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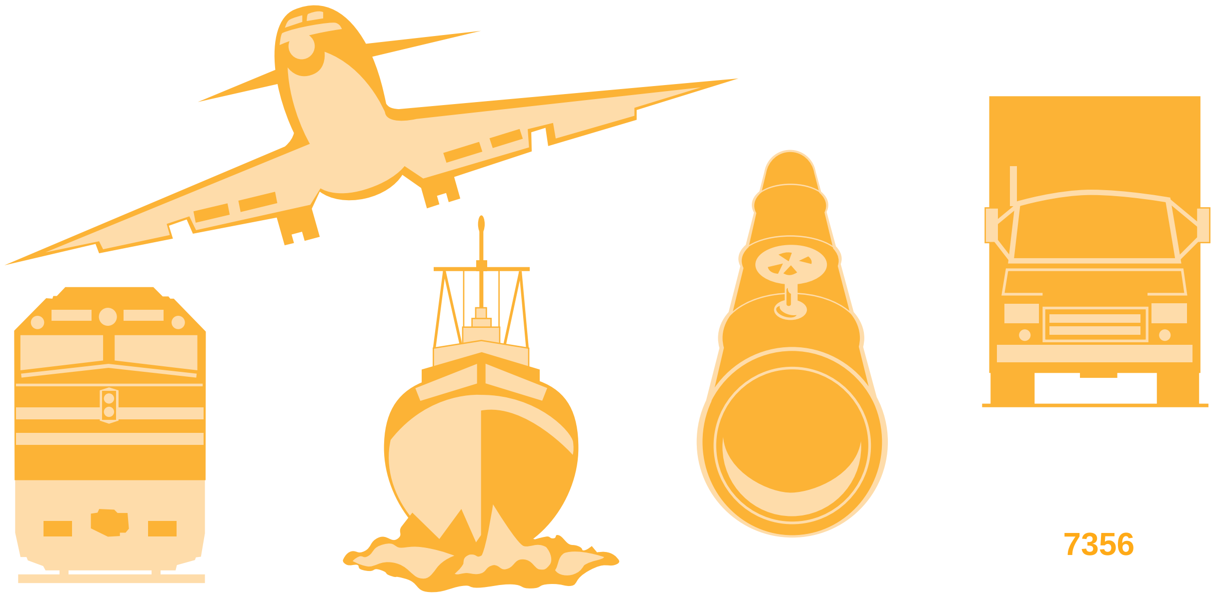
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

VEHICLE- AND INFRASTRUCTURE-BASED TECHNOLOGY FOR THE PREVENTION OF REAR-END COLLISIONS



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Special Investigation Report

Vehicle- and Infrastructure-Based Technology for the Prevention of Rear-End Collisions

NTSB/SIR-01/01
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Notation 7356
Adopted May 1, 2001

National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2001. *Vehicle- and Infrastructure-Based Technology for the Prevention of Rear-End Collisions.* Special Investigation Report NTSB/SIR-01/01. Washington, DC.

Abstract: Between 1999 and 2000, the National Transportation Safety Board investigated nine rear-end collisions in which 20 people died and 181 were injured. Common to all nine accidents was the rear following vehicle driver's degraded perception of traffic conditions ahead. As the Safety Board reported in 1995 and further discussed at its 1999 public hearing, existing technology in the form of Intelligent Transportation Systems can prevent rear-end collisions. In the nine accidents investigated by the Safety Board, one (and sometimes more) of the available technologies would have helped alert the drivers to the vehicles ahead, so that they could slow their vehicles, and would have prevented or mitigated the circumstances of the collisions.

The major issue addressed in this Safety Board special investigation report is the prevention of rear-end collisions through the use of Intelligent Transportation Systems. This report also discusses some of the challenges, including implementation, consumer acceptance, public perception, and training, associated with the deployment of vehicle- and infrastructure-based collision warning systems.

As a result of its investigation, the Safety Board issues recommendations to the U.S. Department of Transportation; the Federal Highway Administration; the National Highway Traffic Safety Administration; truck, motorcoach, and automobile manufacturers; the Intelligent Transportation Society of America; the American Trucking Associations, Inc.; the Owner-Operator Independent Driver Association; and the National Private Truck Council.

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Contents

Acronyms and Abbreviations

ACC -- adaptive cruise control

CWS -- collision warning system

DOT -- U.S. Department of Transportation

Eaton VORAD -- Eaton VORAD Technologies, L.L.C.

Greyhound -- Greyhound Lines, Inc.

ITS -- Intelligent Transportation Systems

NHTSA -- National Highway Traffic Safety Administration

U.S. Xpress -- U.S. Xpress Enterprises, Inc.

Introduction

In 1999, the most recent year for which data are available, more than 6 million crashes occurred on U.S. highways, killing over 41,000 people and injuring nearly 3.4 million others. Rear-end collisions accounted for almost one-third of these crashes[1] (1.848 million) and 11.8 percent of multivehicle fatal crashes (1,923). Commercial vehicles[2] were involved in 40 percent of these fatal rear-end collisions (770), even though commercial vehicles only comprised 3 percent of vehicles and 7 percent of miles traveled on the Nation's highways. Between 1992 and 1998, the percentage of rear-end collisions involving all vehicles increased by 19 percent. In 1999, 114 fatal crashes in work zones involved rear-end collisions, about 30 percent of the multivehicle fatal work zone crashes. Of these, 71 collisions (62 percent) involved commercial vehicles.

In the past 2 years, the National Transportation Safety Board investigated nine rear-end collisions in which 20 people died and 181 were injured (three accidents involved buses and one accident involved 24 vehicles).[3] Common to all nine accidents was the rear following vehicle driver's degraded perception of traffic conditions ahead.[4] During its investigation of the rear-end collisions, the Safety Board examined the striking vehicles and did not find mechanical defects that would have contributed to the accidents. In each collision, the driver of the striking vehicle tested negative for alcohol or drugs. Some of these collisions occurred because atmospheric conditions, such as sun glare or fog and smoke, interfered with the driver's ability to detect slower moving or stopped traffic ahead. In other accidents, the driver did not notice that traffic had come to a halt due to congestion at work zones or to other accidents. Still others involved drivers who were distracted or fatigued.

Regardless of the individual circumstances, the drivers in these accidents were unable to detect slowed or stopped traffic and to stop their vehicles in time to prevent a rear-end collision. According to a 1992 study by Daimler-Benz, if passenger car drivers have a 0.5-second additional warning time, about 60 percent of rear-end collisions can be prevented. An extra second of warning time can prevent about 90 percent of rear-end collisions.[5]

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[1] According to the 1999 Fatal Analysis Reporting System, rear-end collisions accounted for 29.5 percent of all crashes that year. Sometimes referred to as a frontal collision, a rear-end collision occurs when the following vehicle strikes the rear of the lead vehicle.

[2] Heavy (over 10,000 pounds) trucks and motorcoaches.

[3] The accidents occurred in Moriarty, New Mexico; Sweetwater, Tennessee; Trenton, Georgia; Sullivan, Indiana; Tinnie, New Mexico; Wellborn, Florida; West Haven, Connecticut; Elk Creek, Nebraska; and Eureka, Missouri.

[4] Driver inattention is a major causal factor in about 91 percent of rear-end crashes, as reported in: U.S. Department of Transportation, ITS Joint Program Office, *Program Area Descriptions: Motor Vehicle Crashes—Data Analysis and IVI Program Emphasis* (November 1999).

[5] D.R. Ankrum, "Smart Vehicles, Smart Roads," *Traffic Safety* 92(3) (1992): 6-9.

As the Safety Board reported in 1995[6] and further discussed at its public hearing, Advanced Safety Technologies for Commercial Vehicle Applications, held August 31 through September 2, 1999, existing technology in the form of Intelligent Transportation Systems (ITS) can prevent rear-end collisions. ITS, capable of alerting drivers to slowed or stopped traffic ahead, have been available for several years but are not in widespread use. The technology to alert drivers to traffic ahead includes adaptive cruise control (ACC), collision warning systems (CWSs), and infrastructure-based congestion warning systems. ACC detects slower moving vehicles ahead and closes the throttle and applies the engine brake to slow the host vehicle to a comparable speed.[7] CWSs detect slower moving vehicles ahead and warn the driver of the host vehicle about the object ahead so the driver can take appropriate action. Infrastructure-based congestion warning systems use variable message signs to give drivers detailed information about the location of traffic queues. In the nine accidents investigated by the Safety Board, one (and sometimes more) of these technologies would have helped alert the drivers to the vehicles ahead, so that they could slow their vehicles, and would have prevented or mitigated the circumstances of the collisions.

The Safety Board addressed implementation of such systems for commercial vehicles in its 1995 special investigation of collision warning technology and recommended that the U.S. Department of Transportation (DOT) sponsor fleet testing of CWSs for trucks.[8] On August 10, 1999, the Board classified the recommendation “Closed—Unacceptable Action” due to inaction by the DOT on testing of the CWS for trucks at that time. (See the “Related Report and Consequent Recommendations” section of this report for further information.)

Because of the lack of progress in deploying rear-end CWSs, the Safety Board addressed the issue at its summer 1999 public hearing focusing on advanced safety technologies for commercial vehicle applications to determine what had been done since its 1995 report. (See “Public Hearing” section of this report for further information.) At the hearing, representatives of Eaton VORAD Technologies, L.L.C. (Eaton VORAD); U.S. Xpress Enterprises, Inc. (U.S. Xpress); Greyhound Lines, Inc. (Greyhound); and the DOT provided information regarding the CWS and the status of various tests and deployments. As became clear during the public hearing, private industry is beginning to deploy vehicle-based safety systems. The CWS and ACC developed by Eaton VORAD are available as an option on trucks produced by all major manufacturers in the United States. Automobile manufacturers in Europe and Japan have begun to offer ACC on their high-end models, and Lexus and Mercedes are doing the same on their 2001 luxury vehicles in the United States.

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[6] National Transportation Safety Board, *Multiple Vehicle Collision With Fire During Fog Near Milepost 118 on Interstate 40, Menifee, Arkansas, January 9, 1995, and Special Investigation of Collision Warning Technology,* Highway Accident Report NTSB/HAR-95/03 (Washington, DC: NTSB, 1995).

[7] Within limits, most systems can only slow the vehicle by 25 percent, after which driver intervention (braking) is required.

[8] NTSB/HAR-95/03.

According to a March 2000 TRW press release, industry analysts predict the market for ACC, CWSs, and headway control will grow from $11 million in 1998 to $2.4 billion in 2010. In 1999, the DOT commenced operational tests of ACC and CWSs for both cars and trucks. Several States also have projects under way to deploy infrastructure-based technology that alerts drivers to the location of the end of the queue in work zones or congested areas.[9]

The work being done by private industry and the Government is encouraging, but the pace of testing and of standards development for all vehicles and of deployment for commercial vehicles is cause for concern, given the increasing number of rear-end collisions and the number of fatalities when commercial vehicles are involved. Therefore, the Safety Board is again addressing subjects related to ITS, both vehicle- and infrastructure-based, for the prevention of rear-end collisions. The Safety Board has explored the issues involved in deploying technological solutions in this special investigation report, which focuses on some of the challenges, including implementation, consumer acceptance, public perception, and training associated with the deployment of such systems.

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[9] In November 1999, subsequent to the public hearing, the DOT began a field operational test of CWSs on trucks and is currently testing CWSs on automobiles in cooperation with the General Motors Corporation.

Factual Information

This section describes the previous work on this subject performed by the Safety Board, the rear-end collisions discussed for this special investigation, and the systems available or undergoing testing before deployment.

Related Report and Consequent Recommendations

In December 1995, the Safety Board adopted the highway accident report *Multiple Vehicle Collision with Fire During Fog near Milepost 118 on Interstate 40, Menifee, Arkansas, January 9, 1995, and Special Investigation of Collision Warning Technology.*[10]

The Menifee accident was a multiple-vehicle rear-end collision that occurred during localized fog. The collision sequence initiated when the accident lead vehicle entered dense fog, reportedly slowed from 65 mph to between 35 and 40 mph, and was struck in the rear. Subsequent collisions occurred as vehicles drove into the wreckage area at speeds varying from 15 to 60 mph. The accident involved eight loaded truck tractor semitrailer combinations and a local telephone company delivery van, resulting in five fatalities and one minor injury. The Safety Board determined that the probable cause of the accident was that many of the drivers entered the area of dense fog at speeds that precluded successful evasive action to avoid the preceding or stopped vehicles. The Safety Board concluded that "collision warning systems have the potential for avoidance or reduction in the severity of low-visibility collision conditions such as in fog, snow, rain, or darkness" and that "further development of collision warning technology will enhance the ability of these systems to meet the special requirements of commercial vehicles."

During the accident investigation, the Safety Board conducted an investigative conference, Mobile Collision Warning Technology for Low Visibility/Low Awareness Collisions, in April 1995 in Arlington, Virginia. The conference focused on vehicle-mounted technologies that could alert vision-restricted or inattentive drivers to impending hazards. Various technologies were discussed and lectures were held in the areas of driver performance and perception. The Safety Board held that further development was needed to ensure that the CWS provided a commercial driver with adequate headway for successful evasive or mitigative efforts. Extensive testing would help alleviate the risk of incorporating untested technology into day-to-day operation.

As a result of the investigation and the conference, the Safety Board made several recommendations concerning CWSs, which are discussed below.

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[10] NTSB/HAR-95/03.

The Safety Board asked in Safety Recommendation H-95-44 that the Secretary of the DOT:

> H-95-44
>
> In cooperation with the Intelligent Transportation Society of America,[[11]] sponsor 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.

On April 10, 1997, the DOT responded that it did not plan to conduct any fleet testing of rear-end collision warning systems with the commercial carrier industry, but, at that time, it was testing intelligent cruise control[12] for passenger vehicles. The DOT completed an intelligent cruise control operational test with passenger vehicles in 1997, but it did not include collision warning. The National Highway Traffic Safety Administration (NHTSA) held that the results obtained from passenger car vehicles would be applicable to heavy vehicles. The Safety Board classified Safety Recommendation H-95-44 “Closed—Unacceptable Action” on August 10, 1999, because of the time that had elapsed since the recommendation was issued and the lack of action by the DOT, and noted that industry has taken the lead in implementing this technology.

At the Safety Board’s summer 1999 public hearing, Advanced Safety Technologies for Commercial Vehicle Applications, a NHTSA representative stated that NHTSA had previously tried to reach an agreement with private sector partners to conduct a field operational test, but was not successful in doing so. In November 1999, the DOT partially funded a contract for a team led by Volvo Trucks North America, Inc., to perform a field operational test of ACC and a CWS for trucks as part of the Intelligent Vehicle Initiative Generation 0 field operational tests.[13] (See the “U.S. DOT Intelligent Vehicle Initiative” section of this report for further information.)

In Safety Recommendation H-95-46, the Safety Board urged the Federal Communications Commission to:

> H-95-46
>
> Expedite rulemaking action on the allocation of frequencies that would enhance the development possibilities of collision warning systems.

This recommendation was made because industry representatives indicated that allocation of higher operating frequencies was needed to develop narrow beam systems, which would make the systems more affordable and would reduce nuisance alarms.[14] On

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[11] An advisory group to the DOT, formed in 1991, that coordinates the development and deployment of ITS in the United States.

[12] The former name for ACC.

[13] Generation 0 tests contain those technologies that will be ready for production in fiscal year 2003.

December 15, 1995, the Federal Communications Commission allocated spectrum for vehicle collision avoidance systems in the frequency bands of 46.7-46.9 GHz and 76-77 GHz for this purpose. Safety Recommendation H-95-46 was classified "Closed—Acceptable Response" on November 17, 1999.

The Safety Board asked in Safety Recommendation H-95-49 that the Intelligent Transportation Society of America:

> H-95-49
>
> In cooperation with the U.S. Department of Transportation, sponsor 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.

On August 29, 2000, the society responded that in 1998 it had recommended to the DOT a joint program to conduct research and programs related to collision warning systems. In addition, it has since facilitated meetings with Government and manufacturers and cosponsored a demonstration of technologies, including rear-end CWSs. Based on this action, Safety Recommendation H-95-49 was classified "Closed—Acceptable Action" on March 6, 2001, because of the Intelligent Transportation Society of America initiatives to meet with stakeholders and sponsor a demonstration project showcasing front-end collision warning devices.

Public Hearing

From August 31 through September 2, 1999, the Safety Board held the public hearing, Advanced Safety Technologies for Commercial Vehicle Applications.[15] (See appendix A.) At the hearing, the topic of a CWS to prevent rear-end collisions was discussed in depth. Other topics discussed included fatigue technologies, vehicle rollover prevention systems, vehicle stability systems, vehicle diagnostics, vehicle recorders, electronic braking, human interface with technology, and vehicle inspection systems. Representatives of the U.S. Army, the DOT, manufacturers, and technology users provided testimony on rear-end CWSs that will be cited throughout this report.

Accident Narratives

In the past 2 years, the Safety Board has investigated nine accidents in which a vehicle was rear-ended by another vehicle (three accidents involved buses),[16] resulting in

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[14] Alerts that are activated by objects that are not a threat to the vehicle.

[15] National Transportation Safety Board, Docket No. DCA-99-SH-002.

20 fatalities and 181 injuries. (See table 1.) Not all of these accidents[17] involved an on-scene investigation; therefore, some information may not be available.

Table 1. Accidents and injuries.

Accidents	Injuries			
	Fatal	Serious	Minor	None
Moriarty, New Mexico	2	1	7	0
Sweetwater, Tennessee	4	0	1	1
Trenton, Georgia	4	2	1	1
Sullivan, Indiana	0	2	63	0
Wellborn, Florida	3[a]	17	12	9
Tinnie, New Mexico	3	3	7	0
West Haven, Connecticut	2	1	4	0
Elk Creek, Nebraska	0	4	27	0
Eureka, Missouri	2	0	29	3

[a] One fatality was a pedestrian.

Moriarty, New Mexico

On January 14, 1999, about 7:45 a.m., a 1999 Peterbilt truck tractor semitrailer, occupied by the driver and a codriver, was traveling eastbound on Interstate 40 near Moriarty, New Mexico. The truck struck a 1996 Chevrolet Astro minivan, occupied by the driver and four passengers. The truck subsequently struck a 1988 Dodge Aries, occupied by the driver and two passengers, that was ahead of the Astro minivan. The minivan's body was crushed 23 inches forward of the rear axle by the truck; the minivan then rotated, left the roadway, vaulted, and rolled before coming to rest. The Aries left the roadway and received substantial damage to the passenger compartment; its roof was torn away. After impact, the truck also left the roadway, struck a well head and flipped on its left side before coming to rest. Of the three passengers who occupied the center seat of the van, two were fatally injured, and one was seriously injured.[18] The two occupants in the

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[16] The Sullivan, Indiana; the Elk Creek, Nebraska; and the Eureka, Missouri, accidents.

[17] The Tinnie, New Mexico; West Haven, Connecticut; Elk Creek, Nebraska; and Eureka, Missouri accidents.

[18] Title 49 *Code of Federal Regulations* 830.2 defines fatal injury as "Any injury which results in death within 30 days of the accident" and serious injury as an injury that "(1) Requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; (5) involves second or third degree burns, or any burn affecting more than 5 percent of the body surface."

front seats of the minivan, all three occupants of the passenger car, and the driver and codriver of the truck received minor injuries. Postaccident toxicological tests of the truckdriver were negative for drugs and alcohol.

The posted speed limit for that portion of the interstate was 75 mph. At the time of the accident, the two passenger vehicles were traveling eastbound at a witness-reported speed of 25 to 30 mph. Both vehicles had their hazard flashers on. The driver of the minivan reported that she and the occupants of her vehicle, as well as the occupants of the passenger car, had planned to drive slowly on the interstate in order not to be early for school, which started at 8:10 a.m.

The truckdriver reported that she was traveling at 75 mph. The truck's engine electronic control module recorded the vehicle parameters at the time of the accident: The speed was 74 mph, the throttle was at 100 percent, and the brake and clutch were off. The next reading indicated the vehicle speed at 79 mph, the throttle position at 3 percent, the brake off and the clutch on. The remaining readings indicated the truck's speed continued to decrease, consistent with the vehicle slowing.

On January 17, 1999, Safety Board investigators and the New Mexico State Police conducted a series of visibility tests to determine if the position of the sun would have had an effect on the drivers. Three tests were conducted, and in all three tests, the angle of the sun resulted in it being directly visible through the windshield. (See figure 1.) One investigator reported that the sun's position significantly impeded his forward visibility and made it difficult for him to see the vehicle ahead. When using the sun visor, the effects of the sun were negated.

The geometry of the highway was also evaluated to determine whether it could obstruct a driver's view. While several vertical curves were near the accident site, all were within the American Association of State Highway and Transportation Officials guidelines, and none would have obstructed the truckdriver's view of the minivan or the passenger car.

Sweetwater, Tennessee

On May 27, 1999, about 4:37 p.m.,[19] a 1995 Plymouth Voyager minivan with four occupants stopped on southbound Interstate 75 near Sweetwater, Tennessee, due to congestion in a construction zone. A 1997 Kenworth truck tractor semitrailer, traveling at a witness-estimated speed of 45 to 50 mph, skidded approximately 60 feet and struck the Voyager, pushing it into the rear of a flatbed truck in front of it. All four occupants of the minivan were fatally injured; the truckdriver received minor injuries. Postaccident toxicological tests of the truckdriver were negative for drugs and alcohol.

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[19] The accident occurred during rush hour on the Thursday before Memorial Day weekend.

Figure 1. Sun Glare in Moriarty, New Mexico.

The posted speed limit on the interstate was 70 mph. A construction zone between 1 and 1.5 miles ahead required a lane closure, and traffic was stopped. Warning signs about the lane closure were posted 2 miles in advance of the closure and advised a 50-mph speed limit.

The truckdriver stated that before the accident, he glanced down at his speedometer, which read 51 mph, then observed the exit ramp ahead, and when he looked back at the road, saw traffic was stopped. He slammed on his brakes but was unable to stop in time. He remembered seeing the brake lights on the flatbed ahead of the minivan illuminate, which was his cue that traffic had stopped. He said his CB radio was not working, and he was unaware of the congestion ahead.

A slight vertical curve was north of the impact area. Sight distance observations showed traffic could be observed from about 1,440 feet north of the accident site.

Trenton, Georgia

On July 29, 1999, about 12:37 p.m., a 1997 Ford Windstar minivan was stopped in a traffic queue on the ramp from northbound Interstate 59 to eastbound Interstate 24 near Trenton, Georgia, due to a 4-mile construction work zone set up about 2.2 miles east on Interstate 24. A 1996 International truck tractor semitrailer failed to stop for the queue and struck the rear of the minivan, fatally injuring three passengers and seriously injuring the driver and another passenger. The International truck then continued forward, striking the rear of a tractor trailer, which subsequently struck a pickup truck in front of it. The driver of the International truck was fatally injured, the driver of the truck with the trailer received minor injuries, and the pickup truck driver was not injured. Postaccident toxicological tests of the striking truckdriver were negative for drugs and alcohol.

The posted speed limit was 70 mph on Interstate 59. The ramp at the accident site had no curvature. No warning signs were posted on Interstate 59 that construction was under way on Interstate 24.

According to the Georgia Department of Transportation, the work zone traffic control and single lane closure standards used during the repair project were in compliance with the *Manual for Uniform Traffic Control Devices,* which requires that work zone warning signs be placed at a minimum of 1 mile from the work zone area. A lane was closed within the work zone, and traffic had backed up beyond the first warning sign on Interstate 24. No evidence was present that the Georgia Department of Transportation checked the end of the queue and altered work plans to alleviate the queue from extending beyond the signage that was in place.

Sullivan, Indiana

On October 26, 1999, about 8:00 a.m., a 1996 Thomas school bus, following a 1992 Blue Bird bus, was slowing to a stop before a railroad crossing, as required by law, on U.S. Highway 41 near Sullivan, Indiana. The Thomas school bus had its four-way flashers activated. At the same time, the driver of a 1995 Ford truck tractor in combination with two trailers approached the crossing, applied his brakes, skidded about 175 feet, and struck the rear of the Thomas bus, pushing it forward into the rear of the Blue Bird bus. The Thomas bus overturned onto its left side in a grassy area off the right side of the road. The Blue Bird bus traveled forward and overturned onto its right side in the grass median. The tractor and both trailers also went off the right side of the roadway, but remained upright. The truckdriver and one school bus passenger sustained serious injuries; the remaining 63 bus passengers received minor injuries. Postaccident toxicology tests of the truckdriver did not reveal any illegal drugs, alcohol, or other medicines.

The posted speed limit on U.S. 41 was 50 mph; the Indiana State Police estimated that the truck had been traveling between 59 and 62 mph. The weather was clear and dry at the time of the accident. Safety Board investigators and the Indiana State Police conducted sight distance testing under similar weather conditions and found that the truckdriver had about 3,500 feet of unobstructed visibility prior to the railroad crossing.

According to the truckdriver, the last thing that he recalled before the accident was talking to another driver on his CB radio several miles south of the accident site. He did not recall any other events leading up to the accident or the accident itself. The driver also related that he did not have any period of sleep longer than a few hours in the 26 hours before the accident, which occurred near the end of his trip with about 45 minutes driving time left to the truck terminal.

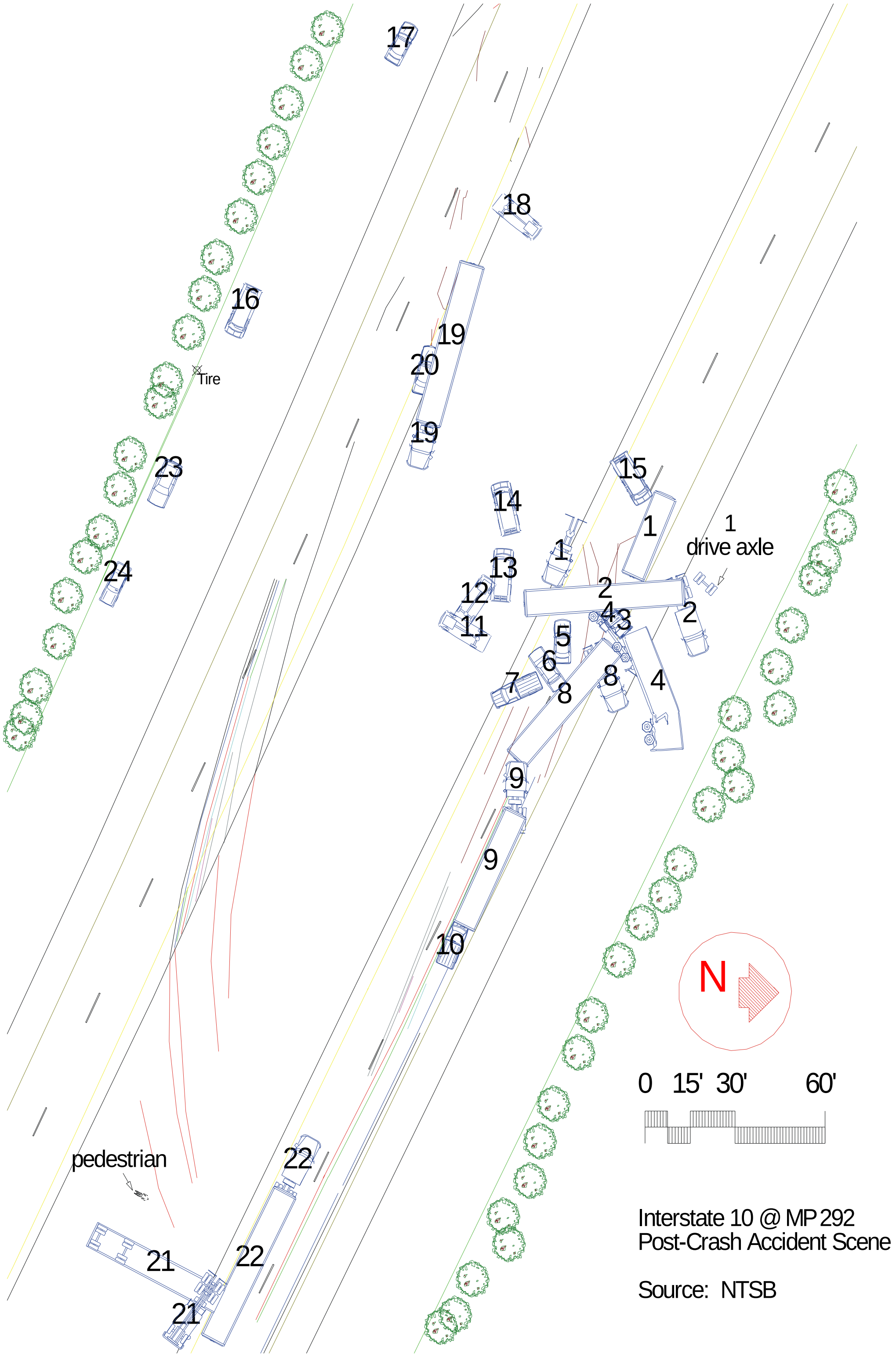
Wellborn, Florida

On March 8, 2000, about 7:58 a.m., a multivehicle collision, involving 24 vehicles (including 8 tractor semitrailers), and postcrash fire occurred on Interstate 10 near Wellborn, Florida. (See figure 2.) Visibility at the time of the collision was reduced significantly as a result of smoke from local forest fires and fog that was in the area, according to witnesses. The accident resulted in 3 fatalities, 17 serious injuries, and 12 minor injuries.

The posted speed limit was 70 mph, with a minimum of 40 mph. The interstate where the accident occurred was a four-lane divided highway; the eastbound and westbound lanes were separated by a depressed grass median. It had a very slight slope (0.4 percent) and no horizontal curves. According to the Florida Highway Patrol and the Florida Department of Forestry, the fires in the area had caused hazardous driving conditions in several areas, so the Florida Department of Transportation had placed “FOG/SMOKE” warning signs with a flashing yellow beacon in pairs adjacent to each side of the highway.

The majority of impacts between the vehicles occurred on the westbound side of the interstate. Additional collisions occurred on the eastbound side of the highway and within the center median. (See figure 2.)

The initial collision on the westbound side occurred when vehicle 1 (truck tractor semitrailer), according to the truckdriver, began to slow to between 50 and 55 mph as the visibility on the highway became increasingly diminished due to the smoke and fog. The



Interstate 10 @ MP 292
Post-Crash Accident Scene

Source: NTSB

Figure 2. Diagram of Wellborn, Florida, accident scene.

truckdriver considered pulling off the road and stopping, but before he could do so, he was struck from behind by vehicle 2. Several subsequent drivers said they began to slow, but were unable to see the wreckage until it was too late to avoid colliding with the other vehicles. A total of 16 vehicles were involved in this initial collision.

The initial collision on the eastbound side occurred when vehicle 18 had stopped on the side of the highway because the smoke and fog conditions had prevented its operator from clearly seeing the roadway ahead. The driver of vehicle 18 had stopped on the shoulder in an area the driver believed was not completely obscured by smoke. The driver of vehicle 17 was traveling about 70 mph some distance behind vehicle 18, and she noticed the FOG/SMOKE signs but did not think the smoke appeared to be very dense. However, when she entered the smoke, she said her visibility began to diminish and that she began to slow down when the left front of her vehicle struck the right rear of vehicle 18. The remainder of the collisions on the eastbound side occurred when subsequent vehicles approached this accident and collided with it or debris from it.

Tinnie, New Mexico

On January 8, 2000, about 11:25 a.m., a 1999 Kenworth truck tractor semitrailer struck the rear of a 1995 Dodge van on U.S. Highway 70 near Tinnie, New Mexico. The van, carrying 12 occupants, had slowed to make a left turn when it was struck. Three occupants sustained fatal injuries, three received serious injuries, and six had minor injuries. The truckdriver received minor injuries. According to the New Mexico State Police, alcohol, drugs, mechanical malfunctions, and the environment were ruled out as contributing to the accident.

The posted speed limit on the two-lane roadway was 60 mph; the truckdriver estimated he was traveling between 55 and 58 mph at impact. According to the truckdriver, he had been following the van for about 20 miles when he lost sight of it at a short incline in the road. When he crested the incline, he saw the van’s brake lights and applied his brakes before striking the van.

When State officers investigated the scene, they found that they had no trouble seeing cones on the road when standing behind the incline referred to by the driver and that the incline was not steep enough to obstruct the truckdriver’s view of the van.

West Haven, Connecticut

On May 24, 2000, about 5:19 a.m., a 1996 truck tractor semitrailer struck and overrode a stopped 1994 Toyota Corolla on Interstate 95 near West Haven, Connecticut. The truck then continued forward, striking a 2000 Volvo truck tractor semitrailer, which was pushed forward into a 1997 Saturn, which then struck a 1977 Lincoln Town Car, which struck a 1991 delivery van, which struck a 1992 Freightliner truck tractor semitrailer. The traffic on the interstate was stopped because a previous accident had closed the right and center lanes and traffic was required to merge into one lane. An overhead variable message sign warned drivers of the lane closures. The drivers of the Corolla and the Saturn were fatally injured. The driver of the striking truck received serious injuries. The occupants of the remaining vehicles received minor injuries. No toxicological tests were performed on the driver of the striking truck.

Elk Creek, Nebraska

On August 22, 2000, about 5:44 p.m., a 1995 MCI motorcoach was struck in the left rear by a 1999 Freightliner truck tractor seimitrailer on Interstate 80 near Elk Creek, Nebraska. The truck then veered left, rolled onto its side, and caught fire. The truck's codriver and 3 bus passengers received serious injuries; the truckdriver, the busdriver, and the remaining 25 passengers received minor injuries. The Nebraska Highway Patrol said the truckdriver did not exhibit any symptoms of intoxication or fatigue.

The motorcoach had been traveling about 35 to 40 mph in the right lane with its four-way emergency flashers activated due to mechanical difficulties. The truck had been traveling about 70 to 75 mph. The truckdriver said that he was distracted, looked down, and, when he looked up again, was about 200 feet from the rear of the motorcoach. He tried to avoid the collision by steering left, but the right front of the truck struck the left rear of the bus.

Eureka, Missouri

On August 27, 2000, about 8:40 a.m., a 1998 Dina motorcoach struck a 1999 Nissan Maxima, pushing the vehicle into the rear of a 1999 Kenworth truck tractor semitrailer on Interstate 44 near Eureka, Missouri. The semitrailer then struck the rear of a 1999 Plymouth sedan, which then hit a 1996 Ford Thunderbird. The Thunderbird was stalled in the right lane of the interstate due to its involvement in a previous accident. The Plymouth was unable to change lanes to pass the Thunderbird and was stopped behind it, followed by the Kenworth truck and the Maxima. The drivers of the motorcoach and the Maxima received fatal injuries. The remaining drivers and passengers received minor or no injuries. An autopsy of the busdriver was unavailable to determine whether drugs or alcohol was a factor.

Vehicle-Based Systems Technology

Two of the three major technologies designed to help prevent rear-end collisions—ACC and the CWSs—are vehicle-based systems, which are incorporated into the vehicle and do not require interaction with the infrastructure or other vehicles. Rear-end collision countermeasures have received NHTSA's largest ITS investment to date and will probably be the first ITS technology to market of all the collision countermeasures in the light vehicle (also referred to as a passenger vehicle) original equipment market.[20] According to NHTSA, the benefits that might be associated with effective collision avoidance systems include avoidance of crashes and reduction in crash severity, crash-related fatalities and

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[20] David L. Smith, "Effective Collision Avoidance Systems for Light Vehicles: A Progress Report," Intelligent Transportation Society of America 10th Annual Meeting and Exposition, May 2000, Boston, Massachusetts.

injuries, property damage losses, and traffic delays. Additional benefits may be reduced driver stress, increased driver comfort and satisfaction, and increased highway throughput.[21]

ACC is defined in the current International Standards Organization[22] draft standard as "an enhancement to conventional cruise control systems which allows the subject vehicle to follow a forward vehicle at an appropriate distance by controlling the engine and/or power train and potentially the brake." A vehicle equipped with ACC will reduce speed automatically (within limits) to match the slower speed of the vehicle it is following.[23] Evaluation of the ACC field operational test conducted by NHTSA suggests that ACC could prevent about 12,000 rear-end collisions on interstate highways per year.[24]

Rear-end CWSs provide warnings (either auditory or visual) to alert drivers to obstacles ahead so the driver can take action, such as braking or steering, to avoid or reduce the severity of crashes that involve the host vehicle (the vehicle equipped with the CWS) striking the rear-end of the vehicle ahead.[25] Based on crash data information, such as speed, accident cause, and contributing factors, a rear-end CWS would have about a 48-percent effectiveness rate in reducing rear-end collisions. This would equate to a reduction of about 791,000 crashes per year.[26] This analysis assumes 100-percent reliability, perfect driver compliance with the warnings, and no risk compensation.[27] Actual benefits may be lower and operational tests currently being sponsored by the DOT could help determine what the actual benefits may be.

Adaptive Cruise Control

ACC systems that are currently on the market use a combination of engine control and brake application to slow the vehicle. The driver sets a speed and a desired following distance, in either feet or seconds.[28] If no vehicles are ahead, the ACC-equipped vehicle operates as a vehicle equipped with conventional cruise control and maintains a set speed.

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[21] U.S. Department of Transportation, National Highway Traffic Safety Administration, *Preliminary Assessment of Crash Avoidance Systems Benefits,* Benefits Working Group (October 1996).

[22] A worldwide federation of national standards bodies, whose mission is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services and to developing cooperation in the sphere of intellectual, scientific, technological, and economic activity.

[23] "Mock Trial: Human Factors Contributions to Litigation Involving Adaptive Cruise Control," *Proceedings of the IEA 2000/HFES 2000 Congress,* August 2000, San Diego, California.

[24] Information obtained from the home page of *The Volpe Journal* Spring 99 "Crash Avoidance" <http://www.volpe.dot.gov/resref/journal/spring99/crasha.html>.

[25] U.S. Department of Transportation, National Highway Traffic Safety Administration, *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems Final Report,* DOT-HS-808-964 (Washington, DC: NHTSA, August 1999).

[26] NHTSA Benefits Working Group, October 1996.

[27] In other words, drivers do not drive in a more risky manner to compensate for the additional safety that the CWS provides.

[28] By setting the time, the distance to the vehicle ahead changes depending on speed. For instance, as speed increases, so does the following distance because the distance is based on speed multiplied by the time set, which is usually permitted to be 1 to 3 seconds.

However, if a slower moving vehicle is ahead, the ACC-equipped following vehicle will slow to a comparable speed at the preset distance. The maximum resultant braking varies between vehicles.[29] Once the slower moving vehicle moves out of the way or speeds up, the following vehicle resumes its preset speed.

ACC differs from CWSs in that it does not necessarily provide a warning to the driver if the closing rate is too high for the system to avoid a collision, although some systems do. ACC does not take evasive action. It is intended for use at highway speeds; most current systems do not operate well below speeds of 30 mph. (Several manufacturers are now working on "stop and go" systems that operate at low speeds.) ACC is marketed as a convenience system, not a safety system, and manufacturers assert that the driver should maintain complete responsibility over the operation of the vehicle.[30]

Adaptive Cruise Control Field Operational Test. In the United States, NHTSA has conducted a field operational test of ACC to evaluate how ACC would work in real world operating conditions and to assess the benefits and public acceptance of the ACC system. (See appendix B for details.) According to the field operational test report, [31] the most significant finding of the field operational test was that

> people are remarkably attracted to ACC and to its relief of driving stress, they choose to engage the system under as broad a set of driving conditions as possible and they seek to prolong each episode of system engagement.

Drivers used ACC in 77 percent of the highway miles driven during the test, and 98 percent of the drivers said that they felt comfortable using ACC.[32] The drivers rated how safe they believed ACC to be as a six on a scale of one (poor) to seven (excellent). As stated in the report, the safety implications of ACC were of great interest to all the partners in the field operational test. With the 35,000 miles logged with ACC engaged, the partners in the field operational test anticipated no more than a 10-percent chance that a police-reported crash would occur if ACC risks matched the risks of conventional driving. No crashes occurred, but the authors concluded that this is only a very crude data point for long-term crash potential.[33]

The authors of the field operational test report believe that in order for ACC to be a safety success, drivers need to understand how the system works, recognize its limitations, and adopt plans to compensate for these limitations. During the field operational test, drivers were given a brief orientation to the system and were able to adopt appropriate plans and mental models of how the system worked. The authors further stated that real

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[29] The industry maximum braking force is about 0.3g (3 m/s^2).

[30] The IEA 2000/HFES 2000 Congress, August 2000.

[31] U.S. Department of Transportation, *Intelligent Cruise Control Field Operational Test, Final Report,* DOT-HS-808-849 (Washington, DC: DOT, May 1998).

[32] DOT-HS-808-849.

[33] DOT-HS-808-849.

world implementation of the system may allow for the determination of the safety impacts of ACC.

Conclusions made by the field operational test researchers were "that the ACC system worked very well, that people learned to use it quickly, and that its great appeal caused it to be heavily utilized."[34] Results of the field operational test also showed that ACC lengthened headway times and led to a less aggressive driving style in many of the drivers. Because the driver shares control with the ACC system, system designs must be tailored to perceptual and cognitive behavior of drivers, meaning the system must not compete with the driver but must operate similar to how the driver expects it to.

Driver Acceptance of Adaptive Cruise Control. In 1998, a study[35] sponsored by the DOT was conducted to determine consumer acceptance of crash avoidance devices, including ACC and CWSs. One finding of the study was that while safety is not a primary consideration in vehicle purchase decisions, safety is incorporated into the purchaser's overall review and perception of the vehicle. Another finding was that recent controversies over air bag injuries and antilock braking systems have left a few people ambivalent or negative about safety features and that these people were concerned the manufacturers may not get the design correct. Older drivers were attracted to "fully loaded" vehicles and were enthusiastic about systems that could help their declining skills. For a majority of survey respondents, the acceptability of a safety device hinged on how details would be implemented (the type of warning and distraction and the unambiguousness of the alert), particularly for a crash avoidance system that integrated front, rear, and side object detection.

Overall, respondents viewed a rear-end CWS favorably. The major concerns were about the nature of warning systems and the reliability of the system. ACC was received with the least enthusiasm. A statistically significant portion of survey respondents rarely used conventional cruise control and were nervous to "surrender control" of their vehicles. Concerns about ACC contrasted with reactions of the people who drove an ACC-equipped vehicle for a few days, suggesting that "hands on" experience may allay some of the initial fears quickly. In the ACC operational test, 98 percent of the drivers using ACC were comfortable with it. Seventy-eight percent of the survey respondents reported that they would likely purchase a CWS; 43 percent of the respondents would likely purchase an ACC.

No data are yet available on the successes or drawbacks of ACC. According to a news article,[36] ACC systems have not been popular in Japan because they are designed to be used on expressways. Very few people in Japan, however, use the expressways frequently enough to justify the cost of the systems. Car companies are even removing conventional cruise control as standard equipment because of low desire by drivers.

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[34] DOT-HS-808-849.

[35] *Consumer Acceptance of Automotive Crash Avoidance Devices,* Charles River Associates Incorporated, CRA Project No. 852-05, April 1998.

[36] Michelle Weinstein, "ITS in Japan," August 30, 2000. Information obtained from the Web site <http://www.itsa.org/human.html>.

Current Adaptive Cruise Control Deployments. ACC systems have been offered in high-end passenger car models for the past 5 years in Japan and for the past year in Europe. ACC systems became available in the United States on model year 2001 Mercedes S- and CLK-Class cars and the model year 2001 Lexus LS430. The ACC developed by Eaton VORAD has recently begun to be offered on heavy trucks in the United States and on Actros trucks in Europe. Delphi Delco Electronics Systems and TRW have also developed ACC systems. In Europe, Jaguar and Daimler/Chrysler offer an ACC as a convenience system on high-end vehicle models, and Daimler Trucks offers it on its Actros trucks. (Table 2 contains a summary of the major systems offered in the United States and Europe.)

Collision Warning Systems

A rear-end CWS alerts a driver to slowed or stopped objects in the vehicle's path ahead. A CWS is not intended to relieve vehicle operators from responsible and safe driving, but is an aid for drivers, if for some reason, such as distraction or environmental factors, they do not notice that the vehicle ahead is slowing. A CWS is generally considered a safety system. It provides an audible alert to the driver that an obstacle is ahead, and it may or may not, depending on the system, provide automatic slowing as ACC does. According to a NHTSA official, some CWSs are being offered in conjunction with ACC, such as the Eaton VORAD system. Also, some ACC systems, such as the Mercedes-Benz system, alert the driver if the ACC is unable to reduce the vehicle's speed enough, but other systems may not.

Most major truck manufacturers currently offer CWSs as an option. The U.S. Army has evaluated a CWS and is outfitting a portion of its fleet of trucks and transporters with CWSs.[37] NHTSA contracted in June 1999 with the General Motors Corporation for an operational test of a rear-end CWS in a passenger vehicle and in November 1999 with Volvo and U.S. Xpress for an operational test of a rear-end CWS and Eaton VORAD's SmartCruise, among other technologies,[38] on commercial vehicles. NHTSA has also sponsored research, such as sensor design and human factors research, with the General Motors Corporation and the Ford Motor Company on predeployment enabling technologies. The Government of Australia is also conducting research on a CWS to determine whether the system helps train drivers to maintain longer headways, thus increasing safety.

U.S. Army Testing. In 1995, the U.S. Army tested a CWS on six convoy vehicles traveling throughout the United States and nine heavy vehicles in Texas to demonstrate and evaluate the use of commercial technologies on military vehicles.[39] The convoy data were analyzed, and the CWS facilitated in avoiding 10 accidents in the 15,000 miles of

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[37] K. Luckscheiter, *National Automotive Center Collision Warning Safety Convoy,* U.S. Army Tank-Automotive and Armaments Command (Warren, Michigan: September 1996).

[38] Other technologies being tested include electronic brakes and disc brakes.

[39] Luckscheiter.

Table 2. Available adaptive cruise control systems

System	Bosch/ BMW[a]	Delphi/ Jaguar/GM FOT[b]	Daimler/ Chrysler[c]	Daimler Trucks	Eaton VORAD[d]	TRW[e]
Platform	High-end passenger cars	Passenger cars	High-end passenger cars	Trucks	Trucks (currently) Passenger cars (future)	Passenger cars
Sensor	Radar	Mechanically scanned microwave radar	Scanning radar	Scanning radar (every 7 milliseconds)	Monopulse radar with yaw sensor	77 GHz radar sensor
Detection	Detection range of 100 meters	Tracks 15 targets (distance to be determined)	Tracks targets to 150 meters		Detection range of 350 feet	Operates to 150 meters at speeds of 20 to 110 mph
Speed reduction method	Motor management and braking	Throttle control and limited braking	Throttle control and limited braking	First engine brake, then transmission retarder, then foundation brakes	Transmission downshift and limited electronically activated braking	Throttle control and limited braking
Driver intervention	Driver responsible for steering maneuvers and hard braking	Audibly warns driver whether harder braking is required	Can slow by 25 percent, then audibly warns driver whether harder braking is required	Can slow by 25 percent, then audibly warns driver whether harder braking is required	Driver can select auditory or visual alerts when intervention is required	Can slow by 30 percent, then warns driver through audio or visual warning
Other features	Electronic Stability Program provides information on driving direction to select relevant vehicles; future systems will work in stop-and-go traffic	Distinguishes between targets and stopped objects		Can be deactivated by driver for city driving	Tracks around curves	Automatically disengages if brakes or stability system engaged

[a] Kevin Jost, "Bosch Adaptive Cruise Control for BMW," *Automotive Engineering International* (October 2000).

[b] "Delphi's Forewarn Collision-Warning System Technology," press release, June 24, 1999, and information obtained from the Web sites <http://www.delphiauto.com> and <http://www.jaguar.com/uk/mdr/xkr.html>.

[c] Information obtained from the Web site <http://www.mercedes.com/e/cars/s-class/facts_e4.htm>.

[d] TRW press release, March 2, 2000.

[e] Information obtained from the Web site <http://www.eaton.com/VORAD/auto.html; public hearing testimony>.

convoy driving. The Army realized two significant lessons from its operational testing: (1) drivers should always be in command and should be able to turn the system off and on when they think it is appropriate, and (2) human factors aspects are so significant that a CWS must be designed so that drivers understand the system and want to use it. The evaluation also concluded that it was imperative for the drivers to be trained on the system because the system was not intuitive. The CWS improved the safety of the convoy, and a positive payback (benefits [reduction in accidents] exceeded costs) was identified for truck applications. The study recommended that the CWS should be installed on all new Army truck procurements and on major rebuilds.

In fiscal year 1996, the Army defined its CWS requirements, and these were added to several high-convoy-use tactical vehicles. Integration is projected to result in a 30-percent decrease in convoy accidents and in a savings of 15 soldier lives per year.[40] The CWS is now an operational requirement for the Army's heavy equipment transporter, heavy expanded mobility tactical truck, and M900 series line-haul tractor. The Army has been systematically outfitting a few segments of its fleet with the CWS, and in 1999, about 60 of its M915 truck tractors, according to an official at the National Automotive Center, were equipped with the CWS.

Crash Avoidance Metrics Partnership. In 1996, the General Motors Corporation and the Ford Motor Company formed, and NHTSA funded, the Crash Avoidance Metrics Partnership to define and develop key precompetitive enabling elements of the rear-end CWS. The partnership focused on light vehicles. According to NHTSA's technical report[41] on the partnership, a rear-end CWS should behave like an ever-vigilant passenger and produce a crash alert only when a passenger would become alarmed. Preliminary minimum functional requirements were developed to specify the crash alert response in a crash-relevant and noncrash driving scenario. Objective test procedures were developed to verify that the CWS performed as required.

However, according to the NHTSA report, current systems may not be able to meet requirements, or systems that do not meet all the requirements may still provide a crash avoidance benefit. Further testing is necessary to establish driver acceptance of the proposed alert timing and interface modality requirements under different operating conditions, such as night, weather, and nonconstant lead vehicle decelerations. True nuisance alert exposure rates are driver dependent. Field operational tests are necessary to understand the level of nuisance alarms acceptable to drivers.

NHTSA is negotiating a follow-on contract with the Crash Avoidance Metrics Partnership to initiate a study to examine driver performance and alert functions/interface modality requirements for rear-end crash scenarios involving nighttime and wet road conditions, nonconstant lead vehicle decelerations, and last-second lane change maneuvers.

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[40] Information obtained from the history page of the U.S. Army Tank-automotive and Armaments Command <http://www.tacom.army.mil/tardec/nac/history/1996.htm>.

[41] DOT-HS-808-964.

Automotive Collision Avoidance Systems Program. In 1997, according to the NHTSA director of the Office of Vehicle Safety Research, NHTSA completed the Automotive Collision Avoidance Systems Program with Delphi Delco Electronics Systems and partially funded by the Defense Advanced Research Project Agency. The study[42] was conducted by a consortium of Government, industry, and academic participants to provide a focused approach to the development of collision avoidance systems for passenger cars. Emphasis was placed on refining technologies and systems to reduce costs and improve warnings and on human factors engineering to determine the best way to warn drivers. During the study, several demonstration vehicles were equipped with a rudimentary CWS to demonstrate the viability of the baseline system architecture.

According to NHTSA officials, a follow-on contract for a field operational test was awarded to the General Motors Corporation[43] in June 1999 to establish system reliability, estimate system effectiveness, and determine user acceptance.[44] The key technical issues to be addressed are the rejection of out-of-path targets and the determination of the most effective driver interface.

U.S. Department of Transportation Intelligent Vehicle Initiative.[45] The DOT is participating in a $5.3 million contract, of which $3.5 million is DOT-funded,[46] led by Volvo Trucks of North America, Inc.[47] One hundred trucks run in revenue service by U.S. Xpress have been equipped with an Eaton VORAD CWS and SmartCruise, and data is being collected over a 2-year period. The data and driver surveys will be analyzed to determine the effectiveness of the displays and to indicate the usability and acceptability of the CWS,[48] particularly with false alarms. The prototype truck was completed in summer 2000, and all of the trucks were delivered in early 2001.

Australian Research and Testing. A major research project is underway in Australia aimed at "stimulating the demand by fleet owners for in-vehicle ITS technologies which have significant potential safety benefits."[49] According to the project

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[42] U.S. Department of Transportation, National Highway Traffic Safety Administration, *Automotive Collision Avoidance Systems Program Final Report,* DOT HS 809 080 (Washington, DC: NHTSA, August 2000).

[43] Other participants in the field operational test were Delphi Delco Electronics/Advanced Electronics Development, Delphi Chassis Systems, Hughes Research Labs, Raytheon/HE Microwave, University of Michigan, and Assistware, Inc.

[44] August Burgett, Ph.D., presentation "Rear-End Collision Warning – Field Operational Test" to Congressional staff on November 4, 1999.

[45] The Intelligent Vehicle Initiative is a safety problem-solving program, comprising Government and industry partnerships, that emphasizes vehicle-based systems to solve safety problems that are identified and defined in the program. The DOT is currently funding $12.7 million in Intelligent Vehicle Initiative contracts, which include the CWS, the ACC, rollover warning systems and lane tracking, lane departure warning systems, electronic brakes, automatic crash notification, and driver interfaces. The Intelligent Vehicle Initiative will be part of the DOT's 10-year National Intelligent Transportation Systems Program Plan and Research Agenda, to be developed by September 2001.

[46] Burgett.

[47] Other participants are U.S. Xpress, Eaton VORAD, Eaton Bosch, North Carolina A&T University, and Aberdeen Proving Ground.

[48] Burgett.

manager, the research is being conducted in an attempt to familiarize drivers with ITS technologies so that drivers will understand what is available and demand it on their vehicles. The project will also help researchers learn the effects on safety and human performance over the short, medium, and long term, particularly with multiple systems integrated.

The Eaton VORAD EVT-300 CWS will be one of eight technologies that will be tested on Ford Fairmont Ghia vehicles.[50] The system will primarily be studied as a method to teach drivers to adopt greater headway distances and provides a visual alert when objects are within 350 feet and an auditory alert when objects are within 2, 1, or 0.5 seconds.

In mid-2000, two prototype vehicles were outfitted with the systems. Phase three will be a limited field test with 10 to 20 vehicles to conclude in mid-2001. Phase four will be a major research study involving fleets of vehicles equipped with the ITS technologies. According to the project manager, societal attitudes and acceptance, as well as driving performance and safety, will be measured.

Current CWS Deployments. At the Safety Board public hearing in summer 1999, the president of Eaton VORAD discussed the CWS that Eaton VORAD has developed and is currently available to the heavy truck industry. Eaton VORAD systems have been used in over 2 billion miles of over-the-road experience.

According to Eaton VORAD, its CWS is a forward-looking radar-based system that detects obstacles ahead of the vehicle and alerts the driver to potential hazards. (See figure 3.) The driver receives a visual alert at 350 feet from the obstacle ahead and again at a time-to-collision[51] of 3 seconds. The driver then receives an auditory alert at a time-to-collision of 2 seconds. The warning from the CWS is based on time-to-collision; therefore, at slower speeds, because the closing distance is reduced, the driver does not receive nuisance alarms. The system can distinguish objects that may not be a hazard, such as a guardrail when the vehicle rounds a curve, because it is equipped with gyros that help determine the path of the vehicle. Eaton VORAD has attempted to minimize the false alerts by improving the technology and the software, but some stationary false object alerts still exist.

In a compilation of accident information from seven CWS-equipped fleets, the average accident reduction was 73 percent in 1 to 2 years (not consistent study periods in each fleet). In a 3-year study of over 1,900 vehicles, the reduction in all accidents was 78 percent.[52] According to Eaton VORAD testimony at the public hearing, the reduction in accidents (rear-end and lane change) by Eaton VORAD customers ranges from

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[49] Michael A. Regan, Claes Tingvall, David Healy, and Laurie Williams, “Trial and Evaluation of Integrated In-Car ITS Technologies: Report on an Australian Research Program,” Seventh World Congress on Intelligent Transport Systems, November 5-9, 2000, Turin, Italy.

[50] Manufactured by the Ford Motor Company of Australia.

[51] Time-to-collision is the amount of time to impact if the driver does not take action to avoid a collision.

Figure 3. Eaton VORAD driver display unit.

35 to 100 percent. However, Eaton VORAD noted that other factors may contribute to the reduction, such as training or other technologies. The data were not collected scientifically but were submitted by Eaton VORAD customers.

According to the testimony of the Greyhound vice president at the public hearing, Eaton VORAD CWSs were first operated on Greyhound buses in the early nineties. After several years, Greyhound removed the systems because they did not meet its needs at the time. Greyhound busdrivers were dissatisfied for several reasons: (1) their driving was being monitored, (2) the auditory alert would go off when no potential for collision was evident, and (3) the radar system would activate radar detectors, causing other drivers to slow rapidly and cut in front of the bus. According to Eaton VORAD, the system has changed significantly since that time; a new radar system is used, measures have been

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[52] "New Statistics Demonstrate Conclusively That Collision Warning Systems Significantly Reduce Accidents," Eaton Vorad press release, September 14, 2000.

taken to reduce the nuisance alarms, and the distance at which a driver is warned is adjustable.

Eaton VORAD is currently marketing the CWS to truck manufacturers, who are beginning to integrate the system into their trucks, particularly the driver displays into the dashboard. Most major truck manufacturers currently offer the Eaton VORAD CWS as optional equipment.

The president of U.S. Xpress testified at the public hearing that his company uses the CWS because it is a proactive system and it gives the driver several additional seconds to react to an emergency situation, thus preventing or reducing the severity of a collision. The company has experienced about a 75-percent reduction in rear-end collisions since incorporating the CWS, as well as employing antilock brakes and other technologies. When the CWS was first introduced at U.S. Xpress, the company president said that drivers wanted to drive the trucks equipped with a CWS because they valued the sense of safety it provided. Now the entire U.S. Xpress fleet is equipped with the CWSs.

However, according to a truckdriver with another trucking company, other drivers have found the Eaton VORAD system to be sometimes annoying, such as when auditory and visual warnings are given when turning, although no risk of collision is present. The Eaton VORAD CWS also at times issues warnings for stationary objects or bridges. According to a sales manager of Eaton VORAD, the company has almost completed software modifications to decrease the number of false alarms due to bridges.

Infrastructure-Based Systems

Approximately 28 percent of rear-end crashes occur when the lead vehicle is not moving,[53] and about 30 percent of multivehicle fatal work zone crashes involve rear-end crashes.[54] Vehicles that are stopped on highways in the travel lanes can be attributed often to congestion due to traffic or work zones. Because of the safety issues related to stopped queues, several researchers and State departments of transportation are exploring technologies to alert drivers to the stopped or slowed traffic ahead, particularly in areas where the approach speed may be high and where the driver may not expect stopped or slowed traffic. An ideal location for the portable infrastructure-based systems is at work zones or on urban highways that often experience recurrent congestion. (See appendix C for examples of these technologies.) One of the features of an infrastructure-based system is that vehicles do not have to be equipped with warning technology, such as a CWS, for the system to alert drivers who may not be aware of stopped traffic ahead in time for them to stop or take evasive action.

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[53] NHTSA Benefits Working Group, October 1996.

[54] *1998 Work Zone Crashes Fact Sheet,* December 15, 1999. Information obtained from the Web site <http://www.atssa.com/pubinfo/1998workzonecrashes.htm>.

According to the manager of the National Work Zone Safety Information Clearinghouse,[55] the Strategic Highway Research Program addressed portable queue warning technologies for work zones in the early nineties. A number of different designs have been developed, but the premise for all is similar. A detection system (radar, in-pavement devices, or video) detects traffic speed and queue length prior to and in a work zone. This information is then sent via a communications link to a processor to analyze the data and to determine the proper information to be related to drivers. The determination is either automatically provided through measures set up in the processor or manually made by someone at a traffic control center. The information on the traffic conditions is then transmitted to variable message signs that are generally spaced at regular intervals upstream of the work zone to a distance beyond the longest estimated queue length. The displayed information can include traffic speed, expected delays, alternate routes, warnings to merge, or the location of the end of the queue.

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[55] In February 1998, the American Road and Transportation Builders Association joined forces with the Federal Highway Administration to improve safety in highway work zones by creating the National Work Zone Safety Information Clearinghouse. The purpose of the clearinghouse is to provide information and referrals to government agencies, public and private organizations, and the general public concerning the safe and effective operation of traffic work zones. The clearinghouse began operations in February 1998 under Federal Highway Administration funding and was mandated to become fully self-supporting by October 1, 2000.

Analysis

The following analysis will discuss ways in which collision warning technologies, both in-vehicle and infrastructure-based, can help prevent rear-end collisions from occurring and thus save lives. The accidents discussed in this report illustrate how collision warning technology can be beneficial to the safety of the driving public. The analysis will further discuss some of the barriers to the implementation of technologies, drawing on testimony from the public hearing, and make recommendations on how these barriers can be overcome so that drivers can use available technology and the roadways may be made safer.

Rear-end collisions accounted for 1.848 million crashes in 1999, resulting in 1,923 fatal crashes. Of the fatal crashes, 770 involved commercial vehicles (trucks weighing more than 10,000 pounds and motorcoaches). This represented 40 percent of the fatal crashes, even though commercial vehicles only accounted for 3 percent of vehicles and 7 percent of miles traveled. In fact, in all types of collisions, trucks accounted for only 9 percent of fatal crashes. In work zones, commercial vehicles were involved in 62 percent of fatal rear-end crashes. The Safety Board concludes that accident statistics and the Safety Board's accident investigation findings indicate that accident consequences are more severe when commercial vehicles are involved in rear-end collisions and that the public can benefit from technology designed to help prevent these collisions.

Vehicle-Based Systems

Collision Warning System

Driver inattention was a major causal factor in about 91 percent of rear-end crashes.[56] This inattention, as in the accidents discussed in this report, may be due to distraction, fatigue, or atmospheric conditions, such as fog or sun glare, that may prevent a driver from detecting an object ahead. Several of these accidents illustrate instances in which a CWS may have prevented or reduced the severity of the collisions. A CWS is not intended to replace driver vigilance; however, it can aid drivers when their attention may be concentrated on something other than the road ahead.

In the Moriarty accident, the truckdriver was traveling eastbound at sunrise at the posted speed limit of 75 mph and did not notice the two passenger vehicles ahead traveling between 25 and 30 mph. As witnessed by investigators on subsequent days, the glare of the rising sun may have obstructed the truckdriver's view. If the truck had been equipped with a CWS, the visual and auditory alarms may have alerted her to the slower moving vehicles ahead, even if she had been unable to see them.

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[56] ITS Joint Program Office, November 1999.

The Safety Board simulated the Moriarty accident incorporating the Eaton VORAD CWS to determine whether it would have provided the driver with adequate warning to prevent the collision. The Eaton VORAD CWS can detect vehicles at a distance of 350 feet, at which time a light is illuminated on the driver display. If the truckdriver had noticed the visual alert when the truck was 350 feet from the slower moving vehicles, she would have had adequate time (assuming a perception-reaction time of 1.6 seconds)[57] to determine the potential hazard, apply the brakes, and steer to avoid the collision without needing to take extraordinary measures.

However, if the driver was not looking at the display or if the environment was bright and the visual alert washed out, the driver may not have noticed the warning light. At a time-to-collision of 3 seconds, a second light on the Eaton VORAD system is illuminated. If the driver continued to approach the vehicles ahead, the Eaton VORAD CWS would have provided an auditory alert at a time-to-collision of 2 seconds or 220 feet, whichever was less (2 seconds in this case). Given that the typical driver perception-reaction time[58] ranges from 0.9 to 2.1 seconds, with the 95th percentile[59] reaction time of 1.6 seconds, the truckdriver would not have had enough time to slow the truck or swerve into the other lane and prevent the collision, if responding to the auditory alert only. In the Moriarty accident, the driver would have been required to react in about 0.73 seconds to the auditory alert to perform a severe lane change maneuver and just barely avoid the collision. In addition, the simulation showed the trailer would have been on the verge of instability during such a maneuver. Even the most well-trained and alert drivers would not have the ability to react so quickly and would likely need additional time to successfully avoid an accident.

In the Sweetwater accident, a tractor semitrailer was entering a congested work zone area. The truckdriver, traveling about 50 mph, failed to observe the congestion in the construction zone because he said that he was looking at the exit ramp ahead. He then applied the brakes, and the truck skidded 60 feet into the stopped vehicles ahead. A CWS may have helped the distracted driver to prevent this accident or alleviate its severity. The currently available CWS for trucks would have provided a visual alert to the driver when he was approximately 220 feet from the end of the traffic queue (3 seconds). If he noticed this alert, he could have started braking sooner than he did, possibly doubling the braking distance and reducing the speed at which the truck would have struck the minivan.[60] However, because the driver was looking at the exit ramp he might not have seen the visual cue, similar to the driver discussed above in the Moriarty accident. An auditory cue would have activated approximately 145 feet before the end of the queue, which, given standard reaction time, would not have provided any additional time for the driver to slow the truck. If the driver had received the auditory warning at the maximum detection

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[57] Thomas A. Dingus, Steven K. Jahns, Abraham D. Horowitz, and Ronald Knipling, "Human Factors Design Issues for Crash Avoidance Systems," eds. Woodrow Barfield and Thomas A. Dingus, *Human Factors in ITS* (New Jersey: Lawrence Erlbaum & Associates, 1998).

[58] The amount of time it takes for a person to perceive the object ahead and react to it.

[59] The 95th percentile means that 95 percent of all drivers will react in the given amount of time, or less.

[60] This assumes a 1.6-second reaction time.

distance, he likely would have had enough time to slow or to steer the truck onto the shoulder or the ramp. This further supports the need for auditory warnings at the point of detection if the distance between vehicles is closing, as described above in the Moriarty accident, with a high speed differential.

In the Sullivan accident, a truck and semitrailer struck the rear end of a school bus stopped at a railroad crossing, causing it to strike another school bus and resulting in both buses overturning. The truckdriver in the Sullivan accident had been without significant rest during the 26-hour period prior to the accident, primarily as a result of an inverted wake-rest cycle[61] on the days he was off duty. The truckdriver, traveling at a police-estimated speed of 59 to 62 mph, applied the brakes and skidded about 175 feet into the stopped school bus. Had the truck been equipped with a CWS, the auditory signal may have alerted the driver so he could focus his attention on the road ahead and take corrective action to avoid a collision. However, the Eaton VORAD system, as it is currently designed,[62] would not have provided an auditory alert with enough time for the driver to avoid the collision because of the truck's high rate of speed. As in the previous accidents, an earlier auditory warning, such as when the visual warning light was initially illuminated, would have been more desirable. Because of the driver's drowsy state, resulting in slower reaction times, he may not have been able to stop without impacting the bus; but the collision would have been less severe or he could have steered around the bus. If a CWS had been available to detect the bus and alert the truckdriver, the collision in Sullivan may have been prevented or the consequences reduced.

The West Haven, Elk Creek, and Eureka accidents all occurred under similar circumstances to those described above. In each accident, a truckdriver or busdriver was approaching slowed or stopped traffic and failed to notice the vehicles ahead. In each accident, if the striking vehicle driver had been alerted to the vehicles ahead, the driver may have been able to take evasive action, such as braking or steering, and prevented or reduced the severity of the accident.

Today, highways are not limited to a speed restriction of 55 mph; traffic can travel at speeds up to 75 mph or more. At these high speeds, when a great speed differential may be present, such as when traffic is moving more slowly or is stopped, the driver needs more time than is needed at slower speeds to take action to prevent a collision. If a driver is distracted or is not looking at the CWS display and does not notice the light illuminated on the CWS at the maximum distance, he/she will have to rely on the auditory alert. According to a NHTSA official, the Automotive Collision Avoidance System driver interface is expected to clearly warn, such as with a display of "exceed capability," if drivers are exceeding the limitations of the CWS, such as on high-speed roadways. The reasons given by the manufacturers for the detection distance not being greater on the current CWS is that as detection distance increases, so does the number of false alarms

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[61] The driver was driving at the time that on the previous day he was sleeping.

[62] The Eaton VORAD system does give an immediate warning if the vehicle ahead is moving at a speed of 20 percent, or less, of the host vehicle's speed. This warning is primarily to alert the driver of cars pulling onto the roadway ahead. The passenger cars in the Moriarty accident were traveling at 33 percent of the truck's speed.

because the radar beam is wider than the lane width and objects that are not threats, such as bridge abutments or vehicles in another lane, particularly in a curve, are detected. Eaton VORAD is currently working on measures to eliminate these false alarms. Both the Eaton VORAD and the Automotive Collision Avoidance System collision warning systems are currently being tested by NHTSA.

In the Wellborn accident, numerous collisions occurred in the eastbound and westbound lanes of the interstate during a period when smoke and fog covered the roadway. The issue of using a CWS in limited visibility situations was thoroughly discussed in the Safety Board's previous report concerning CWSs.[63] The Wellborn accident was strikingly similar to the Menifee accident that the Safety Board detailed in that 1995 special investigation report. In both cases, the vehicles entered an area of low visibility and were unable to see the slowed or stopped traffic ahead in time to prevent a subsequent collision. In 1995, the Safety Board concluded that CWSs have the potential for avoidance or reduction in the severity of low-visibility condition collisions such as in fog, snow, rain, or darkness; this conclusion still holds true. Drivers of vehicles equipped with a CWS would have been alerted to an obstacle ahead in the travel lanes even though they could not see it; the drivers then would have been able to stop or slow enough to maneuver around the obstructions. The Safety Board concludes that recent accident investigation findings, coupled with the nearly 1.8 million rear-end collisions that continue to occur each year, underscore the need for effective CWSs to help alert drivers to obstacles ahead, thereby increasing their reaction time and preventing collisions or reducing the severity of impact.

Adaptive Cruise Control

Although ACC is referred to by manufacturers as a convenience system, its operation can contribute to safety; however, ACC will not provide maximum braking to the vehicle and will not reduce the speed of the vehicle below a certain threshold (generally around 25 percent). Because of the infancy of ACC technology, the Safety Board has not investigated any accidents in which an ACC system was in use. However, the Wellborn and Tinnie accidents may have been avoided or alleviated had the vehicles been equipped with ACC.

The Wellborn accident occurred during smoke and fog on Interstate 10. The first truck to enter the smoky area eastbound began to slow down because of the limited visibility. The next truck did not slow its speed and ran into the first truck. This accident resulted in the trucks blocking both of the eastbound lanes, which led to a number of subsequent accidents.

Had the second truck been equipped with and using an ACC system, it would have automatically begun to slow to a speed similar to that of the first truck and probably would not have struck the first truck. It would have formed a convoy with a 2- to 3-second headway (depending on the driver-selected setting) and followed the first truck through the smoke without colliding. The remainder of the vehicles, had they likewise been

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[63] NTSB/HAR-95/03.

equipped with an ACC system, would have traveled through the smoke in a similar manner, adapting to the speed of the vehicle ahead.

According to the driver of the truck in the Tinnie accident, he had been following the van for about 20 miles at approximately 60 mph. In this case, an ACC system may have helped the driver maintain a safe distance behind the van and his truck would have begun to slow when the van slowed. The van slowed beyond the capabilities of a truck's ACC (for instance, if it were the Actros system, the truck would not have been able to slow to a speed below 45 mph without driver intervention). However, the slowing of the truck likely would have alerted the driver to the action of the van ahead so that he could take appropriate action to slow accordingly. Even though the passenger car ACC field operational test found that ACC may reduce vigilance, it also found that drivers said that when the car began to slow, it brought their attention back to the roadway in front of them, so they could take action if necessary.

The primary concern that the Safety Board has about ACC use in poor visibility conditions is that drivers may not know whether their vehicles need to slow by more than the ACC's capability. Some of the vehicles in Wellborn may have been traveling at speeds less than 25 percent of the speed at which other following vehicles were traveling. Current ACC systems are designed to only slow the vehicle by about 25 percent, after which the driver must take action. If the driver is in a smoky environment (or other low visibility situation) and cannot see the vehicle in front of him, as was the case in the Wellborn accident, the ACC would begin to slow the vehicle due to the slower vehicle ahead. However, without a cue, the driver may not be able to determine whether the ACC is slowing at an appropriate rate or whether the driver needs to intervene and slow the vehicle. The Mercedes passenger car ACC system does provide the driver with a warning that the vehicle is incapable of slowing as necessary. According to a NHTSA official, some manufacturers say they will only offer ACC in conjunction with a warning system such as a CWS; however, the current Jaguar system does not alert the driver if the vehicle is not automatically slowing sufficiently to prevent a collision. Without performance standards for system operation and driver interaction with ACC, the usage of numerous and nonuniform systems may result in operator confusion; thus, a driver may not understand how the system works and may not react appropriately if the system cannot slow the vehicle adequately.

Implementation and Deployment

System Usage. The Secretary of the DOT has set a goal of equipping 25 percent of new trucks and 10 percent of new cars with ITS technologies by 2010. Rear-end CWS technology could help meet that goal, as well as contribute to the goal of reducing fatalities by 50 percent for truck-related accidents and 20 percent for accidents overall. Severe injuries and fatalities can and do occur when trucks run into passenger vehicles or vice versa. The 1998 Fatal Analysis Reporting System data indicated that 40 percent of fatal rear-end collisions involved commercial vehicles. As shown in the discussion of the accidents cited in this report, the CWS can help reduce the fatalities and injuries associated with rear-end collisions and support the DOT in achieving its goals.

Field experience is critical to understanding the full advantages (and disadvantages) of safety systems—crash tests and simulations alone cannot represent all situations.[64] The Safety Board is therefore pleased that the DOT is now involved in the operational tests of ACC and CWSs. At the conclusion of these tests, a multitude of data and information will be available on the functionalities of rear-end CWSs. Nevertheless, these systems were available several years ago, and, in 1995, the Safety Board recommended that testing be conducted on CWSs. Had the DOT begun testing at that time, the understanding and deployment of these systems would be far greater than it is currently. Because of the delay, the benefits that could have been obtained through the use of ACC or CWSs were not realized.

As evidenced by the experience of companies whose trucks are equipped with CWSs and by Safety Board investigations, CWSs can help reduce rear-end collisions. Each of the accidents described in the previous section may not have occurred, or their severity may have been considerably less, had the striking vehicles been equipped with ACC to maintain an appropriate headway or with a CWS to alert the driver of traffic ahead. In these accidents alone, 20 lives may have been saved.

Even though the DOT has begun to field test ACC and CWSs, it has no plans to require the use of these systems. At the public hearing, the Safety Board heard testimony that some companies were voluntarily equipping their fleets with CWSs or ACC or both, and although the Safety Board lauds these efforts, the Board also recognizes that these carriers are in the minority. Relying on the industry to ensure that its trucks are equipped with this advanced safety technology is an ineffective strategy; the Safety Board has recommended the use of on-board recorders for commercial vehicles for over 10 years. The DOT has failed to encourage or mandate these devices, even though recorders can help increase safety by collecting accident data[65] and, according to on-board computer manufacturers, can help companies increase productivity by monitoring drivers' hours of service and providing information to the company to manage the truck, load, and driver. The DOT has, in effect, left it to the industry to deploy these devices. As a result, few trucks are currently equipped with on-board recorders, and no standard exists for those that are so equipped.

One of the greatest challenges for vehicle-based systems is the time necessary for full deployment of any system. For instance, it has been 14 years since all new vehicles were required to be equipped with center high-mounted stop lamps, and still many older cars are on the road today (due to normal turnover) that do not have these stop lamps. Without full deployment, the projected number[66] of rear-end collisions prevented will be reduced.

System Standardization. As new technologies begin to be implemented, standardization of the driver interface and the operational characteristics of the systems must occur to prevent driver confusion. The locations of driver-activated safety systems, such as brake pedals, are standardized. NHTSA testified at the hearing that it is focusing

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[64] Joseph C. Marsh, IV, presentation "Evaluating the Safety of Air Bags – Lessons Learned for ITS," ITS America Workshop on Safety Evaluations on May 1, 1995.

[65] Found in field tests in Europe and in the experience of a large oil drilling company in Texas.

[66] NHTSA projected 49 percent.

much of its research on the human interface with the technologies that are being tested. Highway warning signs have uniform symbols, yet several ACC systems are currently on the market with no standards for their operation. For the driver to develop an appropriate mental model of how a system works, there needs to be consistency among systems.

The DOT is taking the first step toward standardization by conducting operational tests, but it should do more to encourage, and even mandate, the use of CWSs to prevent rear-end collisions. NHTSA has stated that no current plans exist for rulemaking on rear-end CWSs. The DOT wants to understand how CWSs work so it can make appropriate recommendations on standards, if necessary. NHTSA did state, however, that if the operational tests are successful and action by industry or by users to implement CWSs is still slow action, then it would consider enacting a rulemaking that would include requirements for test procedures, effectiveness, false alarms, and benefits. As discussed previously in the Moriarty accident, current CWSs may not provide sufficient warning to the driver in some situations. The Safety Board concludes that without performance standards for system operation and driver interface, the usage of numerous and nonuniform systems may result in operator confusion; thus, CWS technologies may not provide the driver with the ability to prevent rear-end collisions in some situations.

Because of the delay by the DOT to encourage or mandate the use of this technology, the Safety Board is concerned that the potential benefits of the technology are not being attained. If this equipment is not introduced into cars and trucks, over the next 10 years many lives may be lost in highway crashes, at the current rate of fatalities in rear-end collisions, that otherwise may have been saved by the technology. A rulemaking by NHTSA may come too late. For instance, the operational test of ACC was completed over 2 years ago, and ACC systems are still not offered in the United States, even though ACC showed a safety benefit in the operational tests, and ACC is offered in Europe and Japan. The Safety Board believes that the DOT should complete rulemaking on ACC and CWS performance standards for new commercial vehicles. After promulgating standards, the DOT should require that all new commercial vehicles be equipped with a CWS. The DOT should also complete rulemaking on ACC and CWS performance standards for new passenger cars. At a minimum, the standards for both commercial vehicles and passenger cars should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning.

Consumer Acceptance and Public Perception

Although requiring the use of CWSs is critical, consumer acceptance of the technology is equally critical. For example, educating the public of the benefits of seat belts has been as important as equipping the vehicles with or requiring the use of seat belts. The DOT study on consumer acceptance of various automotive technologies reported that drivers, particularly older drivers, were enthusiastic about ACC and CWSs, but were wary of how they operated and their reliability. While only 43 percent of the drivers surveyed would purchase an ACC system, 98 percent of drivers who actually drove with an ACC system in the field operational test said they would purchase one.

Some drivers may be wary of new technology before using it; when air bags were first employed, people were initially apprehensive. To educate the public, the DOT and Allstate Insurance Company sponsored a demonstration of air bags using crash dummies.[67] The exhibit traveled to 100 cities over a 3-year period beginning in 1990. The purpose of the exhibit, according to Allstate's chairman and chief executive officer, was to "encourage consumers to purchase cars with air bags because we know they save lives and reduce injuries." A similar program could be developed to educate the public on the safety benefits of CWSs. The average driver, whether a passenger car or commercial vehicle driver, does not know what actually exists in the way of ITS and has never experienced what it is like to drive with some of these technologies.[68]

In discussing what the Government can do to promote the implementation of technology at the Safety Board's public hearing, a trucking company representative said that the Government could provide more information on the technologies, so that the data presented by the manufacturers is not suspect (consumers may think the manufacturer is just trying to sell something). He added that electronics in trucks are still relatively new and that consumers are not yet completely comfortable with it. If the Government were to publish solid data on the benefits of certain technologies, and on the benefits of multiple technologies, the trucking industry may be more apt to adopt the electronics. This is part of the impetus of the current Volvo operational test; the DOT can gather the data and form unbiased opinions and recommendations regarding the CWS technology. Transmitting this information to the public is crucial to the acceptance of the ACC and CWS technologies.

The Intelligent Transportation Society of America is a group that can help disseminate the positive experiences with ACC and CWSs. In the past, it has sponsored demonstrations of technologies in the developmental stages resulting in positive perceptions of ITS for the future. A demonstration of existing technologies that are under deployment may show the driving public what is available and the success of the field operational test. The group is in an ideal position to champion the results of the field operational tests and to educate the public of the benefits of ACC and CWSs.

The Safety Board concludes that information concerning the use and benefits of effective CWSs and ACC is critical to their acceptance by the driving public. The Safety Board believes that NHTSA, the Federal Highway Administration, the Intelligent Transportation Society of America, and the truck, motorcoach, and automobile manufacturers should develop and implement a program to inform the public and commercial drivers on the benefits, use, and effectiveness of CWSs and ACC.

Training

The object of training is to ensure that specific skills or procedures are learned. Training can occur through verbal instruction, demonstration, guidance, practice,[69] or the

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[67] Insurance Institute of Highway Safety, *IIHS Status Report*, Volume 25, Number 10 (Arlington, VA: November 17, 1990).

[68] Regan, Tingvall, Healy, and Williams.

[69] Gavriel Salvendy, ed., *Handbook of Human Factors* (New York: John Wiley and Sons, Inc., 1987).

use of videos or computers. Training is one of the standard methods used to aid people in acquiring safe behavioral practices.[70]

According to the president of U.S. Xpress, the company provides its drivers with extensive training on all the technologies that are employed in its trucks. For example, a driver will receive orientation on the ACC so he understands what happens if the truck begins to slow down, why the truck is slowing (because a vehicle is ahead), and how the driver should react. Recurrent training is also provided and is considered by U.S. Xpress to be necessary for drivers to be successful and to understand the technology.

Training has been provided in the operational tests that have been conducted to date with ACC or CWSs. In the ACC operational test conducted by NHTSA and the University of Michigan Transportation Research Institute in 1996 and 1997, the drivers received a limited introduction to the functions and capabilities of the system. This understanding allowed the drivers to use the ACC in the manner for which it was intended and made them aware of the necessity of intervening when harder braking was necessary.[71] The drivers surveyed during the Army field test believed that training was imperative because the systems were not intuitive without training.[72] Despite the DOT and Army experiences, according to an Eaton VORAD official at the Safety Board's public hearing, trucking fleets have indicated that a CWS is easy to learn without training. One of the parameters being explored in the Australian study is whether drivers are able to intuitively determine the operation of CWSs without training.

A July 1991 accident investigated by the Safety Board demonstrates the necessity of training on new technologies. A 1989 school bus, descending a two-lane roadway near Palm Springs, California, increased speed, left the road, plunged down an embankment, and collided with several large boulders. The busdriver and 6 passengers were killed, and 47 other passengers were injured.[73] The bus engine was equipped with a then-new automatic upshift overspeed protection feature[74] to prevent engine and transmission damage. While information on this feature was provided in the operator manual for the transmission, neither the training coordinator nor the busdriver's behind-the-wheel instructor had seen the operator manual, and the instructor was not aware of the automatic upshift capability. The busdriver training program did not discuss the upshift feature. The Safety Board concluded that although the automatic transmission upshift feature did not cause or contribute to this accident, an upshift occurrence may be the first warning that the transmission can no longer help maintain speed control and immediate action must be taken to reduce speed to effect a downshift back to the desired gear range. The Safety

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[70] Mark S. Sanders and Ernest J. McCormick, *Human Factors in Engineering and Design*, 7th ed. (McGraw Hill, Inc., 1993).

[71] DOT-HS-808-849.

[72] Luckscheiter.

[73] National Transportation Safety Board, *Mayflower Contract Services, Inc., Tour Bus Plunge From Tramway Road and Overturn Crash Near Palm Springs, California, July 31, 1991*, Highway Accident Report NTSB/HAR-93/01 (Washington, DC: NTSB, 1993).

[74] This feature upshifts the transmission to the next higher gear if the vehicle momentum on a downgrade drives the engine beyond its maximum governed rpm setting. The engine also cannot be downshifted until the speed is brought into the gear's speed range.

Board advised that the training curriculum be expanded to include automatic transmission upshift characteristics and proper operation in mountainous terrain.

The importance of training cannot be overstated, based on the experience of U.S. Xpress, the operational tests, and previous Safety Board accident investigations. Training is critical to the understanding of complex technical system functionalities so that drivers can respond adequately when the technology is in use. The Safety Board concludes that commercial drivers need to be oriented to the use of CWSs and ACC in order to understand system capabilities, how the driver interface works, and how the system functions. Commercial vehicle drivers receive training and refresher courses throughout their driving careers. These courses provide an opportunity for drivers to learn about new safety technologies that are incorporated into their vehicles. The Safety Board believes that truck and motorcoach manufacturers should develop a training program for operators of commercial vehicles equipped with a CWS or ACC and provide this training to the vehicle operators. Further, the Safety Board believes that the American Trucking Associations, Inc., the Owner-Operator Independent Driver Association, and the National Private Truck Council should encourage their members to obtain or provide, or both, training to those drivers who operate CWS- or ACC-equipped trucks.

Infrastructure-Based Systems

Infrastructure-based systems detect stopped or slowed traffic and relay relevant traffic information, such as the location or the speed of a traffic queue, to drivers upstream of the end of the queue. The systems can be stationary, for instance, in locations that experience frequent traffic congestion, or portable,[75] as in work zones. Two of the accidents investigated by the Safety Board occurred upstream of work zones. Despite the signage at these work zones, drivers did not receive adequate information to prepare them to stop for these traffic queues ahead.

Because the Sweetwater work zone was in a specific location (it was not a moving work zone), an infrastructure-based system may have provided more detailed and accurate signs, such as information on the length of the backup, traffic speeds, and the location of the end of the queue. It appears that the driver did notice the signs that were in place warning of work zone speeds of 50 mph based on the fact that he did reduce his speed to the posted speed limit in the work zone. However, no signs were present to warn the driver that the traffic was stopped. Traffic conditions affect the location of the end of a queue in a work zone. An infrastructure-based system that detected the end of the queue and alerted drivers upstream to the slowed and stopped conditions ahead may have provided the truckdriver with sufficient warning to slow his truck and prevent the accident. The signs that were in place may have presented adequate warning to the driver during a majority of the day; however, in congested periods, such as rush hour on days before a holiday, the

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[75] Portable systems can be moved to different work zone locations as required, but when in place at a work zone remain fixed.

signs did not offer the driver sufficient warning about the location of the end of the queue, which was lengthening.

The Trenton accident, like the Sweetwater accident, occurred upstream of a work zone. However, unlike the Sweetwater accident, no signs were erected on Interstate 59 to alert drivers that they were approaching a construction zone. Therefore, the driver of the truck was likely traveling at the posted speed limit of 70 mph. The work zone was set up to meet the *Manual on Uniform Traffic Control Devices* standards. However, these standards did not provide for adequate warning to drivers, as the end of the queue extended beyond the signs posted 1 mile upstream of the construction. An infrastructure-based system with signs and detectors that extended beyond the end of the queue to alert drivers to the existence of slowed or stopped traffic may have provided the driver with sufficient warning to slow or stop.

In both the Sweetwater and Trenton accidents, a queue length detection and warning system would have helped to warn the drivers of the stopped traffic ahead. Both of these accidents exemplify the need for and benefits of queue length detectors and warning signs. An efficient means of alleviating the accident risk due to backups while expeditiously accomplishing the work may be to use ITS to detect the queue ends and to warn traffic of backups. The location at which an operating sign is activated changes as the queue grows. As part of a queue length detection system, active signs providing information on speeds and queue length upstream of the end of the queue may help alert drivers to congestion ahead, resulting in fewer or less severe accidents. The Safety Board concludes that the number of accidents that continue to occur at construction work zones suggests that efforts to inform drivers of congestion at these work zone sites have not been adequate.

Although an active infrastructure-based system can alert drivers to changing conditions ahead, this would probably not have been feasible in the case of the Wellborn accident. The smoke from the forest fires was intermittent over a 32-mile stretch of Interstate 10, and it was difficult, if not impossible, to determine where visibility might have been obstructed because of the constantly changing smoke. Placing active message signs and weather information systems for low visibility every mile along Interstate 10 would be prohibitively costly. If the sign spacing were further apart, the signs might lose their effectiveness. Drivers stated that they did not heed the stationary signs that were present on Interstate 10 warning them of fires in the area because they saw several signs for miles, but no indication of fire or smoke, except in the accident area. While the Safety Board has made previous conclusions and recommendations[76] for systems to detect low-visibility conditions in places where they occur often, a similar situation was not present on Interstate 10. The low-visibility conditions were a product of smoke and fog, of which this location had no history.

One of the difficulties with queue length detectors is that the end of the queue can vary by location or by time of day. Where to place the sensors so that upstream queues do not exceed the detection range but the message warning is not so far back that it loses

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[76] Safety Recommendations H-90-93, H-92-86 and -87.

relevance is difficult to determine. For instance, in the Trenton accident, the end of the queue exceeded the position of the static signs warning of the work zone. In the Wellborn accident, the FOG/SMOKE warning signs with flashing beacons that remained in the area when hazardous conditions no longer existed decreased the public's confidence in the warning signs.

Many agencies rely on the expertise and experience of field personnel who know how far back traffic typically queues along a given section of roadway. Tools do exist to predict queue length. However, according to information provided by the Work Zone Safety Information Clearinghouse, because driver behavior can change dramatically in response to congestion (traffic diverting to other routes), to accurately predict queue lengths with any degree of certainty is difficult, prior to the formation of congestion. Therefore, multiple variable message signs can be spaced upstream of the traffic and activated when the queue approaches that location.

The Federal Highway Administration, in cooperation with the American Association of State Highway Transportation Officials, updates the *Manual on Uniform Traffic Control Devices* every 5 years. The most recent update, the Millennium Edition, was released January 17, 2001. This manual contains recommended practices for all roadway traffic control devices (in particular, signage and signals). While not required to, many States adopt the *Manual on Uniform Traffic Control Devices* guidelines.

The Safety Board believes that the Federal Highway Administration should develop a procedure that States can use to conduct a risk analysis for work zone backups; require, where appropriate, the use of a queue length detection and warning system; and incorporate that procedure for a queue length detection and warning system for work zones in the *Manual on Uniform Traffic Control Devices* work zone guidelines.

Conclusions

1. Recent accident investigation findings, coupled with the nearly 1.8 million rear-end collisions that continue to occur each year, underscore the need for effective collision warning systems to help alert drivers to obstacles ahead, thereby increasing their reaction time and preventing collisions or reducing the severity of impact.

2. Accident statistics and accident investigation findings indicate that accident consequences are more severe when commercial vehicles are involved in rear-end collisions and that the public can benefit from technology designed to help prevent these collisions.

3. Without performance standards for system operation and driver interaction with adaptive cruise control, the usage of numerous and nonuniform systems may result in operator confusion; thus, a driver may not understand how the system works and may not react appropriately if the system cannot slow the vehicle adequately.

4. Without performance standards for system operation and driver interface, the usage of numerous and nonuniform systems may result in operator confusion; thus, collision warning system technologies may not provide the driver with the ability to prevent rear-end collisions in some situations.

5. Information concerning the use and benefits of effective collision warning systems and adaptive cruise control is critical to their acceptance by the driving public.

6. Commercial drivers need to be oriented to the use of collision warning systems and adaptive cruise control in order to understand system capabilities, how the driver interface works, and how the system functions.

7. The number of accidents that continue to occur at construction work zones suggests that efforts to inform drivers of congestion at these work zone sites have not been adequate.

Recommendations

To the U.S. Department of Transportation:

> 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-01-06)
>
> 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-01-07)
>
> 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-01-08)

To the 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. (H-01-09)

To the Federal Highway Administration:

> Develop and implement, in cooperation with the National Highway Traffic Safety Administration, 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 control. (H-01-10)
>
> Develop a procedure that States can use to conduct a risk analysis for work zone backups; require, where appropriate, the use of a queue length detection and warning system; and incorporate that procedure for a queue length detection and warning system for work zones in the *Manual on Uniform Traffic Control Devices* work zone guidelines. (H-01-11)

To the 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 control. (H-01-12)
>
> Develop a training program for operators of commercial vehicles equipped with a collision warning system or adaptive cruise control and provide this training to the vehicle operators. (H-01-13)

To the 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 control. (H-01-14)

To the Intelligent Transportation Society of America:

> 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 control. (H-01-15)

To the American Trucking Associations, Inc., the Owner-Operator Independent Driver Association, and the National Private Truck Council:

> Encourage your members to obtain or provide, or both, training to those drivers who operate collision warning system- or adaptive cruise control-equipped trucks. (H-01-16)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Carol J. Carmody Acting Chairman	**John A. Hammerschmidt** Member
	John Goglia Member
	George W. Black, Jr. Member

Adopted: May 1, 2001

Member Hammerschmidt did not concur with Safety Recommendation H-01-07 and the associated analysis.

Appendix A

Public Hearing

PUBLIC HEARING ON ADVANCED SAFETY TECHNOLOGY APPLICATIONS FOR COMMERCIAL VEHICLES

August 31 – September 2, 1999

Sheraton Nashville Downtown
623 Union Street

Nashville, Tennessee

PURPOSE: To identify advanced technologies that can improve the safety of trucks and buses and to discuss the benefits of such systems and the future needs.

Tuesday, August 31, 1999

8:30 – 9:00	**OPENING REMARKS AND INTRODUCTIONS**	
9:00 – 9:30	**OPENING REMARKS FROM DEPARTMENT OF TRANSPORTATION**	
	U.S. DOT	*Eugene Conti*, Assistant Secretary
9:30 – 10:45	**U.S. GOVERNMENT PERSPECTIVES** What is the U.S. Government doing to support the development and implementation of advanced technologies in trucks and buses?	
	U.S. DOT	*Christine Johnson* ITS Joint Program Office
	U.S. Army	*Paul Skalny* Tank Automotive Command
10:45 – 11:30	*BREAK AND MEDIA TOUR OF TRUCKS AND PRODUCT SHOWCASE*	
11:30 – 12:45	**INTERNATIONAL PERSPECTIVES** What advances in truck and bus technologies are being made in other countries?	
	Australian Perspective	*Peter Sweatman* Road User International
	European Perspective	*Luc Werring* European Union DG VII Transport
12:45 – 2:00	*LUNCH*	

2:00 – 4:00 **ADVOCACY AND USER GROUP PERSPECTIVES**

How do various groups support and what are their concerns regarding the development of advanced technology?

Technology Advocates	*John Collins* ITS America
Unions	*Scott Madar* International Brotherhood of Teamsters
Insurance Industry	*Jack Burkert* Lancer Insurance

4:00 – 4:15 *BREAK*

4:15 – 5:30 **FATIGUE TECHNOLOGIES**

What technologies exist to help alert drivers and combat fatigue? How can these technologies be used to monitor hours of service and fitness for duty? What are the pros and cons of using technology to monitor and combat fatigue?

Operator Monitors	*Dr. David Dinges* University of Pennsylvania School of Medicine
Fatigue Study	*Bill Rogers* American Trucking Associations

Wednesday, September 1, 1999

8:30 – 10:15 **VEHICLE COMPONENTS**

What technologies are being (or will be) placed on trucks and buses to make transportation safer?

Vehicle Dynamics/Stability	*Rick Youngblood* Eaton Corporation
Rollover Warning Systems	*Scott* Stevens Raytheon/Oak Ridge National Laboratories
Vehicle Diagnostics/Prognostics	*Arnold Vanderbock* Detroit Diesel

10:15 – 10:30 *BREAK*

10:30 – 12:15 **BRAKING TECHNOLOGIES**

What is electronic braking, and what are the benefits and drawbacks of electronic braking technology on trucks and buses?

Electronic Braking	*Steven Moran* Allied Signal
Brake Out-of-Adjustment Alert	*Graydon Choinski* Indian Head Industries
Benefits/Drawbacks	*Dr. Richard Grace* Carnegie Mellon Research Institute

12:15 – 1:30 *LUNCH*

1:30 – 3:15 **COLLISION WARNING SYSTEMS I**

What technologies are in use today or under development to help drivers prevent collisions?

Emerging Technologies	*Dr. August Burgett* U.S. DOT Advanced Safety Systems Research Division
Collision Warning Systems	C*hris Royan* Eaton Vorad Technologies
User of Collision Warning	*Max Fuller* U.S. Xpress Enterprises Systems

3:15 – 3:30 *BREAK*

3:30 – 5:15 **HUMAN INTERFACE WITH TECHNOLOGY**

What are the benefits of collision warning systems? What types of information can and should be given to the driver that can be used, and how will this be integrated?

Types of Warnings	*Dr. Phil Spelt* Oak Ridge National Laboratories
Integration Issues	*Dr. Tom Dingus* Virginia Tech Center for Transportation Research

THURSDAY, SEPTEMBER 2, 1999

8:30 – 10:15 **VEHICLE INSPECTION**

What technology can be used to expedite vehicle inspections and the use of safety data? What is the experience of inspectors and industry in the use of new inspection technologies? What are the potential benefits of these technologies?

CVISN/Nomad (Rover)	*Ken Jennings* Virginia Department of Transportation
Roadside Inspection	*Larry Minor* FHWA Office of Motor Technologies and Benefits Carrier Research and Standards
Federal Inspector Experience	*John Harmon* Tennessee Highway Patrol

10:15 – 10:30 *BREAK*

10:30 – 12:15 **DATA RECORDERS**

How can the uses of data recorders help reduce accidents or reconstruct accidents if they do occur? How can the uses of real-time data recording help inspectors target unsafe carriers?

U.S. Data Recorders	*Les Dole* CADEC Corporation
Real-time Data Recording and Reporting	*Noah Rifkin* Veridian Engineering
Accident Reconstruction Data Collection	*Dr. Gerhard Lehmann* Mannesmann VDO

12:15 – 1:30 *LUNCH*

1:30 – 3:15 **VEHICLE MANUFACTURERS AND BUS DEVELOPMENTS**

What technologies are being developed by truck manufacturers to make transportation safer? How are these technologies as well as vendor products being integrated? What do they foresee on the truck of the future? What technologies are being developed by bus companies to make driving safer? How are these technologies being implemented? What has their experience been with advanced technologies for safety?

Manufacturers	*Gary Rossow* Freightliner
	Mark Kachmarsky

		Mack
	Bus Company	*Jack Haugsland* Greyhound Lines, Inc.
3:15 – 3:30	**CLOSING STATEMENT**	

Appendix B

Adaptive Cruise Control Field Operational Test

Background

From July 1996 to September 1997, NHTSA and the University of Michigan Transportation Research Institute[77] conducted a field operational test of an ACC system. Ten passenger cars were equipped with the ACC and were operated by a total of 108 volunteer drivers for 2 - to 5-week periods in their normal driving patterns. The ACC was used approximately 35,033 miles of the 114,044 miles driven, and the vehicle operations were recorded.

The ACC system that was tested provided a headway control function by adapting the speed of the host vehicle to the speed of the vehicle ahead. When no vehicle was present ahead of the host vehicle, the host vehicle traveled at a preset speed. The drivers were able to select one of three headway settings: closer, middle, or farther (1.1, 1.5, or 2.1 seconds,[78] respectively). To prevent false alarms, the ACC tested in the field operational test did not detect or respond to objects that were moving at less than 30 percent of the speed of the host vehicle.

The ACC automatically accelerated and decelerated smoothly to maintain the desired headway or driver-selected speed when no target was present. Deceleration was accomplished through throttle reduction and transmission downshifting, if necessary. The brake lights were illuminated when the transmission downshifted to alert the following driver that the host vehicle was slowing. The sensors were scanning infrared beams, which detect both near and far targets. Atmospheric conditions (such as rain and snow) could limit the sensors' ability to detect an object. (Eaton VORAD, Jaguar, and Mercedes' ACC systems currently utilize radar to alleviate this problem.)

The ACC utilized the conventional cruise control interface with additional elements. The ACC informed the driver of targets ahead and the operating status of the system. A display was used to indicate the set speed; a light with an audible tone indicated when visibility was poor, and a light indicated when the ACC had detected a preceding target. A set of switches was used to select the headway time.

Field Operational Test Findings

Ninety-eight percent of the participants were comfortable with the ACC (84 percent were comfortable within the 1st day of use), primarily because it relieved

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[77] The Institute's partners included Automotive Distance Control Systems GmbH, Haugen Associates, and the Michigan Department of Transportation. The Volpe National Transportation System Center and Science Applications International Corporation conducted an independent evaluation of the field operational test.

[78] These times were selected based on naturalistic driving and simulator experiments.

"throttle stress," which is stress resulting from the motions of the throttle during manual driving. Drivers were also relieved of "headway stress," which is stress caused by the human's poor ability to perceive range to the vehicle ahead and relative velocity (the difference in speeds between the two vehicles). The ACC reduced the interruptions in system use that are common to conventional cruise control.

On a scale of 1 (poor) to 7 (excellent), participants rated how safe they believed using the ACC system as 6 and the likelihood of the ACC increasing safety as 5.4. Drivers stated that they believed that manual driving was safest, followed by ACC, then conventional cruise control. Drivers reported driving more cautiously when the ACC was activated.

Drivers reported very few detection failures or false alarms (warning in a situation when no vehicle was present). Drivers did notice some false alarms, although rare, that resulted in false decelerations, such as when in curves or when passing a large tractor trailer. The drivers' main concern was about being struck from behind if their vehicle slowed at an inappropriate time. In rare situations, the sensors missed a target. However, since the ACC system did not cause the vehicle to accelerate rapidly, drivers were able to take appropriate action to slow the vehicle. (The driver was responsible and the ACC was only used as an aid.)

The ACC was used in 50 percent of all miles traveled at speeds over 35 mph and in 77 percent of all miles traveled at speeds over 65 mph. The drivers chose when to turn the ACC on, and these choices were usually based on driving conditions (the ACC was generally not used in denser traffic conditions) and driver interaction in those conditions. While ACC use was most prevalent on freeways, the ACC was used twice as often on nonfreeway roads than conventional cruise control.

When the ACC was activated, the driver served as "supervisor" over the system and monitored surrounding traffic to determine when intervention was necessary. Since the ACC automatically managed headway conflicts, the driver learned to withhold intervention and waited to see whether the ACC resolved the situation. This resulted in higher deceleration levels when the driver did intervene by braking—about twice the level as when the driver intervened with conventional cruise control. Even though the proportion of higher deceleration levels was greater for the ACC, in absolute numbers, it was extremely rare and less than in manual driving.[79]

Many drivers said that they liked the deceleration cue the ACC provided when it began to slow the car down due to an arising headway conflict. This feature served to bring drivers' attention to the road ahead. If the deceleration cue seemed unusual, the drivers could quickly decide if immediate action was needed.

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[79] U.S. Department of Transportation, National Highway Traffic Safety Administration, *Evaluation of the Intelligent Cruise Control System Volume 1—Study Results*, DOT-VNTSC-NHTSA-98-3, DOT-HS-808-969, October 1999.

The ACC system tested in the field operational test performed closing and following operations similar to the way these tasks are performed in manual driving, except the ACC maintained longer headways than drivers do in manual driving. Longer headways can help increase safety by increasing the amount of time drivers have to react to the vehicle ahead. The style of driving was influenced by the ACC. For drivers whose manual driving was classified as "tailgater," they either adapted their driving to accept a longer headway or turned the system off when they wanted to drive more aggressively. All of the drivers tended toward longer headways with the ACC on than in manual driving, although younger drivers generally chose the shortest headway selection.

Drivers in their 60s used the ACC the most, likely because it meshed with their more conservative style of driving, according to the study. Approximately 5 percent of the users were "very uncomfortable" with the ACC and would not use it in the future.

Safety Implications of the Field Operational Test

The objective and the subjective results combined present a mixed picture of whether the ACC would provide either positive or negative impacts. More headway time and a deceleration type of warning, if the driver is inattentive, appear to have safety benefits. However, drivers may become overly reliant on or overconfident in the system, which may result in inattention that may lead to slowed or delayed reactions to potential hazards. In the field operational test, drivers were more aware of the total driving situation using the ACC, but they would sometimes apply the time provided by the reduced mental workload to perform auxiliary tasks. One of the concerns was a possibility that drivers would think the system would do more for them than they could do for themselves,[80] so they could drive with more riskiness. However, the study found that drivers drove more safely by allowing the system to place them at a longer following distance than they would normally adopt when driving manually.

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[80] August Burgett, Ph.D., presentation "Rear-End Collision Warning—Field Operational Test" to Congressional staff on November 4, 1999.

Appendix C

Infrastructure-Based Systems

Pennsylvania Department of Transportation Queue Length Detector[81]

The Pennsylvania Department of Transportation developed a system to warn drivers of congestion. Known as the computerized highway information processing system, it relies on a queue length detector and 15 variable message signs positioned along the road to warn drivers of accidents ahead or placed in advance of a work zone to alert drivers of slowed or stopped traffic. Information on the estimated length of delay is also provided.

The variable message signs change in response to signals from the queue length detectors. The portable detectors project an infrared beam across traffic lanes and measure how long it takes vehicles to cross through the beam. If the length of time is longer than a preset limit, a message is sent to the variable message signs via a central computer and radio signals in less than 30 seconds.

Adaptir Real-Time Information System[82]

A Maryland State Highway Administration project took the approach that drivers on occasion fail to heed static warnings as they approach work zones because the signs are sometimes unreliable. Signs may still be in place after work crews leave, or variable message signs may not accurately post current traffic conditions.

"Adaptir" was developed to measure traffic speeds using radar at several points upstream of a work zone. A central control system analyzes the data to pinpoint congestion and delays and then selects a prerecorded message to display on the variable message signs just upstream of the congested area. The system is reported to decrease traffic congestion by up to 25 percent, which equates to an increase in safety.[83]

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[81] "Queue Length Detector Reduces Risk of Rear-End Accidents in Work Zones," *FOCUS—Using Products of the Strategic Highway Research Program to Build Better, Safer Roads,* April 1998 <http://www/tfhrc.gov/focus/archives/Fcs498/048chips.htm>.

[82] "Real-Time Information Reduces Accidents and Congestion in Work Zones," *FOCUS—Using Products of the Strategic Highway Research Program to Build Better, Safer Roads,* January 1999 <http://ww.tfhrc.gov/focus/archives/fcs199/workzone.htm>.

[83] <http://www.amsig.com/ppt/itms.ppt>.

In 1996, Maryland tested Adaptir; the system worked well, but some communication problems were experienced, which have since been solved. Kentucky and California[84] are also currently using Adaptir.

Minnesota Department of Transportation Smart Work Zone[85]

In 1996, the Minnesota Department of Transportation conducted an operational test of the portable traffic management system to provide useful real-time information to motorists about traffic conditions as they approached and passed through the work zone. The system consisted of a video image processing method to record the traffic conditions such as volume, speed, and incident detection; wireless communications to send the information back and forth from the site; a traffic control center where an operator reviewed the video information and made traffic control decisions; and variable message signs to relay the information to the driver.

During the portable traffic management system usage, the variability in speed of traffic decreased by over 70 percent, which equates to an increase in safety. In addition, the average speed approaching the work zone was reduced by 9 mph. About 66 percent of drivers remembered seeing the variable message signs and thought that they were more informed about traffic and that the variable message signs correctly reflected traffic conditions.

Overall, the operational test of the portable traffic management system in the work zone was successful, despite some wireless communications problems related to transmitter placement. The system was relatively easy to set up and operate and had beneficial effects on traffic, and motorists liked the information. The portable traffic management system continues to be operated in Minnesota.

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[84] Federal Highway Administration, *Quality Journal Best Practices* <http://www.fhwa.dot.gov/quality/HP-CA9.htm>.

[85] *Portable Traffic Management System Smart Work Zone Applications. Operational Test Evaluation Report*, SRF Consulting Group, Inc., SRF No. 0942089.7/11, May 1997.

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