead vehicle scenario. The results of the test showed differences based on the type of forward CAS utilized by a manufacturer: lidar-, radar- or camera-based. Out of eight lidar-based systems tested, only three made an emergency stop before colliding with the lead vehicle in tests of up to 16 mph, while the other five lidar-based AEB systems prevented a collision in tests of up to 12 mph. None of the eight lidar-based systems mitigated a collision at 25 mph or greater, beyond providing a minimal velocity reduction (less than 2 mph). Both radar-based AEB systems prevented collisions at least up to 19 mph. While one of the radar-based systems failed to provide any mitigation in tests beyond 22 mph, the other radar-based system provided substantial mitigation in all tested velocities (more than a 50 percent reduction in velocity in tests up to 31 mph). Only one camera-based system was tested, and this stereo camera system prevented collisions with the lead vehicle in all tested velocities, up to 31 mph.

Appendix D: Forward CAS Availability in Passenger Vehicles

Make	Model	CWS	CWS + AEB
Acura	MDX 4D 2WD	Optional	Optional
Acura	MDX 4D 4WD	Optional	Optional
Acura	RLX 4D 2WD	Standard	Optional
Acura	RLX HYBRID 4D 4WD	Standard	Not Available
Audi	A4 4D 2WD (NEW)	Optional	Not Available
Audi	A4 ALLROAD QUAT SW 4WD	Optional	Not Available
Audi	A4 QUATTRO 4D 4WD (NEW)	Optional	Not Available
Audi	A5 CABRIO CONV 2WD	Optional	Not Available
Audi	A5 CABRIO CONV QUAT 4WD	Optional	Not Available
Audi	A5 QUATTRO 2D 4WD	Optional	Not Available
Audi	A6 QUATTRO 4D 4WD	Optional	Optional
Audi	A7 QUATTRO 5D 4WD	Optional	Optional
Audi	A8 QUATTRO 4D 4WD	Optional	Optional
Audi	A8L QUATTRO 4D 4WD	Optional	Optional
Audi	Q5 4D 4WD	Optional	Not Available
Audi	Q7 4D 4WD	Optional	Not Available
Audi	RS5 QUATTRO 2D 4WD	Optional	Not Available
Audi	RS5 QUATTRO CONV 4WD	Optional	Not Available
Audi	RS7 QUATTRO 5D 4WD	Optional	Optional
Audi	S4 QUATTRO 4D 4WD (NEW)	Optional	Not Available
Audi	S5 CABRIO CONV QUAT 4WD	Optional	Not Available
Audi	S5 QUATTRO 2D 4WD	Optional	Not Available
Audi	S6 QUATTRO 4D 4WD	Optional	Optional
Audi	S7 QUATTRO 5D 4WD	Optional	Optional
Audi	S8 QUATTRO 4D 4WD	Optional	Optional
Audi	SQ5 4D 4WD	Optional	Not Available
BMW	228I 2D 2WD	Optional	Not Available
BMW	328 D 4D 2WD	Optional	Not Available
BMW	328 D SW 4WD	Optional	Not Available
BMW	328 D XDRIVE 4D 4WD	Optional	Not Available
BMW	328 I 4D	Optional	Optional
BMW	328 I XDRIVE GT 5D 4WD	Optional	Optional
BMW	328 XI 4D 4WD	Optional	Optional
BMW	328 XI SW 4WD	Optional	Optional

BMW	335 I 4D 2WD	Optional	Optional
BMW	335 I XDRIVE GT 5D 4WD	Optional	Optional
BMW	335 XI 4D 4WD	Optional	Optional
BMW	428 I 2D 2WD	Optional	Not Available
BMW	428 I CONV 2WD	Optional	Not Available
BMW	428 I CONV 4WD	Optional	Not Available
BMW	428 XI 2D 4WD	Optional	Not Available
BMW	435 I 2D 2WD	Optional	Not Available
BMW	435 I CONV 2WD	Optional	Not Available
BMW	435 XI 2D 4WD	Optional	Not Available
BMW	528 I 4D 2WD	Optional	Optional
BMW	528 XI 4D 4WD	Optional	Optional
BMW	535 D 4D 2WD	Optional	Optional
BMW	535 D XDRIVE 4D 4WD	Optional	Optional
BMW	535 I GT 4D 2WD	Optional	Optional
BMW	535 I GT 4D 4WD	Optional	Optional
BMW	535 I/535 IS 4D 2WD	Optional	Optional
BMW	535 XI 4D 4WD	Optional	Optional
BMW	550 I 4D 2WD	Optional	Optional
BMW	550 I 4D 4WD	Optional	Optional
BMW	550 I GT 4D 2WD	Optional	Optional
BMW	550 I GT 4D 4WD	Optional	Optional
BMW	640 I 2D 2WD	Optional	Optional
BMW	640 I CONV 2WD	Optional	Optional
BMW	640 I GRAN COUPE 4D	Optional	Optional
BMW	640 XI 2D 4WD	Optional	Optional
BMW	640 XI CONV 4WD	Optional	Optional
BMW	640 XI GRAN COUPE 4D 4WD	Optional	Optional
BMW	650 I 2D 2WD	Optional	Optional
BMW	650 I CONV 2WD	Optional	Optional
BMW	650 I GRAN COUPE 4D 2WD	Optional	Optional
BMW	650 XI 2D 4WD	Optional	Optional
BMW	650 XI CONV 4WD	Optional	Optional
BMW	650 XI GRAN COUPE 4D 4WD	Optional	Optional
BMW	740 I 4D	Optional	Optional
BMW	740 LI 4D	Optional	Optional
BMW	740 LXI 4D 4WD	Optional	Optional
BMW	750 I 4D 2WD	Optional	Optional
BMW	750 LI 4D 2WD	Optional	Optional
BMW	750 LXI 4D 4WD	Optional	Optional

BMW	750 XI 4D 4WD	Optional	Optional
BMW	760 LI 4D	Standard	Optional
BMW	ACTIVE HYBRID 3 4D	Optional	Optional
BMW	ACTIVE HYBRID 5 4D	Optional	Optional
BMW	ACTIVE HYBRID 7 4D	Optional	Optional
BMW	i3 ELECTRIC SW	Optional	Optional
BMW	M235I 2D 2WD	Optional	Not Available
BMW	M5 4D	Optional	Optional
BMW	M6 2D	Optional	Not Available
BMW	M6 CONV	Optional	Not Available
BMW	M6 GRAN COUPE 4D	Optional	Not Available
BMW	X3 4D 4WD	Optional	Not Available
BMW	X5 4D 2WD	Optional	Optional
BMW	X5 4D 4WD	Optional	Optional
BMW	X6 4D 4WD	Optional	Optional
Buick	ENCLAVE 4D 2WD	Optional	Not Available
Buick	ENCLAVE 4D 4WD	Optional	Not Available
Buick	ENCORE 4D 2WD	Optional	Not Available
Buick	ENCORE 4D 4WD	Optional	Not Available
Buick	LACROSSE 4D 2WD	Optional	Optional
Buick	LACROSSE 4D 4WD	Optional	Optional
Buick	REGAL 4D 4WD	Optional	Optional
Buick	REGAL 4D FWD	Optional	Optional
Buick	VERANO 4D	Optional	Not Available
Cadillac	ATS 4D 2WD	Optional	Optional
Cadillac	ATS 4D 4WD	Optional	Optional
Cadillac	CTS 4D 2WD	Optional	Optional
Cadillac	CTS 4D 4WD	Optional	Optional
Cadillac	ELR ELECTRIC 2D	Standard	Optional
Cadillac	SRX 4D 2WD	Optional	Optional
Cadillac	SRX 4D 4WD	Optional	Optional
Cadillac	XTS 4D 2WD	Optional	Optional
Cadillac	XTS 4D 4WD	Optional	Optional
Chevrolet	IMPALA 4D	Optional	Optional
Chevrolet	MALIBU 4D (NEW)	Optional	Not Available
Chevrolet	SONIC 4D	Optional	Not Available
Chevrolet	SONIC 5D	Optional	Not Available
Chevrolet	SS 4D	Standard	Not Available
Chevrolet	VOLT ELECTRIC 4D	Optional	Not Available
Chevrolet Truck	EQUINOX 4D 2WD	Optional	Not Available

Chevrolet Truck	EQUINOX 4D 4WD	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 4X2 NEW	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 4X4 NEW	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 CR 4X2 NEW	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 CR 4X4 NEW	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 E C 4X2 NEW	Optional	Not Available
Chevrolet Truck	SLVRDO 1500 E C 4X4 NEW	Optional	Not Available
Chevrolet Truck	TRAVERSE 4D 2WD	Optional	Not Available
Chevrolet Truck	TRAVERSE 4D 4WD	Optional	Not Available
Chrysler	300 4D 2WD	Optional	Not Available
Chrysler	300 4D 4WD	Optional	Not Available
Chrysler	300 HEMI 4D 2WD	Optional	Not Available
Chrysler	300 HEMI 4D 4WD	Optional	Not Available
Dodge	CHARGER 4D 2WD	Optional	Not Available
Dodge	CHARGER 4D 4WD	Optional	Not Available
Dodge	CHARGER HEMI 4D 2WD	Optional	Not Available
Dodge	CHARGER HEMI 4D 4WD	Optional	Not Available
Dodge Truck	DURANGO 4D 4X2	Optional	Optional
Dodge Truck	DURANGO 4D 4X4	Optional	Optional
Ford	FUSION 4D 2WD	Optional	Not Available
Ford	FUSION 4D 4WD	Optional	Not Available
Ford	FUSION HYBRID 4D 2WD	Optional	Not Available
Ford	FUSION PLUG-IN HYBRID 4D	Optional	Not Available
Ford	TAURUS 4D 2WD	Optional	Not Available
Ford	TAURUS 4D 4WD	Optional	Not Available
Ford	TAURUS SHO 4D 4WD	Optional	Not Available
Ford Truck	EDGE 4D 2WD	Optional	Not Available
Ford Truck	EDGE 4D 4WD	Optional	Not Available
Ford Truck	EXPLORER 4D 4X2	Optional	Not Available
Ford Truck	EXPLORER 4D 4X4	Optional	Not Available
Ford Truck	FLEX 4D 2WD	Optional	Not Available
Ford Truck	FLEX 4D 4WD	Optional	Not Available
GMC Truck	ACADIA 4D 2WD	Optional	Not Available
GMC Truck	ACADIA 4D 4WD	Optional	Not Available
GMC Truck	SIERRA 1500 4X2 NEW	Optional	Not Available
GMC Truck	SIERRA 1500 4X4 NEW	Optional	Not Available
GMC Truck	SIERRA 1500 CR 4X2 NEW	Optional	Not Available
GMC Truck	SIERRA 1500 CR 4X4 NEW	Optional	Not Available
GMC Truck	SIERRA 1500 E C 4X2 NEW	Optional	Not Available
GMC Truck	SIERRA 1500 E C 4X4 NEW	Optional	Not Available

GMC Truck	TERRAIN 4D 2WD	Optional	Not Available
GMC Truck	TERRAIN 4D 4WD	Optional	Not Available
Honda	ACCORD 2D	Optional	Not Available
Honda	ACCORD 4D	Optional	Not Available
Honda	ACCORD CROSSTOUR 4D 2WD	Optional	Not Available
Honda	ACCORD CROSSTOUR 4D 4WD	Standard	Not Available
Honda	ACCORD HYBRID 4D	Optional	Not Available
Honda	ACCORD PLUG-IN HYBRID 4D	Standard	Not Available
Honda	CIVIC HYBRID 4D	Standard	Not Available
Honda	ODYSSEY VAN (NEW)	Optional	Not Available
Hyundai	EQUUS 4D	Standard	Not Available
Infiniti	Q50 4D 2WD	Optional	Optional
Infiniti	Q50 4D 4WD	Optional	Optional
Infiniti	Q50 HYBRID 4D 2WD	Optional	Optional
Infiniti	Q50 HYBRID 4D 4WD	Optional	Optional
Infiniti	Q70 4D 2WD	Optional	Optional
Infiniti	Q70 4D 4WD	Optional	Optional
Infiniti	Q70 HYBRID 4D 2WD	Optional	Optional
Infiniti	QX50 4D 2WD	Optional	Optional
Infiniti	QX50 4D 4WD	Optional	Optional
Infiniti	QX60 4D 2WD	Optional	Optional
Infiniti	QX60 4D 4WD	Optional	Optional
Infiniti	QX60 HYBRID 4D 2WD	Optional	Optional
Infiniti	QX60 HYBRID 4D 4WD	Optional	Optional
Infiniti	QX70 4D 2WD	Optional	Optional
Infiniti	QX70 4D 4WD	Optional	Optional
Infiniti	QX80 4D 4X2	Optional	Optional
Infiniti	QX80 4D 4X4	Optional	Optional
Jaguar	XF 4D	Optional	Not Available
Jaguar	XF 4D 4WD	Optional	Not Available
Jaguar	XJ LWB 4D	Optional	Not Available
Jaguar	XJ LWB 4D 4WD	Optional	Not Available
Jaguar	XJ SWB 4D	Optional	Not Available
Jaguar	XJ SWB 4D 4WD	Optional	Not Available
Jaguar	XK 2D	Optional	Not Available
Jaguar	XK CONV	Optional	Not Available
Jaguar	XKR 2D	Optional	Not Available
Jaguar	XKR CONV	Optional	Not Available
Jeep	CHEROKEE 4D 4x2	Optional	Optional
Jeep	CHEROKEE 4D 4X4	Optional	Optional

Jeep	GRAND CHEROKEE 4D 4X2	Optional	Optional
Jeep	GRAND CHEROKEE 4D 4X4	Optional	Optional
Land Rover	RANGE ROVER 4D 4X4	Optional	Optional
Land Rover	RANGE ROVER 4D 4X4 LWB	Optional	Optional
Land Rover	RANGE ROVER EVOQUE 2D 4WD	Optional	Not Available
Land Rover	RANGE ROVER EVOQUE 4D 4WD	Optional	Not Available
Land Rover	RANGE ROVER SPORT 4D 4x4	Optional	Not Available
Lexus	CT 200H HYBRID 4D	Optional	Optional
Lexus	ES 300H HYBRID 4D	Optional	Not Available
Lexus	ES 350 4D	Optional	Optional
Lexus	GS 350 4D 2WD	Optional	Optional
Lexus	GS 350 4D 4WD	Optional	Optional
Lexus	GS 450H HYBRID 4D 2WD	Optional	Optional
Lexus	GX 460 4D 4X4	Optional	Optional
Lexus	IS 250 4D 2WD	Optional	Optional
Lexus	IS 250 4D 4WD	Optional	Optional
Lexus	IS 250 CONV 2WD	Optional	Optional
Lexus	IS 350 4D 2WD	Optional	Optional
Lexus	IS 350 4D 4WD	Optional	Optional
Lexus	IS 350 CONV 2WD	Optional	Optional
Lexus	IS F 4D 2WD	Optional	Optional
Lexus	LS 460 4D 2WD	Optional	Optional
Lexus	LS 460 4D 4WD	Optional	Optional
Lexus	LS 460 L 4D 2WD	Optional	Optional
Lexus	LS 460 L 4D 4WD	Optional	Optional
Lexus	LS 600H L HYBRID 4D 4WD	Optional	Optional
Lexus	LX 570 4D 4X4	Optional	Not Available
Lexus	RX 350 4D 2WD	Optional	Optional
Lexus	RX 350 4D 4WD	Optional	Optional
Lexus	RX 450H HYBRID 4D 2WD	Optional	Optional
Lexus	RX 450H HYBRID 4D 4WD	Optional	Optional
Lincoln	MKS 4D 2WD	Optional	Not Available
Lincoln	MKS 4D 4WD	Optional	Not Available
Lincoln	MKS ECOBOOST 4D 4WD	Optional	Not Available
Lincoln	MKT 4D 4WD	Optional	Not Available
Lincoln	MKX 4D 2WD	Optional	Not Available
Lincoln	MKX 4D 4WD	Optional	Not Available
Lincoln	MKZ 4D 4WD	Optional	Not Available
Lincoln	MKZ HYBRID 4D 2WD	Optional	Not Available
Lincoln	ZEPHYR/MKZ 4D 2WD	Optional	Not Available

Mazda	3 4D	Optional	Not Available
Mazda	3 5D	Optional	Not Available
Mazda	6 4D 2WD	Optional	Not Available
Mercedes-Benz	C CLASS 2D 2WD	Optional	Optional
Mercedes-Benz	C CLASS 2D 4WD	Optional	Optional
Mercedes-Benz	C CLASS 4D 2WD	Optional	Optional
Mercedes-Benz	C CLASS 4D 4WD	Optional	Optional
Mercedes-Benz	CL CLASS 2D 2WD	Optional	Optional
Mercedes-Benz	CL CLASS 2D 4WD	Optional	Optional
Mercedes-Benz	CLA CLASS 4D 2WD	Standard	Optional
Mercedes-Benz	CLA CLASS 4D 4WD	Standard	Optional
Mercedes-Benz	CLS CLASS 4D 2WD	Optional	Optional
Mercedes-Benz	CLS CLASS 4D 4WD	Optional	Optional
Mercedes-Benz	E CLASS 2D 2WD	Standard	Optional
Mercedes-Benz	E CLASS 2D 4WD	Standard	Optional
Mercedes-Benz	E CLASS 4D 2WD	Standard	Optional
Mercedes-Benz	E CLASS 4D 4WD	Standard	Optional
Mercedes-Benz	E CLASS CONV 2WD	Standard	Optional
Mercedes-Benz	E CLASS HYBRID 4D	Standard	Optional
Mercedes-Benz	E CLASS SW 4WD	Standard	Optional
Mercedes-Benz	G CLASS 4D 4X4	Standard	Standard
Mercedes-Benz	GL CLASS 4D 4WD	Optional	Not Available
Mercedes-Benz	GLK CLASS 4D 2WD	Optional	Not Available
Mercedes-Benz	GLK CLASS 4D 4WD	Optional	Not Available
Mercedes-Benz	M CLASS 4D 4X2	Standard	Optional
Mercedes-Benz	M CLASS 4D 4X4	Standard	Optional
Mercedes-Benz	S CLASS LWB 4D 2WD	Standard	Optional
Mercedes-Benz	S CLASS LWB 4D 4WD	Optional	Optional
Mercedes-Benz	SL CLASS CONV	Optional	Not Available
Mercedes-Benz	SPRINTER 2500 CG VAN	Optional	Not Available
Mercedes-Benz	SPRINTER 2500 PASS VAN	Optional	Not Available
Mercedes-Benz	SPRINTER 3500 CG VAN	Optional	Not Available
Mitsubishi	OUTLANDER 4D 2WD	Optional	Optional
Mitsubishi	OUTLANDER 4D 4WD	Optional	Optional
Nissan	ROGUE 4D 2WD	Optional	Not Available
Nissan	ROGUE 4D 4WD	Optional	Not Available
Porsche	911 CARRERA CABRIOLET	Optional	Optional
Porsche	911 CARRERA COUPE	Optional	Optional
Porsche	911 TARGA 4WD (NEW)	Optional	Optional
Porsche	911 TURBO CONV 4WD	Optional	Not Available

Porsche	911 TURBO COUPE 4WD	Optional	Not Available
Porsche	BOXSTER CONV	Optional	Optional
Porsche	CAYENNE 4D 4WD	Optional	Optional
Porsche	CAYENNE HYBRID 4D 4WD	Optional	Optional
Porsche	CAYMAN COUPE	Optional	Optional
Porsche	MACAN 4D 4WD	Optional	Optional
Porsche	PANAMERA 4D 2WD/4WD	Optional	Optional
Porsche	PANAMERA GTS 4D 4WD	Optional	Optional
Porsche	PANAMERA HYBRID 4D	Optional	Optional
Porsche	PANAMERA TURBO 4D 4WD	Optional	Optional
Rolls Royce	GHOST 4D	Optional	Not Available
Rolls Royce	GHOST EWB 4D	Optional	Not Available
Rolls Royce	WRAITH 2D	Optional	Not Available
Subaru	FORESTER 4D 4WD W/EYESIGHT	Standard	Standard
Subaru	LEGACY 4D 4WD W/EYESIGHT	Standard	Standard
Subaru	OUTBCK SW 4WD W/EYESIGHT	Standard	Standard
Toyota	AVALON 4D	Optional	Optional
Toyota	AVALON HYBRID 4D	Optional	Optional
Toyota	HIGHLANDER 4D 2WD	Optional	Optional
Toyota	HIGHLANDER 4D 4WD	Optional	Not Available
Toyota	HIGHLANDER HYBRID 4D 4WD	Optional	Not Available
Toyota	LAND CRUISER 4D 4X4	Standard	Not Available
Toyota	PRIUS HYBRID 4D	Optional	Optional
Toyota	PRIUS PLUG IN HYBRID 5D	Optional	Optional
Toyota	PRIUS V HYBRID SW	Optional	Optional
Toyota	SIENNA VAN 2WD	Optional	Optional
Volvo	S60 4D 2WD	Optional	Optional
Volvo	S60 4D 4WD	Optional	Optional
Volvo	S80 4D 2WD	Optional	Optional
Volvo	S80 4D 4WD	Optional	Optional
Volvo	XC60 4D 2WD	Optional	Optional
Volvo	XC60 4D 4WD	Optional	Optional
Volvo	XC70 SW 2WD	Optional	Optional
Volvo	XC70 SW 4WD	Optional	Optional

Appendix E: Safety Alert for Consumers

NTSB
SAFETY ALERT
National Transportation Safety Board

★ Addressing Deadly Rear-End Crashes ★

Forward Collision Avoidance Systems Can Save Lives

The Problem

- Between 2012 and 2014, almost half of all two-vehicle crashes were rear-end crashes. These crashes killed more than 1,700 people each year.
- In that same time frame, the NTSB investigated nine rear-end crashes involving a passenger or a commercial vehicle striking the rear of another vehicle, which killed 28 and injured 90 people.
- A 2007 National Highway Traffic Safety Administration (NHTSA) study showed that 87 percent of rear-end crashes involved a driver failing to attend to the traffic ahead.

The Solution

- Considerable research on forward collision avoidance systems (CAS) in both passenger and commercial vehicles has shown that these systems can prevent or mitigate rear-end crashes.
    - Forward CAS typically consist of (1) *collision warning* that alerts a driver of the impending crash, and (2) *autonomous emergency braking* (also known as "crash imminent braking") that automatically applies brakes.
- NHTSA is recommending the use of forward CAS.
- Broad deployment of forward CAS in all vehicles is necessary to reduce the severity of rear-end crashes.

What You Can Do

- When purchasing a vehicle, **consumers** should consider vehicles equipped with collision warning and autonomous emergency braking. To find out which vehicles offer these features, go to NHTSA's safercar.gov website.
- **Commercial vehicle fleet owners** should consider transitioning their fleets to vehicles equipped with collision warning and autonomous emergency braking.

For more information: See report NTSB/SIR-15/01, *Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes*, on the NTSB website (www.ntsb.gov).

Glossary of Terms

Adaptive cruise control: A system that maintains a vehicle's pre-set speed. Unlike traditional cruise control, adaptive cruise control can autonomously adjust the pre-set speed by reducing the velocity when the forward vehicle slows and then increasing to the pre-set speed when sufficient forward distance is available. The rate of deceleration is limited, which means that the system cannot maintain the safe distance when the forward vehicle decelerates rapidly.

Autonomous emergency braking system: A safety system that, acting independently of a driver, applies brakes to avoid or mitigate a crash. The system typically activates only in critical situations after a warning has been provided to a driver.

Camera-based system: Uses machine vision algorithms to analyze the image of the environment, parsing out relevant targets and detecting conflicts. Camera-based systems require good separation or sufficient contrast between all the objects in the environment and the presence of certain markers—for example, lane markers—to successfully detect conflicts. The quality of the camera and its algorithm affect the level of accuracy and speed of detection, as well as the camera's range and capability to detect targets at night.

Cascaded braking: When part of autonomous emergency braking (AEB), it is the initial partial application of brakes, followed by full braking force. It serves a dual purpose: (1) acts as another cue to a driver regarding the potential conflict, and (2) provides the AEB additional time during which to determine the imminence of the collision and whether full braking is required.

Collision warning system: An in-vehicle system that provides a warning to a driver regarding an imminent collision. The warning can be presented through visual, auditory, or haptic (touch) cues, or a combination of different cues.

Connected vehicle: A vehicle that is equipped with technology that allows it to communicate with another vehicle—vehicle-to-vehicle (V2V)—or with infrastructure—vehicle-to-infrastructure (V2I). Connected vehicles are expected to provide drivers with a 360-degree awareness about vehicles with similarly equipped systems within a range of approximately 300 meters.

Control group: In research, a group of participants not exposed to a condition or receiving a treatment being investigated (the effectiveness of which is being examined). In research investigating the effectiveness of a collision warning system, this group would include participants whose data are being collected while they are driving a vehicle without a warning system.

Crashworthiness: The capacity of a vehicle to protect its occupants during a crash.

Dynamic brake assist system: Usually a component of a collision avoidance system that can have a dual function: (1) pre-charge brakes in anticipation of a driver's response, and (2) provide additional braking force in situations when a driver does not apply sufficient pressure when braking.

Electronic stability control: A safety system that maintains control of the vehicle during extreme steering maneuvers or road conditions by keeping the vehicle headed in the driver's intended direction. The system accomplishes this by automatically braking individual wheels to prevent the vehicle heading from changing too quickly or not quickly enough.

Engine control module: A type of electronic control unit that controls various automotive components and allows recording of the status of various components, such as braking and acceleration.

Fatality Analysis Reporting System (FARS): A nationwide census of fatal motor vehicle crashes. To be included in FARS, a crash must result in the death of a person within 30 days of the crash. The database includes more than 100 elements that characterize the crash, the vehicles, and the people involved.

Forward collision avoidance system: A technology that prevents crashes by detecting a conflict ahead and alerting the driver. Some systems may also aid in brake application or automatically apply brakes. The complete forward CAS in passenger vehicles typically includes a collision warning system, dynamic brake support (DBS), and autonomous emergency braking; in commercial vehicles, the DBS is limited or absent.

Fusion-based collision avoidance system: A collision avoidance system that uses a combination of multiple systems (for example, lidar, radar, or camera) to monitor the traffic around a vehicle to detect potential collisions.

General Estimates System: Nationally representative sample of police-reported motor vehicle crashes of all types, from minor to fatal. This database includes about 90 elements that characterize the crash, the vehicles, and the people involved.

Haptic warning: An alert that involves providing tactile sensations to a driver, in the form of pressure, vibrations, or motion.

Human factors: A study examining the way in which humans interact with any aspect of the manmade environment. Within the context of vehicles, human factors examine a wide range of such interactions, including the manner in which a driver responds to and perceives the dynamics of the vehicle, the ease of interpretation of the instrument panel, and the accuracy of the interaction with a navigation system, as well as the quickness and success of response to a vehicle's collision warning system.

Human-machine interface: Any part of a machine with which a human interacts (either through inputing and/or receiving information). This interaction can occur through haptic, visual, or auditory cues. Within a collision warning system, the human-machine interface refers to flashing lights or an auditory tone alerting a driver to a potential collision.

Lidar-based system: Sends out light waves toward a particular location, for example, forward of a vehicle. Once the waves reach an obstacle, such as a stopped vehicle ahead, they bounce back to the source. The time required for the light to reflect back to the system is then used to calculate the distance between the source, the lidar-system-equipped vehicle, and the detected target.

Naturalistic driving research: In pure naturalistic research, the target of the observation is unaware of the ongoing research. In driving naturalistic research, the drivers are frequently aware that their driving behavior is being monitored; however, such monitoring is typically unobtrusive (conducted through cameras and recording of vehicle dynamics) and without the physical presence of researchers.

Radar-based system: Sends out radio waves which bounce off objects—for example, a decelerating lead vehicle—and return to the source. The system measures the time it takes for the echo to arrive and then calculates the Doppler effect, providing the radar-based system the means to directly measure velocities.

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