National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: October 21, 2010

In reply refer to: H-10-12 through –15,
H-01-6 and -7 (Reiteration and Reclassification),
H-08-15 (Reiteration), and
H-06-16 (Reclassification)

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On June 26, 2009, a multivehicle accident occurred on Interstate 44 (I-44) near Miami, Oklahoma, shortly after a minor accident in the same vicinity occurred. The minor accident took place about 1:13 p.m., when a 2001 Ford Focus traveling eastbound at milepost 321.7 on I-44 drifted into a truck-tractor semitrailer parked on the right shoulder. After the Focus sideswiped the semitrailer, the car's driver overcorrected to the left, lost control, and struck the concrete center median barrier. The Focus came to rest in the roadway, blocking the left eastbound lane. As the trailing traffic began to slow and stop, it formed a queue. Several motorists exited their vehicles and began to push the disabled Focus to the right shoulder. The queue of stopped vehicles and approaching but slowing vehicles extended back from the accident site approximately 1,500 feet to about milepost 321.5.

Meanwhile, about 1:19 p.m., a 76-year-old truck driver operating a 2008 Volvo truck-tractor in combination with an empty 2009 Great Dane refrigerated semitrailer was traveling eastbound in the outside (right) lane of I-44 at approximately 69 mph. (The posted speed limit was 75 mph.) The truck driver did not react to the queue of slowing and stopped vehicles and collided with the rear of a 2003 Land Rover sport utility vehicle (SUV). As both vehicles moved forward, the Land Rover struck a 2003 Hyundai Sonata and then departed the right lane and shoulder, coming to rest off the roadway. The Volvo continued forward, struck and overrode the Hyundai Sonata, struck and overrode a 2004 Kia Spectra, and then struck the rear of a 2000 Ford Windstar minivan. The Volvo overrode a portion of the Windstar while pushing it into the rear of a livestock trailer being towed by a 2004 Ford F350 pickup truck. The Ford pickup truck was pushed forward and struck a 2008 Chevrolet Tahoe SUV. The Volvo combination unit came to rest approximately 270 feet past the point where it initially struck the Land Rover. As a result of the Volvo combination unit's striking the slowed and stopped vehicle queue on I-44, 10 passenger vehicle occupants died, 5 received minor-to-serious injuries, and the driver of the Volvo combination unit was seriously injured.[1]

The National Transportation Safety Board determined that the probable cause of this accident was the Volvo truck driver's fatigue, caused by the combined effects of acute sleep loss, circadian disruption associated with his shift work schedule, and mild sleep apnea, which resulted in the driver's failure to react to slowing and stopped traffic ahead by applying the brakes or performing any evasive maneuver to avoid colliding with the traffic queue. Contributing to the severity of the accident were the Volvo truck-tractor combination unit's high impact speed and its structural incompatibility with the passenger vehicles.

Among the issues discussed in the National Transportation Safety Board (NTSB) accident report are the significance of heavy vehicle aggressivity in collisions between dissimilar vehicles, the lack of Federal requirements for heavy commercial vehicle event data recorders (EDR), and the lack of Federal requirements for forward collision warning systems (FCWS).

Heavy Vehicle Aggressivity

When crashes such as the Miami accident occur, the larger size and greater weight of the heavy commercial vehicle, disproportionate to the smaller, lighter-weight passenger vehicle(s), cause serious injury and often death to the passenger vehicle occupants, due to the larger vehicle's intrusion into the passenger vehicle's occupant compartment, resulting in loss of survivable space. In this accident, the front bumper of the Volvo truck-tractor was higher than the passenger vehicle bumpers and, as a result, the Volvo's bumper and stiffer frame entered the occupant compartments of the passenger vehicles. In the case of the Hyundai and the Kia, the Volvo also drove over the shorter vehicles. Further, the proportional difference in mass between the heavy commercial vehicle (40,400 pounds, unloaded) and the lighter passenger vehicles (the Kia weighed 2,600 pounds) was as high as 15 to 1; this, combined with the speed of the Volvo truck-tractor semitrailer traveling close to 69 mph at impact, compounded the disadvantage for the passenger cars and their occupants. The Volvo's speed contributed to the truck's tremendous kinetic energy at impact, which was dissipated during the collision with the slower moving and stopped passenger vehicles. Because of differences in vehicle weight and structural stiffness, as well as the geometric mismatch of bumper heights, the Volvo truck-tractor's design did not absorb the crash forces from the impact, and the dissipated kinetic energy was transferred to the lighter weight, less stiffer framed passenger vehicles. As a result, these vehicles were catastrophically destroyed.

Due to these factors, survivable space within the first four passenger vehicles struck by the Volvo truck-tractor semitrailer was minimal. Influencing the survivability of a crash for vehicle occupants are several factors: the degree of loss of occupant space, the crash force exerted on each vehicle occupant, and the postcrash environment. Variation in these parameters

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[1] For additional information, see *Truck-Tractor Semitrailer Rear-End Collision Into Passenger Vehicles on Interstate 44, Near Miami, Oklahoma, June 26, 2009*, Highway Accident Report NTSB/HAR-10/02 (Washington, DC: National Transportation Safety Board, 2010), which is available on the NTSB website at <http://www.ntsb.gov/publictn/2010/HAR1002.pdf>.

can result in different outcomes for each vehicle occupant; while one passenger may be killed, another may sustain serious injury, and yet another may walk away uninjured.[2]

Consequently, although the Kia sedan's driver and two rear seat occupants (children in booster seats with 3-point restraints) and the Land Rover's rear seat child passenger survived due to the survivable space available to them, the Land Rover's driver and front passenger, all four occupants of the Hyundai, and all four occupants of the Ford Windstar were killed. The NTSB concludes that the combination of the high impact speed of the Volvo truck-tractor semitrailer and the structural incompatibility between the Volvo and the passenger vehicles resulted in extensive intrusion deformation and crush damage to the passenger compartments of the Land Rover, Hyundai, Kia, and Ford Windstar; a loss of survivable space in those vehicles; and the deaths of 10 passenger vehicle occupants.

Occupant protection demands that survivable space be maintained for all passengers and that the interior structure provide sufficient support and energy absorption so that crash forces are survivable. Differences in vehicle weight, stiffness, and structural components (resulting in geometric mismatch) are referred to as "vehicle aggressivity." Vehicles with high aggressivity, such as heavy trucks, often compromise the survivable space within any smaller vehicles they strike, in part because the difference in height between the two vehicles results in override and permits the stiffer elements of the commercial vehicle's front structure to intrude into the passenger vehicle. It is not practical to significantly reduce the weight of a truck-tractor semitrailer or to increase the weight of a passenger vehicle to better match the truck's; consequently, compatibility must be addressed through other means. Deflection of the passenger car and energy absorption into the truck frame might be achieved by design modification, thereby providing some reduction of heavy vehicle aggressivity.[3]

Research conducted in the United States and Europe has focused on ways to improve the outcome when smaller vehicles strike, or are struck by, heavier trucks. Some methods have included matching the geometry of bumper structures, creating energy-absorbing structures[4] to offset the weight differences of the impacting vehicles, and designing the front of the truck to act as a deflector or to redirect[5] the struck vehicle away from the front of the truck, thus reducing the total change in velocity of the smaller vehicle. Europe has adopted standards for front underride protection.[6]

In 1996, research was being conducted to design a new heavy truck bumper with an energy-absorbing honeycomb block, covered by an impact surface that swiveled upon impact,

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[2] W. Spitz, ed., *Spitz and Fisher's Medicolegal Investigation of Death: Guidelines for the Application of Pathology to Crime Investigation*, 3rd edition (Springfield, Illinois: Thomas Publisher, 1993), p. 579.

[3] See <http://www-nrd.nhtsa.dot.gov/departments/nrd-01/summaries/havp_02.html> (accessed June 10, 2010).

[4] A. Berg and others, "Passive Safety of Trucks in Frontal and Rear-end Collisions With Cars," *Proceedings of the 18th International Technical Conference on Enhanced Safety of Vehicles, Nagoya, Japan* (Washington, DC: National Highway Traffic Safety Administration, 2003).

[5] A. Prasad and others, *Reducing Heavy Truck Aggressivity in Collisions With Passenger Cars*, DOT HS 808 476 (Washington, DC: National Highway Traffic Safety Administration, 1995).

[6] Economic Commission for Europe Regulation 93, Part I, "Uniform Provisions Concerning the Approval of Front Underrun Protection Devices."

thus deflecting the car away from the truck's path. Testing showed that such a barrier (a prototype of the bumper) deflected the car as desired, with minimum intrusion into the passenger compartment.[7] However, Volvo has reported that its heavy trucks in the United States do not currently have the front underride protection systems (FUPS) offered on its European truck models, due to differences in design and weight between European heavy trucks and heavy trucks manufactured, sold, and operated in the North American marketplace. Moreover, there are no U.S. standards or guidelines for equipping heavy trucks with FUPSs.

The NTSB considered this issue during the investigation of an accident involving a tractor semitrailer in Hampshire, Illinois, that rear-ended several vehicles, causing catastrophic damage.[8] In its report on this accident, the NTSB made a recommendation regarding vehicle compatibility to the U.S. Department of Transportation (DOT) as follows:

> Include heavy vehicles in your research, testing, and eventual rulemaking on highway vehicle incompatibility, especially as that incompatibility affects the severity of accidents. (H-06-16)

Despite its having been issued 4 years ago, the only update on progress concerning this recommendation received by the NTSB to date has been the DOT's May 2010 transfer of the recommendation to the National Highway Traffic Safety Administration (NHTSA), a subordinate agency.

One of the goals of the 21st Century Truck Partnership (21CTP)—which comprises multiple Federal government agencies, including several within the DOT, and industry representatives—is to improve truck and bus safety by fostering advancements in vehicle design and performance, such as reducing truck frontal aggressivity in multivehicle collisions. In December 2000, the 21CTP published a "roadmap," which set a milestone of mid-2009 for completing laboratory tests and field trials of systems designed to reduce the destructive effects of truck accidents.[9] Then, in late 2006, the 21CTP published its *Roadmap and Technical White Papers*,[10] which no longer included any milestone date for this project.

The 2006 roadmap document stated that the 21CTP goal is to work collaboratively with DOT-led research programs to determine the feasibility of enhanced occupant survivability in collisions involving large trucks. However, the 21CTP roadmap also stated, "Because transportation safety is the primary mission of the DOT, much of the 21CTP heavy vehicle safety interests will be carried out with the leadership from the DOT." It further stated, "The 21CTP

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[7] K. Mendis and others, "Concepts to Reduce Heavy Truck Aggressivity in Truck-to-Car Collisions," *Proceedings, 15th International Technical Conference on Enhanced Safety of Vehicles, Melbourne, Australia* (Washington, DC: National Highway Traffic Safety Administration, 1996).

[8] *Multivehicle Collision on Interstate 90, Hampshire–Marengo Toll Plaza, Near Hampshire, Illinois, October 1, 2003*, Highway Accident Report NTSB/HAR-06/03 (Washington, DC: National Transportation Safety Board, 2006).

[9] 21st Century Truck Partnership, *Roadmap and Technical White Papers*, 21CTP-001 (Washington, DC: U.S. Department of Energy, December 2000).

[10] 21st Century Truck Partnership, *Roadmap and Technical White Papers*, 21CTP-0003 (Washington, DC: U.S. Department of Energy, December 2006). For additional information, see <http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/21ctp_roadmap_appendix_2007.pdf> (accessed August 10, 2010).

facilitates progress toward the DOT safety goals but does not encompass all the paths to reduced fatalities and injuries."

To date, neither the DOT nor the 21CTP members have completed laboratory tests or field trials in this safety area. NHTSA has not published any information indicating future testing or the intent to implement changes in the industry.

The DOT has discussed the need to reduce fatalities resulting from large truck accidents and has stated that research concerning intelligent transportation system (ITS) technologies for accident avoidance and implementation of such systems are priorities. The NTSB agrees that the deployment of vehicle-based technologies for collision avoidance and mitigation is crucial to highway safety and has issued several recommendations intended to spur progress in this area. In fact, the NTSB considers that collision avoidance systems, such as FCWS and lane departure warning systems, as well as collision mitigation systems, such as adaptive cruise control (ACC) and active braking—which slow down heavy commercial vehicles when a crash is imminent—could significantly increase the effectiveness of heavy vehicle aggressivity countermeasures and provide additional protection to passenger vehicle occupants during collisions between heavy commercial motor vehicles (CMV) and passenger vehicles. A multifaceted approach of working to reduce or mitigate heavy vehicle aggressivity while simultaneously studying how collision avoidance and mitigation systems and ITS could help to further decrease passenger vehicle occupant fatalities in such collisions has the greatest likelihood of success. ITS implementation should involve many DOT agencies working in concert, including NHTSA, the Research and Innovative Technology Administration, the Federal Highway Administration (FHWA), and the Federal Motor Carrier Safety Administration (FMCSA).

The 21CTP has stated that its primary goal is safety and that the use of aerodynamic designs in tractor-trailer construction offers the possibility of making the frontal structures of trucks more complementary and compatible with passenger cars, thereby increasing the likelihood that the occupants of smaller vehicles involved in collisions with trucks may survive. The NTSB concludes that even though heavy truck incompatibility is a major cause of death for occupants of passenger cars, light trucks, and vans involved in crashes with heavy trucks, to date, the DOT and NHTSA have not made this issue a priority and have not allocated sufficient resources to study and address it.

Because of the lack of timely progress by 21CTP members and the DOT in testing systems intended to mitigate the damage caused by truck accidents, the NTSB reclassifies Safety Recommendation H-06-16 to NHTSA "Closed—Unacceptable Action/Superseded" and supersedes H-06-16 with the recommendation that NHTSA, to improve highway vehicle crash compatibility, develop performance standards for FUPSs for trucks with gross vehicle weight ratings (GVWR) over 10,000 pounds. Due to the lack of timely action on the superseded recommendation, this new Safety Recommendation H-10-12 is classified "Open—Unacceptable Response." Further, the NTSB recommends that NHTSA, after establishing performance standards for FUPSs for trucks with GVWRs over 10,000 pounds, require that all such newly manufactured trucks be equipped with FUPSs meeting the performance standards.

In the Hampshire report,[11] the NTSB also issued the following safety recommendation to the U.S. Department of Energy (DOE):

> Report to the National Transportation Safety Board the 21st Century Truck Partnership's plans and timetable for prioritizing research, testing, and design enhancements that address heavy truck aggressivity. (H-06-15)

The DOE initially responded that it was "in the process of compiling a report describing the long-range 21CTP goals for truck safety, as well as other research and development activities." It stated in a 2007 update that it anticipated "completion of this report by the end of the current fiscal year, September 30, 2007." The status of Safety Recommendation H-06-15 was "Open—Acceptable Response." However, the DOE has not updated the NTSB on the progress of these efforts since 2007. Therefore, the NTSB has reiterated Safety Recommendation H-06-15, and the recommendation is reclassified "Open—Unacceptable Response."

Event Data Recorders

Although the truck-tractor was equipped with an advanced electronic control module (ECM) in combination with an aftermarket Mobius on-board computer, both of which supported the capture of limited accident-related data, it was not equipped with a dedicated crash EDR, which would have captured vital crash information and allowed for a significantly higher level of science to be applied to the NTSB's investigation and analysis of this accident. A dedicated crash EDR intended to assist in collision reconstruction and analysis would have captured both operator and vehicle-based data just before and during the crash sequence. A dedicated EDR, specifically intended for crash data retrieval following a crash event, can provide critical high-resolution performance data concerning driver, vehicle, and safety systems. To enhance crash testing with real-world data, data from vehicle crashes must be available for analysis.

During the 2007 SAE International symposium on highway EDRs,[12] industry representatives reported that many motor carrier operators currently use vehicle data recorders. However, the Miami accident truck-tractor was not equipped with a dedicated or more sophisticated EDR that would have provided additional parameters and precision data regarding both driver and vehicle dynamics throughout the accident sequence. Crash pulses[13] and/or Delta V are often used to calculate vehicle occupant kinematics, help evaluate injury exposure, and assess the effectiveness of passenger protection and safety devices and systems. Using these data, investigators and engineers can predict potential injury mechanisms and assess the effects of various design elements on occupant protection systems and vehicle designs for crash mitigation.

In addition, EDR data can be used to enhance the development of advanced technologies for the manufacture of truck cab, frontal, and side structures. The data can contribute to the

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[11] NTSB/HAR-06/03.

[12] Highway Vehicle Event Data Recorder Symposium, September 5–6, 2007 (Ashburn, Virginia: SAE International, 2007).

[13] The term "crash pulse" refers to acceleration versus time history. It may be more helpful to think in terms of crash forces, because the forces to which a vehicle is subjected as a result of a collision are a direct function of the crash pulse.

development of computer models to verify the energy-absorption capabilities of heavy-duty vehicles and be used in studies on frontal-structure aggressivity. They can also advance the use of finite element and occupant kinematic analyses of candidate structural designs to identify optimized designs and assist in determining the capacity of sandwich, cored, and foam materials for energy-absorption applications.[14]

Large truck design may affect the severity of trauma sustained by occupants of all vehicles—whether heavy or not—involved in a heavy vehicle crash. Vehicle design and performance attributes are important concerns; optimized design may improve large truck safety and help reduce truck-crash-related fatalities. Although crash forces may be estimated by comparing an accident vehicle's physical damage to that of instrumented crash test data, this method is not always reliable. This unreliability, coupled with the lack of availability of heavy vehicle crash test data, makes the collection of real-world data crucial to researchers and design engineers.

A lack of useful event data associated with the Miami accident represents another missed opportunity to better understand the crash forces and crashworthiness issues involved when heavy vehicles strike other vehicles. The NTSB concludes that the heavy truck in the Miami accident lacked a dedicated EDR designed for accident reconstruction and to provide accelerometer-based crash pulse data, which are critical to the evaluation of vehicle performance and could have been used in vehicle incompatibility research; therefore, these data are again unavailable to investigators and researchers.

The NTSB considers that adequate on-board recording devices are necessary in all modes of transportation because information from them can be used to identify safety trends, develop corrective actions, and conduct more efficient and precise accident investigations. Cockpit voice recorders and flight data recorders, commonly referred to as black boxes, have been required on commercial airliners for decades. Since 1993, event recorders have also been required on trains. In marine transportation, voyage data recorders are now required on all international passenger and cargo ships.

The NTSB has also made previous recommendations regarding recorders for highway trucking transport. Although the recommendation was primarily aimed at reducing fatigue-related accidents, in 1990,[15] the NTSB recommended that the FHWA:

> Require automated/tamper-proof on-board recording devices, such as tachographs or computerized logs, to identify commercial truck drivers who exceed hours-of-service regulations. (H-90-28)

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[14] *Roadmap and Technical White Papers*, 21CTP-001.

[15] *Fatigue, Alcohol, Other Drugs, and Medical Factors in Fatal-To-The-Driver Heavy Truck Crashes (Volume 1)*, Safety Study NTSB/SS-90/01 (Washington, DC: National Transportation Safety Board, 1990).

The NTSB reiterated Safety Recommendation H-90-28 in its 1995 study on truck driver fatigue,[16] explaining that the intent of the recommendation was to provide a tamper-proof mechanism that could be used to enforce the hours-of-service regulations, rather than relying on drivers' handwritten logs. In a February 1997 response, the FHWA acknowledged that on-board recording devices would eventually be an important tool for monitoring the hours of service of CMV drivers. However, the FHWA stated that "the FHWA position is that the benefits and practicality of on-board recorders must be firmly established before rulemaking ensues." In 1997, the NTSB classified Safety Recommendation H-90-28 "Closed—Unacceptable Action" due to the lack of positive action by the FHWA.

In 1998, as the result of an accident investigation involving two truck-tractor semitrailer vehicles in Slinger, Wisconsin,[17] the NTSB recommended that the American Trucking Associations, Inc., the Motor Freight Carriers Association, the International Brotherhood of Teamsters, the Independent Truckers and Drivers Association, the National Private Truck Council, and the Owner-Operator Independent Drivers Association, Inc., advise their members to equip their commercial vehicle fleets with automated and tamper-proof on-board recording devices, such as tachographs or computerized recorders, to identify information concerning both driver and vehicle operating characteristics (Safety Recommendations H-98-23 and -26). Both recommendations were classified "Closed—Unacceptable Action" in 2001.

The NTSB has also made recommendations to NHTSA concerning EDRs in heavy commercial vehicles that carry passengers, specifically, school buses and motorcoaches. In 1999, the NTSB issued the following two recommendations to NHTSA as a result of a special investigation report on bus crashworthiness:[18]

> Require that all school buses and motorcoaches manufactured after January 1, 2003, be equipped with on-board recording systems that record vehicle parameters, including, at a minimum, lateral acceleration, longitudinal acceleration, vertical acceleration, heading, vehicle speed, engine speed, driver's seat belt status, braking input, steering input, gear selection, turn signal status (left/right), brake light status (on/off), head/tail light status (on/off), passenger door status (open/closed), emergency door status (open/closed), hazard light status (on/off), brake system status (normal/warning), and flashing red light status (on/off) (school buses only). For those buses so equipped, the following should also be recorded: status of additional seat belts, airbag deployment criteria, airbag deployment time, and airbag deployment energy. The on-board recording system should record data at a sampling rate that is sufficient to define vehicle dynamics and should be capable of preserving data in the event of a vehicle crash or an electrical power loss. In addition, the on-board recording system should be mounted to the bus body, not the chassis, to ensure that the data necessary for defining bus body motion are recorded. (H-99-53)

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[16] *Factors That Affect Fatigue in Heavy Truck Accidents, Volume 1: Analysis*, Safety Study NTSB/SS-95/01 (Washington, DC: National Transportation Safety Board, 1995).

[17] *Multiple Vehicle Crossover Accident, Slinger, Wisconsin, February 12, 1997,* Highway Accident Report NTSB/HAR-98/01 (Washington, DC: National Transportation Safety Board, 1998).

[18] *Bus Crashworthiness*, Highway Special Investigation Report NTSB/SIR-99/04 (Washington, DC: National Transportation Safety Board, 1999).

> Develop and implement, in cooperation with other government agencies and industry, standards for on-board recording of bus crash data that address, at a minimum, parameters to be recorded, data sampling rates, duration of recording, interface configurations, data storage format, incorporation of fleet management tools, fluid immersion survivability, impact shock survivability, crush and penetration survivability, fire survivability, independent power supply, and ability to accommodate future requirements and technological advances. (H-99-54)

The NTSB reiterated Safety Recommendation H-99-53 in its report on a 2007 motorcoach ramp override accident in Atlanta, Georgia, that killed seven passengers.[19] In that report, the NTSB determined that EDR data would have yielded information on vehicle parameters and driver actions prior to the accident, as well as on vehicle dynamics throughout the accident sequence, which would have been valuable in reconstructing and evaluating occupant kinematics, injury exposure, and the potential benefits of occupant protection devices and systems. Safety Recommendations H-99-53 and -54 were reiterated in the NTSB's 2009 special investigation on pedal misapplication in heavy vehicles, a report that focused primarily on school buses.[20] The NTSB concluded that the presence of EDRs in heavy vehicles would provide essential and specific information regarding the causes and mechanisms of pedal misapplication and claims of unintended acceleration. Safety Recommendations H-99-53 and -54 were classified "Open—Unacceptable Response" because of NHTSA's failure to require the use of EDRs on buses.

Most recently, in its report on a motorcoach rollover accident in Dolan Springs, Arizona,[21] the NTSB concluded that the availability of recorded event data would have resulted in a more complete account of the preaccident events leading to the rollover. In addition, the NTSB found that having EDRs on all buses above 10,000 pounds GVWR would greatly increase the understanding of crash causation and be helpful in further establishing design requirements for crashworthiness and occupant protection systems. Therefore, the NTSB superseded Safety Recommendation H-99-53 with the following recommendation to NHTSA:

> Require that all buses above 10,000 pounds gross vehicle weight rating be equipped with on-board recording systems that: (1) record vehicle parameters, including, at minimum, lateral acceleration, longitudinal acceleration, vertical acceleration, heading, vehicle speed, engine speed, driver's seat belt status, braking input, steering input, gear selection, turn signal status (left/right), brake light status (on/off), head/tail light status (on/off), passenger door status (open/closed), emergency door status (open/closed), hazard light status (on/off), brake system status (normal/warning), and flashing red light status (on/off; school buses only); (2) record status of additional seat belts, airbag deployment criteria, airbag deployment time, and airbag deployment energy; (3) record data at a sampling rate sufficient to define vehicle dynamics and be capable of preserving data in the event of a vehicle crash or an electrical power loss; and (4) are mounted to the bus

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[19] *Motorcoach Override of Elevated Exit Ramp, Interstate 75, Atlanta, Georgia, March 2, 2007,* Highway Accident Report NTSB/HAR-08/01 (Washington, DC: National Transportation Safety Board, 2008).

[20] *Pedal Misapplication in Heavy Vehicles*, Highway Special Investigation Report NTSB/SIR-09/02 (Washington, DC: National Transportation Safety Board, 2009).

[21] *Bus Loss of Control and Rollover, Dolan Springs, Arizona, January 30, 2009*, Highway Accident Report NTSB/HAR-10/01 (Washington, DC: National Transportation Safety Board, 2010).

body, not the chassis, to ensure recording of the necessary data to define bus body motion. (H-10-7)

Safety Recommendation H-99-53 specified that EDRs be required for school buses and motorcoaches; and, by superseding Safety Recommendation H-99-53 with H-10-7, the NTSB recognized that EDRs should be required for all buses over 10,000 pounds GVWR. As illustrated by the Miami accident, EDR data would also be very useful with respect to accidents involving heavy vehicles, by permitting the reconstruction of preaccident events and the evaluation of crash dynamics for both heavy vehicles, such as truck-tractors, and any involved passenger vehicles.

In addition to pressing for EDRs to be installed on heavy vehicles, the NTSB has advocated EDRs for light vehicles. In its 2004 report on the Santa Monica, California, farmer's market accident,[22] the Board issued Safety Recommendation H-04-26, asking NHTSA to require light vehicles to be equipped with EDRs. On August 28, 2006, NHTSA published a final rule establishing performance standards for voluntarily installed EDRs. As a result of manufacturers voluntarily equipping most of their light vehicles with EDRs, the NTSB classified Safety Recommendation H-04-26 "Closed—Acceptable Alternate Action." Although NHTSA has made progress in developing EDR standards for light vehicles (such as publishing a final rule addressing the survivability requirements and information to be collected by EDRs for light vehicles), there is still no requirement for the installation and use of light vehicle EDRs. Further, NHTSA has not developed standards nor required the use of EDRs for heavy commercial vehicles, including motorcoaches, school buses, and truck-tractor semitrailer units.

Establishing EDR performance standards for heavy highway vehicles is necessary to create a foundation for the timely and efficient incorporation of EDRs into such vehicles. Without such required standards, the heavy vehicle industry will continue to operate without reasonable guidelines or requirements regarding what EDR technology should be installed and what data the EDR should collect. NHTSA should develop EDR standards for all heavy vehicles, not just motorcoaches and school buses, because the lack of data from non-passenger-carrying heavy vehicles deprives researchers of valuable crash data needed to develop crashworthiness and design applications affecting heavy vehicles and other vehicles that may be involved in a heavy vehicle crash. Neither NHTSA nor the FMCSA defines light or heavy vehicles, although the FMCSA's definition for a CMV includes a vehicle weighing 10,001 pounds or more (per 49 *Code of Federal Regulations* 390.5).[23] The NTSB considers that EDR standards and the requirement that they be used, such as recommended for school buses and motorcoaches (in Safety Recommendations H-99-53 and H-10-7), should apply to all heavy highway vehicles. Thus, future postaccident data for these types of vehicles would provide a more complete and

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[22] *Rear-End Collision and Subsequent Intrusion Into Pedestrian Space at Certified Farmer's Market, Santa Monica, California, July 16, 2003*, Highway Accident Report NTSB/HAR-04/04 (Washington, DC: National Transportation Safety Board, 2008).

[23] "Commercial motor vehicle" refers to any self-propelled or towed motor vehicle used on a highway in interstate commerce to transport passengers or property when the vehicle: (1) has a GVWR or gross combination weight rating, or gross vehicle weight or gross combination weight of 10,001 pounds or more, whichever is greater; or, (2) is designed or used to transport more than 8 passengers (including the driver) for compensation; or, (3) is designed or used to transport more than 15 passengers, including the driver, and is not used to transport passengers for compensation.

accurate record of the crash pulse and vehicle dynamics involved in heavy highway vehicle crashes.

Therefore, the NTSB concludes that due to the lack of government standards and requirements for the design and use of highway vehicle EDRs, valuable high-fidelity crash data continue to go unrecorded and, thus, are unavailable for analysis. The NTSB recommends that NHTSA develop and implement minimum performance standards for EDRs for trucks with GVWRs over 10,000 pounds that address, at a minimum, the following elements: data parameters to be recorded; data sampling rates; duration of recorded event; standardized or universal data imaging interface; data storage format; and device and data survivability for crush, impact, fluid exposure and immersion, and thermal exposure. The standards should also require that the EDR be capable of capturing and preserving data in the case of a power interruption or loss, and of accommodating future requirements and technological advances, such as flashable and/or reprogrammable operating system software and/or firmware updates. The NTSB also recommends that NHTSA should, after establishing performance standards for EDRs for trucks with GVWRs over 10,000 pounds, require that all such vehicles be equipped with EDRs meeting the standards.

Forward Collision Warning Systems

Rear-end crashes occur when the front of a following vehicle strikes the rear of a lead vehicle. Fatality Analysis Reporting System data show that from 2001 to 2009, 1,453 fatalities occurred in 2-vehicle rear-end collisions involving a large truck rear-ending a passenger vehicle(s). In 2008, one out of nine traffic fatalities resulted from a collision involving a large truck. That year, about 380,000 large trucks were involved in traffic crashes in the United States, and 4,066 were involved in fatal crashes. A total of 4,229 people died (11 percent of all the traffic fatalities reported in 2008) and an additional 90,000 were injured in those crashes.[24] In 2009, 3,380 people died in crashes that involved a large truck.[25] Because rear-end crashes resulting from heavy vehicles tend to be more catastrophic, due to the extreme force of impact these vehicles may cause,[26] the NTSB has been exploring technical solutions for preventing rear-end collisions for at least 15 years.

The NTSB first discussed FCWS technology in a 1995 report concerning an investigation of a highway accident that occurred in fog in Menifee, Arkansas.[27] In the Menifee accident report, the NTSB recommended, via Safety Recommendation H-95-44, that the DOT,

[24] See <http://www-nrd.nhtsa.dot.gov/Pubs/811158.pdf> (accessed June 22, 2010).

[25] See <http://www-nrd.nhtsa.dot.gov/Pubs811363.pdf> (accessed September 16, 2010).

[26] A. Hesham and others, *Safety Benefit Evaluation of a Heavy Vehicle Forward Collision Warning System*, paper 10-0207 presented at the January 10–14, 2010, Transportation Research Board 89th Annual Meeting in Washington, D.C.

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

> In cooperation with the Intelligent Transportation Society of America, 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. (H-95-44)

Due to the time elapsed since the recommendation's issuance and noting that industry had taken the lead in implementing the technology, the NTSB classified Safety Recommendation H-95-44 "Closed—Unacceptable Action" on August 10, 1999.

The NTSB also focused on the issue of technology in a 2001 special investigation report that addressed the findings from a 1999 public hearing on "Advanced Safety Technologies for Commercial Vehicle Applications."[28] The 1995 Menifee report and the 2001 special investigation discussed how technology, in the form of ITS, can be used to prevent rear-end collisions.

In the 9 years since the special investigation report on technology was published, the NTSB has investigated 9 rear-end collisions (including the Miami accident), in which 39 people died and 124 were injured.[29] In addition, the NTSB investigated the 2005 Osseo, Wisconsin, motorcoach accident, in which another vehicle was blocking the roadway and the motorcoach struck the underside of the overturned vehicle head-on.[30] In this accident, 5 people were killed and 36 were injured. In all, these 10 accidents involved truck-tractor semitrailers, motorcoaches, school buses, and passenger vehicles. (See table 1.)

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

[29] (a) *Work Zone Collision Between a Tractor-Semitrailer and a Tennessee Highway Patrol Vehicle, Jackson, Tennessee, July 26, 2000*, Highway Accident Report NTSB/HAR-02/01 (Washington, DC: National Transportation Safety Board, 2002). (b) *Collision of a Greyhound Lines, Inc., Motorcoach and Delcar Trucking Truck-Tractor Semitrailer, Loraine, Texas, June 9, 2002*, Highway Accident Report NTSB/HAR-03/01 (Washington, DC: National Transportation Safety Board, 2003). (c) NTSB/HAR-06/03. (d) *Rear-End, Chain Reaction Collisions at U.S. Border Patrol Checkpoint, Interstate Highway 87 Near North Hudson, New York, February 22, 2004, and September 19, 2004*, Highway Accident Brief NTSB/HAB-05/03 (Washington, DC: National Transportation Safety Board, 2005). (e) *Rear-End Chain Reaction Collision, Interstate 30 West, Near Sulphur Springs, Texas, June 13, 2004*, Highway Accident Brief NTSB/HAB-08/02 (Washington, DC: National Transportation Safety Board, 2008). (f) *Rear-End Chain Reaction Collision, Interstate 94 East, Near Chelsea, Michigan, July 16, 2004*, Highway Accident Brief NTSB/HAB-07/01 (Washington, DC: National Transportation Safety Board, 2007). (g) *Rear-End Chain-Reaction Collision, State Route 121, Near Lake Butler, Florida, January 25, 2006,* Highway Accident Brief NTSB/HAB-08/05 (Washington, DC: National Transportation Safety Board, 2008).

[30] *Truck-Tractor Semitrailer Rollover and Motorcoach Collision With Overturned Truck, Interstate Highway 94, Near Osseo, Wisconsin, October 16, 2005*, Highway Accident Report NTSB/HAR-08/02 (Washington, DC: National Transportation Safety Board, 2008).

Table 1. Relevant collisions investigated by the NTSB since the issuance of the special investigation report on technologies for the prevention of collisions (NTSB/SIR-01/01).

Year	Accident	Crash Type	Fatalities	Injuries
2000	Jackson, TN	Tractor-semitrailer struck highway patrol vehicle	1	1
2002	Loraine, TX	Motorcoach struck truck-tractor semitrailer	3	31
2003	Hampshire, IL	Truck-tractor combination unit struck specialty bus, leading to multivehicle chain-reaction collision	8	15
2004	North Hudson, NY (February)	Motorcoach struck truck-tractor semitrailer, leading to multivehicle chain-reaction collision (border crossing queue)	0	53
2004	North Hudson, NY (September)	Tractor-semitrailer struck passenger car, leading to multivehicle chain-reaction collision (border crossing queue)	4	3
2004	Sulphur Springs, TX	Tractor-auto transporter struck passenger vehicle, leading to chain-reaction collision	5	2
2004	Chelsea, MI	One truck-tractor semitrailer struck another, which then struck passenger vehicle	1	2
2005	Osseo, WI	Truck-tractor semitrailer rolled over, leading to motorcoach collision with overturned truck	5	36
2006	Lake Butler, FL	Truck-tractor combination unit struck passenger vehicle, which then struck school bus	7	11
2009	Miami, OK	Tractor-semitrailer struck passenger vehicle, leading to multivehicle chain-reaction collision	10	6
		TOTAL	44	160

Common to each of these NTSB-investigated accidents was the crucial circumstance that the following vehicle driver had a degraded perception of traffic conditions ahead. During its investigation of these collisions, the NTSB examined the striking vehicles and found no mechanical defects that would have contributed to the accidents. Also, in each case, the driver of the striking vehicle tested negative for alcohol and drugs. Some of these collisions occurred because atmospheric conditions, such as nighttime darkness or smoke, interfered with the driver's ability to detect slower moving or stopped traffic ahead. In other cases, the drivers did not notice that traffic had come to a halt due to other accidents, tollbooths, congestion at work zones, and even school buses dropping off students. Still others involved drivers who were distracted or fatigued. Regardless of the individual circumstances, the striking vehicle drivers in these accidents were unable to detect slowed or stopped traffic ahead and to stop their vehicles in time to prevent a rear-end collision.

FCWSs utilize radar-based technology or, more recently, camera-based systems with vehicle detection algorithms, to recognize images of motorized vehicles. Both types of FCWSs provide audible and visual alerts to warn the driver when other vehicles or stationary objects are within predefined distances or closing speeds in the forward path of the vehicle. FCWSs began to appear as safety devices on large trucks in the 1990s.[31] FCWSs currently on the market can detect objects at distances of up to 500 feet[32] and display warnings at distances of up to 350 feet or at calculated following distance periods of up to 3.00 seconds. The FMCSA has collaborated with the trucking industry to test and evaluate these systems, has defined voluntary operational requirements, and is now promoting voluntary adoption of these systems within the trucking industry. Although FCWSs are established technologies available on newly manufactured truck-tractors, the 2008 model year Volvo truck-tractor involved in this accident was not equipped with an FCWS. No regulations currently mandate the use of FCWS technology, but many carriers have chosen to install and use such systems voluntarily throughout their fleets.

In its 2001 special report on technology for the prevention of rear-end crashes,[33] the NTSB reported that, in 1999, the DOT had begun operational testing of ACC systems and FCWSs for cars and trucks. The NTSB also reported that rear-end collisions accounted for 1.8 million crashes in 1999, including 1,923 fatal crashes. Of the fatal crashes, 770 involved commercial vehicles (trucks weighing more than 10,000 pounds and motorcoaches). Thus, CMVs were involved in 40 percent of the fatal rear-end crashes, even though they accounted for only 3 percent of vehicles and 7 percent of miles traveled. Although the NTSB has acknowledged that an FCWS is not intended to replace driver vigilance, such a system can aid drivers when they are distracted or fatigued, or when their attention is concentrated on something other than the road ahead. The NTSB concluded that accident statistics and the 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 such collisions. As a result, in its special report, the NTSB asked the DOT[34] to take the following actions:

> Complete rulemaking on adaptive cruise control and collision warning system performance standards for new commercial vehicles. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning. (H-01-6)
>
> After promulgating performance standards for collision warning systems for commercial vehicles, require that all new commercial vehicles be equipped with a collision warning system. (H-01-7)

Safety Recommendation H-01-6 is on the NTSB Most Wanted List of Transportation Safety Improvements in the issue area "Prevent Collisions by Using Enhanced Vehicle Safety Technology." Deployment of vehicle collision avoidance technology has been on the Most Wanted List since November 2007.

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[31] The VORAD system, previously owned by Eaton and now owned by Bendix, was introduced in 1995.

[32] The Bendix VORAD VS-400 detects vehicles in the same lane within 350 feet of the radar. The Meritor WABCO OnGuard system detects and tracks vehicles up to 500 feet in front of the host vehicle. Vehicle images in the camera-based system from Mobileye enter the detection range approximately 328–394 feet in front of the host vehicle.

[33] NTSB/SIR-01/01.

[34] These recommendations were originally assigned to the FMCSA; the DOT subsequently transferred them to NHTSA.

In the Miami accident, an FCWS alert could have drawn the accident driver's attention to the hazard ahead, which was the slowing traffic. The truck-tractor semitrailer was traveling about 103 feet per second. With the maximum available warning detection distance of 350 feet provided by an FCWS, the Miami accident driver would have received a warning from the system about 3.40 seconds before striking the rear of the slowly moving traffic queue. Within this 3.40-second warning period, the driver would have to have (1) been effectively alerted; (2) comprehended the severity of the alert and the situation ahead; and (3) mechanically executed a reaction, including moving his foot from its rest location (the cruise control was engaged) and placing it on the brake and applying maximum (emergency) braking immediately. If any time (and distance) had remained from the 3.40 seconds after (1) through (3) above, it could have gone toward slowing the vehicle or enabling the driver to take an evasive action to mitigate the impact force of the tractor semitrailer upon the passenger vehicles.[35]

It should be noted that, for an alert driver,[36] the average projected reaction time to an unexpected situation can range from 0.75 second to about 2.50 seconds for a 90th percentile driver.[37,38] Research supports that, in the middle of this range, drivers have a perception reaction time to a common but unexpected stimulus (such as the unanticipated brake lights of a car ahead) of about 1.25 seconds.[39] Given a reasonably clear and straightforward situation, most drivers will respond within 1.50 seconds of the first appearance of an object or condition of concern;[40] they will react to a surprise event (such as an object moving unexpectedly into the vehicle's path) in 1.50 to 1.75 seconds.[41]

Some FCWSs are equipped with ACC,[42] which uses the same detection technology as the FCWS to adjust or disengage the conventional cruise control when it is in use. An active braking system that can automatically apply the foundation brakes[43] of the vehicle is also an available technology. If a collision is deemed imminent, an FCWS with active braking does not wait for the driver to react; in such a critical situation, braking is applied automatically to reduce the

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[35] Perception time/distance + physical reaction time/distance + brake lag time/distance + effective braking time/distance = total stopping distance.

[36] FCWS manufacturers acknowledge that their systems are designed to aid alert and conscientious drivers; such systems will not necessarily compensate for driver impairments, such as fatigue.

[37] Brake reaction time includes the time it takes for the driver to see the object and to recognize it as stationary or slow moving against the background of the roadway and other objects, such as walls, fences, trees, poles, or bridges. The American Association of State Highway and Transportation Officials (AASHTO) considers minimum brake reaction times to be between 1.64 and 3.50 seconds, and the recommended design criterion of 2.50 seconds for brake reaction time exceeds the 90th percentile of reaction time for all drivers, considered by AASHTO as adequate for more complex situations.

[38] M. Green, "How Long Does It Take To Stop? Methodological Analysis of Driver Perception-Brake Times," *Transportation Human Factors*, vol. 2, no. 3 (2000), pp. 195–216.

[39] M. Green, pp. 195–216.

[40] R. Dewar and P. Olson, *Human Factors in Traffic Safety* (Tucson, Arizona: Lawyers and Judges Publishing Co., 2001).

[41] M. Green, pp. 195-216.

[42] The systems are sometimes bundled together in a package.

[43] According to the Bendix *Airbrake Handbook* (2004), the foundation brake is the actual braking mechanism located at each end of the axle. It generally consists of an air or spring brake chamber (with slack for S-cam) and a mechanical brake mechanism, including the friction material.

severity of the impending collision. Once active braking is initiated to mitigate the accident (not when initiated to slow the vehicle to maintain following distance, such as with the ACC), it also may be referred to as "collision mitigation braking" (CMB). When these technologies are bundled together, they are often referred to as "collision mitigation systems." If the Miami accident truck had been equipped with an FCWS that included an active braking system, the driver's reaction time would not have been a factor—only the brake lag time would have contributed to the distance traveled before maximum braking was achieved.

An FCWS alone or bundled with ACC and active braking could have significantly affected the outcome of the Miami accident, depending on a number of factors, including the point at which the system detected the Land Rover ahead of it. The unloaded truck-tractor semitrailer had a gross weight of 40,400 pounds (a loaded truck-tractor semitrailer can weigh up to 80,000 pounds). Most cars weigh less than 4,000 pounds. Thus, when a commercial truck strikes a passenger car in the rear, the large difference in mass between the vehicles means that this impact most likely will not bring the heavy truck to a stop or even slow it appreciably; consequently, the impact itself does relatively little to keep the truck from continuing to move and to involve more vehicles.[44] An FCWS can reduce the risk of these rear-end crashes by identifying fast-closing speed situations and providing the driver with additional time to react. It should be noted that ACC systems are designed to maintain a predetermined[45] following interval behind another vehicle, thereby providing more time to resolve driving conflicts to reduce the probability of a rear-end collision.[46]

An FCWS with active braking can begin to decelerate a vehicle automatically, having the added benefit either of reducing the speed of the vehicle if the driver does not intervene or of supplementing deceleration before the driver applies braking. Active braking systems, such as the Bendix Wingman ACB (active braking with cruise control) and the Meritor WABCO OnGuard, do not apply the foundation brakes at the full emergency brake application level that a driver can.

To illustrate some possible scenarios for this accident under different circumstances, the NTSB worked with several FCWS manufacturers[47] and developed some potential outcomes had the accident truck been equipped with an FCWS alone or bundled with ACC and/or active braking. Three of the possible outcomes are presented below. NTSB investigators were unable to determine the speed of the Land Rover just prior to its being struck by the Volvo; therefore, the first two of the following scenarios are based on witness interviews indicating either that the struck vehicles were stopped in traffic or that the Land Rover was moving slowly (just over 10 mph). The third instance is the "best case" scenario, in which the Land Rover was just beginning to decelerate from the posted speed limit of 75 mph when the Volvo FCWS detected it at 70 mph, with the Volvo 350 feet or more behind it.

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[44] R. Craft, FMCSA Paper: *Rear-End Large Truck Crashes*, 2002. See <http://www.fmcsa.dot.gov/facts-research/briefs/rear.pdf> (accessed July 20, 2010).

[45] The manufacturer sets a default following interval, or the carrier or driver can set it.

[46] See <http://www.fmcsa.dot.gov/facts-research/research-technology/report/forward-collision-warning-systems.htm> (accessed June 22, 2010).

[47] Bendix VORAD, Meritor WABCO, and Mobileye.

All calculations in the scenarios and tables below considered a roadway coefficient of 0.65 *g* deceleration for the Volvo and an initial truck speed of about 70 mph. They also assumed the postaccident inspection condition of the brakes, which were within adjustment limits, on the truck-tractor semitrailer. An air brake lag time of 0.50 second was used, in addition to the driver perception reaction times of 2.50, 1.50, and 0.75 seconds. The term "distance to decelerate" used in the tables below is the distance between the accident truck-tractor and the Land Rover when the truck driver receives the first FCWS alert. The "warning time" is the time the truck driver would have between the first FCWS alert and the estimated impact.

Scenario 1—FCWS and Land Rover Stopped. Had the Land Rover, the first vehicle struck by the Volvo truck, been stopped (stationary) in the traffic queue, an FCWS on the Volvo could have detected it at either 308 or 350 feet,[48] calculated the closing distance, and sounded an audible alert. Table 2 shows the reductions in impact speeds possible, had the Volvo truck driver perceived the meaning of the alert and reacted, given the 0.75- to 2.50-second range of driver perception reaction time to the FCWS warning. This table shows the possible outcomes using FCWS alone, without the added benefit of ACC or active braking.

Table 2. Scenario 1: FCWS for stationary Land Rover in traffic queue.[a]

Distance To Decelerate (feet)	Warning Time (seconds)	Driver's Reaction Time (seconds)	Initial Speed of Truck (mph)	Impact Speed (mph)
308–350	3.00–3.40	2.50	70	**70–64**
308–350	3.00–3.40	1.50	70	**56–50**
308–350	3.00–3.40	0.75	70	**45–39**

[a]Land Rover is stationary in traffic queue; note that some currently available FCWSs cannot detect stationary objects or vehicles. Air brake lag time is 0.50 second.

The Volvo driver, although he was fatigued, was not incapacitated, and had he received an alert warning from an FCWS, he might have reacted with emergency braking. The accident truck could not have slowed down tremendously, given the assumption of a 2.50-second perception reaction time and the stopped traffic ahead. Under such circumstances, it can be estimated that the impact speed range would be 70 to 64 mph. If the FCWS alert had immediately redirected the driver's attention to the traffic ahead, and the driver had reacted very quickly, faster reaction times of 1.50 and 0.75 second would have reduced the impact speed to a range of 56 to 39 mph. Although 56- and 39-mph impacts are significant, they are less severe than a 70-mph impact. In addition, at the lower speeds, the Volvo driver might even have been able to take evasive steering action to avoid or mitigate the accident. The driver could have attempted an evasive maneuver, such as steering to the right, onto the roadway's paved shoulder, or even off the road and onto the grassy right-hand right-of-way, to prevent striking the passenger vehicles.

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[48] Mobileye reported that its system would detect the vehicle at a distance of 3.00 seconds, which is 308 feet (using the estimated 70-mph speed of the truck). Bendix reported that its Wingman ACB and SmartCruise systems would detect and emit the collision imminent alert at 350 feet. Meritor WABCO reported that its system, OnGuard, does not currently detect stationary vehicles.

Scenario 2—FCWS and Land Rover Moving Slowly. Had the Land Rover been moving slowly in traffic at 10 mph, the truck-tractor combination unit would have gained an additional 44 to 50 feet of distance over which to decelerate in this scenario, depending on the warning and perception reaction times used. The radar-based FCWSs would have detected the Land Rover at a range of 350 feet: one system would have emitted the audible alert at 350 feet, while another would have calculated the closing distance and sounded an audible alert at approximately 318 feet in closing distance. The camera-based system would have detected the slowly moving Land Rover at a following distance period of 3.00 seconds, which equates to 308 feet, and would have emitted an alert at this distance.

Table 3 shows that, had the traffic ahead been moving slowly, affording the Volvo truck a longer time and greater distance over which to decelerate, the impact speed of the truck could have been reduced to 38 mph under the most conservative reaction and warning time assumptions. Assuming a quicker driver reaction time of 1.50 seconds, the Volvo's impact speed could have been reduced to a range of between 24 and 14 mph. Given a driver reaction time of 0.75 second, the impact speed might have been reduced to as low as 9 mph, or the impact might even have been avoided.

Table 3. Scenario 2: FCWS for Land Rover moving 10 mph in traffic queue.[a]

Distance to Decelerate (feet)	Warning Time (seconds)	Driver's Reaction Time (seconds)	Initial Speed of Truck (mph)	Impact Speed (mph)
352–400	3.00–3.40	2.50	70	**38–31**
352–400	3.00–3.40	1.50	70	**24–14**
352–400	3.00–3.40	0.75	70	**9–0**

[a]Land Rover is moving at 10 mph; the systems detect the slower moving Land Rover at 350 feet and calculate the closing distance. Because the Land Rover is moving (constant slow speed of 10 mph), this increases the distance traveled progressively from the detection and collision calculation threshold even while the truck is moving faster, thus providing a slightly longer warning time to collision distance. Air brake lag time is 0.50 second.

One manufacturer indicated that with a bundled system on the Volvo truck, consisting of an FCWS with ACC and active braking, the driver could have brought the vehicle to a stop if he had applied 0.60 *g* emergency braking approximately 2.00 seconds after the active braking system engaged. In this scenario, the active braking itself might have alerted the driver to the impending hazard and caused him to initiate an appropriate response. According to the manufacturer, even if the driver had not initiated any emergency braking but the Volvo had been so equipped, this system might have been able to initiate CMB and slow the Volvo to an impact speed range of 48 to 53 mph without any driver action.

Scenario 3—FCWS With Bundled System and Land Rover Beginning to Decelerate From 75 mph When the FCWS Detects it at 70 mph. Both of the scenarios described above assume that the Volvo truck-tractor was 350 feet behind the Land Rover (or any other vehicle) when the FCWS detected it as stopped or slow moving traffic. If, instead, both vehicles were traveling about 70 mph when the truck's FCWS detected the Land Rover—with at least 350 feet of separation distance—and the FCWS had been tracking the Land Rover when it began to slow in response to the traffic queue, this could have affected the accident outcome significantly.

In this case, if the Volvo truck had been equipped with an FCWS with ACC and active braking, the system would have automatically slowed the Volvo to a preset safe following distance (one manufacturer's default setting is 3.60 seconds) without driver input. Further, once the system detected that the vehicle ahead was continuing to slow, the Volvo with the FCWS, ACC, and active braking would have maintained the 3.60-second following distance by continuously slowing. When the Land Rover reached 0 mph, the Volvo truck-tractor semitrailer would also have slowed to 0 mph at a distance of 32 feet behind the Land Rover, thus entirely preventing the accident. The above "best case" scenario illustrates what might have been possible in the Miami accident with a vehicle equipped with an FCWS with active braking; under these very specific circumstances, such a system could have prevented an accident without any driver input.[49]

As discussed earlier, the Volvo's impact speed generated tremendous kinetic energy, which was dissipated when it collided with the slower moving passenger vehicles, causing them catastrophic damage. Kinetic energy is the mathematical expression of the truck's maximum ability to do damage.[50,51] Because kinetic energy is proportional to the square of the vehicle speed, the energy of the impacting vehicle and its ability to do damage decline quickly as speed is reduced. Table 4 below shows the amount of kinetic energy that the accident Volvo had at about 70 mph, when it struck the passenger vehicles, as well as the amount it would have had with the incremental reduction in speed provided either by an FCWS alone or by an FCWS with a bundled system, as described above. A reduction in speed from about 70 to 50 mph would have cut the kinetic energy of the impacting heavy commercial vehicle in half. Further reducing the impact speed to 39 mph would have caused an energy reduction of nearly 70 percent. The scenario of the FCWS system bundled with ACC and active braking, without any input from the driver, could have resulted in a reduction in speed from about 70 to 39 mph at impact. (See table 4.)

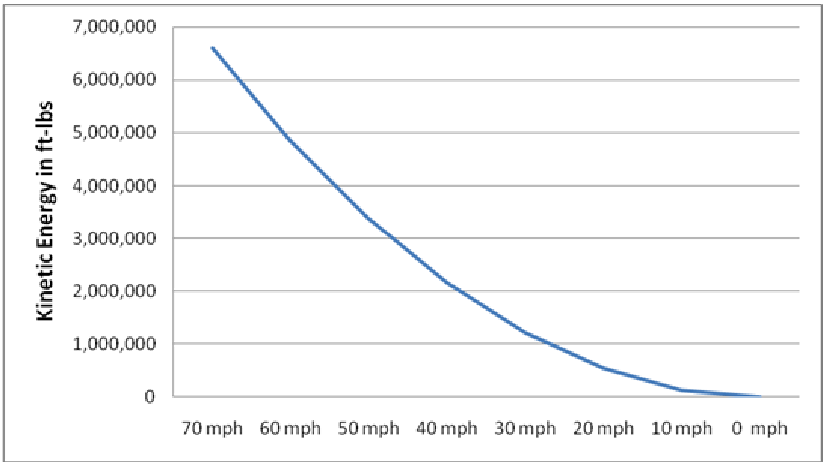
[49] Had the accident truck traveling about 70 mph detected and tracked the Land Rover traveling ahead at a similar speed, systems like the Wingman ACB and OnGuard could have slowed the truck-tractor at the same rate that the Land Rover slowed on approach to the stopped traffic, without any braking from the truck driver, given that the Land Rover did not initiate hard braking in excess of 0.30 to 0.35 *g*.

[50] Kinetic energy is defined as the energy of an object in motion and is equal to the work it would do if it were brought to rest. An object of mass (m) moving at velocity (v) has a kinetic energy equal to $1/2\ mv^2$.

[51] Not all of the kinetic energy of the truck was dissipated as vehicle damage. Kinetic energy was also dissipated as a result of friction forces between the ground and the truck and between vehicles.

Table 4. Scenario 3: Kinetic energy vs. speed.

Speed (mph)	Kinetic Energy (million ft-lbs)	Reduction in Kinetic Energy (%)
70	6.60	0.00
60	4.85	26.53
50	3.37	30.56
40	2.15	36.00
30	1.21	43.75
20	0.53	55.56
10	0.13	75.00
0	0.00	100.00



Depending on variables (such as the speed and distance of the vehicles ahead of the Volvo truck), even a bundled system might not have provided the fatigued Volvo driver sufficient time to react to the warning, brake the vehicle, and *prevent* the accident. However, it could have provided enough time for him to react, brake, and *mitigate* the severity of the accident or perhaps to *avoid* the collision through steering inputs.

It might not have been possible to bring the heavy Volvo truck-tractor semitrailer to a complete stop with FCWS and related technologies before any collision occurred. However, as can be seen in table 4, the slower the truck had been traveling at impact, the lower the kinetic energy involved in the accident and the less severe the damage to the struck passenger vehicles would have been. This scenario most likely would have resulted in less severe injuries to the occupants of those vehicles. In fact, if the Volvo truck-tractor had been equipped with an FCWS bundled with ACC and active braking, assuming that scenario 3 circumstances had existed in the seconds before the accident, it is possible that the system could have entirely prevented the accident. Therefore, the NTSB concludes that an FCWS with ACC and active braking would have provided the driver with the best opportunity to prevent, or reduce the severity of, the truck-tractor semitrailer's impact with the passenger vehicles in the traffic queue.

The NTSB considers that installing new technologies in CMVs—such as FCWSs, ACC, active braking, and electronic stability control—has the potential to reduce accidents substantially. Following the investigation of an October 2005 accident in which five people were killed when a motorcoach collided with an overturned truck-tractor semitrailer combination unit on Interstate 94 near Osseo, Wisconsin,[52] the NTSB issued Safety Recommendation H-08-15 to NHTSA, asking the agency to take the following action:

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

Since February 26, 2010, Safety Recommendation H-08-15 has been "Open—Acceptable Response." Also in the Osseo report, the NTSB reiterated Safety Recommendations H-01-6 and -7 to NHTSA.

In a letter dated June 4, 2009, NHTSA responded to these NTSB recommendations by providing an update on its current projects evaluating the application of various technologies for commercial trucks and motorcoaches. NHTSA is conducting a test track evaluation of commercially available CMB systems and has indicated that an initial evaluation of their performance capabilities will be completed in 2010. A NHTSA project to evaluate the potential safety benefits of active braking systems is expected to be completed in 2011. Based on these reports of progress from NHTSA, Safety Recommendations H-01-6 and -7 were classified "Open—Acceptable Response."

Due to their high mileage exposure[53] and the severity of crashes involving them, combination-unit trucks have the highest crash cost per vehicle over the operational life of the vehicle; therefore, FCWSs may provide a relatively higher safety benefit for this class of trucks.[54] However, government and industry entities are still conducting operational testing and encouraging voluntary implementation of FCWSs. Although the work being done by private industry and the government is encouraging, the slow pace of testing and standards development and the limited deployment of FCWSs in commercial vehicles are cause for concern, given the large number of rear-end collisions and the high rate of fatalities that result when commercial vehicles are involved.

For years, the NTSB has been advocating the implementation of in-vehicle systems that enhance the safety of heavy vehicles, both by mitigating accident severity and preventing accidents altogether. Safety benefits are often not the result of one system on its own; more often, it is the synergy of systems working together that can prevent and mitigate a larger percentage of accidents, resulting in the greatest reduction of highway injuries and fatalities. Although FCWS use within a heavy vehicle is crucial to provide warning of an impending collision, integrating this safety system with related technologies would provide even greater opportunity for preventing accidents, as well as for reducing the severity and frequency of rear-end accidents. The NTSB considers that FCWSs have great promise and that the added feature of active braking increases their potential for preventing accidents. However, the pace of NHTSA's progress in this

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[52] NTSB/HAR-08/02.

[53] Combination vehicles account for about 30 percent of all CMVs but about 65 percent of commercial vehicle miles traveled.

[54] See <http://www.fmcsa.dot.gov/facts-research/research-technology/report/forward-collision-warning-systems.htm> (accessed June 16, 2010).

vital area has been too slow. Because NHTSA is still evaluating these systems and is not yet near rulemaking that would require them to be used in commercial vehicles, the NTSB reiterates Safety Recommendations H-01-6 and -7 and H-08-15. Further, although the NTSB acknowledges that NHTSA has made some progress in conducting research in this area, due to the lack of timely completion of the recommended actions, Safety Recommendations H-01-6 and -7 are reclassified “Open—Unacceptable Response.” The status of Safety Recommendation H-08-15 remains “Open—Acceptable Response.”

As a result of the investigation, the National Transportation Safety Board makes the following new recommendations to the National Highway Traffic Safety Administration:

> To improve highway vehicle crash compatibility, develop performance standards for front underride protection systems for trucks with gross vehicle weight ratings over 10,000 pounds. (H-10-12) [This recommendation supersedes Safety Recommendation H-06-16 and is classified “Open—Unacceptable Response.”]

> After establishing performance standards for front underride protection systems for trucks with gross vehicle weight ratings over 10,000 pounds, require that all such newly manufactured trucks be equipped with front underride protection systems meeting the performance standards. (H-10-13)

> Develop and implement minimum performance standards for event data recorders for trucks with gross vehicle weight ratings over 10,000 pounds that address, at a minimum, the following elements: data parameters to be recorded; data sampling rates; duration of recorded event; standardized or universal data imaging interface; data storage format; and device and data survivability for crush, impact, fluid exposure and immersion, and thermal exposure. The standards should also require that the event data recorder be capable of capturing and preserving data in the case of a power interruption or loss, and of accommodating future requirements and technological advances, such as flashable and/or reprogrammable operating system software and/or firmware updates. (H-10-14)

> After establishing performance standards for event data recorders for trucks with gross vehicle weight ratings over 10,000 pounds, require that all such vehicles be equipped with event data recorders meeting the standards. (H-10-15)

The National Transportation Safety Board reiterates and reclassifies Safety Recommendations H-01-6 and -7 to the National Highway Traffic Safety Administration:

> Complete rulemaking on adaptive cruise control and collision warning system performance standards for new commercial vehicles. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning. (H-01-6) [Safety Recommendation H-01-6 is reclassified “Open—Unacceptable Response.”]

> After promulgating performance standards for collision warning systems for commercial vehicles, require that all new commercial vehicles be equipped with a collision warning system. (H-01-7) [Safety Recommendation H-01-7 is reclassified "Open—Unacceptable Response."]

The National Transportation Safety Board reiterates Safety Recommendation H-08-15 to the National Highway Traffic Safety Administration:

> Determine whether equipping commercial vehicles with collision warning systems with active braking and electronic stability control systems will reduce commercial vehicle accidents. If these technologies are determined to be effective in reducing accidents, require their use on commercial vehicles. (H-08-15) [The status of Safety Recommendation H-08-15 remains unchanged; the status is "Open—Acceptable Response."]

Finally, the National Transportation Safety Board reclassifies Safety Recommendation H-06-16 to the National Highway Traffic Safety Administration:

> Include heavy vehicles in your research, testing, and eventual rulemaking on highway vehicle incompatibility, especially as that incompatibility affects the severity of accidents. (H-06-16) [Safety Recommendation H-06-16 is reclassified "Closed—Unacceptable Action/Superseded"; it is superseded by Safety Recommendation H-10-12.]

The NTSB also issued safety recommendations to the Federal Motor Carrier Safety Administration and Associated Wholesale Grocers, Inc. The NTSB reiterated recommendations to the U.S. Department of Energy and the Federal Motor Carrier Safety Administration.

In response to the recommendations in this letter, please refer to Safety Recommendations H-10-12 through -15, H-01-6 and -7, H-08-15, and H-06-16. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, WEENER, and ROSEKIND concurred in the issuance of the new recommendations, the reiteration and reclassification of Safety Recommendations H-01-6 and -7, and the reiteration of Safety Recommendation H-08-15. Chairman HERSMAN and Members SUMWALT and ROSEKIND concurred in the reclassification of H-06-16 as “Closed—Unacceptable Action/Superseded” and the classification of Safety Recommendation H-10-12 as “Open—Unacceptable Response.”

[Original Signed]
By: Deborah A.P. Hersman
Chairman