FINAL
CONTRACT REPORT

PASSENGER VEHICLE CRASHES INTO STATIONARY LARGE TRUCKS: INCIDENCE AND POSSIBLE COUNTERMEASURES

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Passenger Vehicle Crashes Into Stationary Large Trucks: Incidence and Possible Countermeasures

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Supplementary Notes

Abstract

House Joint Resolution No. 23, 2002 Session of Virginia's General Assembly, requested that the Virginia Transportation Research Council and the Crash Investigation Team of Virginia Commonwealth University's Transportation Safety Training Center conduct a study of highway crashes involving trucks and other large vehicles stopped on the roadway or shoulder and struck in the rear. The purpose of the study was to determine the spatial and perceptual factors, physiological elements, and ingredients that combine to cause or materially contribute to these crashes; how and why these crashes occur; and practical countermeasures to reduce the number and severity of these crashes.

To answer the question of how and why these crashes occur, Virginia crash data from 1997 through 2001 were analyzed. In only a few crashes was a large truck stopped on the roadway or shoulder struck in the rear by a passenger vehicle. Rear-end crashes in which the leading vehicle was stopped were more numerous, but single-vehicle roadway departure crashes into parked vehicles were more severe. Environmental, roadway, and surface conditions had little influence. The major contributing factor was driver inattention.

With regard to the psychological and perceptual factors contributing to these crashes, it is likely that large trucks are more conspicuous than other stopped vehicles because of their size, unique profile, and requirements for reflectorized tape. However, large trucks stopped or parked continue to be struck in the rear by passenger vehicles. The cause here is also driver inattention in several forms, none of which can be directly attributed to any particular crash without a detailed crash investigation.

As to possible countermeasures, two approaches stand out: increasing driver attention and removing large trucks from the shoulder. Existing methods for increasing driver attention include using infrastructure warning systems and continuous shoulder rumble strips. Future improvements to driver attention are linked to technically advanced collision warning systems that will enter the marketplace before 2012 and provide an automatic warning to drivers of possible collisions. Removing large trucks from the shoulder is more of a problem and is tied to the larger issue of the supply and demand for public and private commercial vehicle parking. Short-term improvements include amending and strictly enforcing existing parking regulations, developing a pilot program to alert truck drivers of available parking facilities, and investigating the use of Virginia's weigh stations for large truck parking. The long-term approach includes conducting studies designed to document the extent of large truck parking on the ramps and shoulders of Virginia's limited access highways, assessing the adequacy of large-truck parking statewide, and prioritizing locations with the greatest need for public and private development of large-truck parking facilities.

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

February 2003
VTRC 03-CR17

NOTICE

ABSTRACT

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INTRODUCTION

When a crash involves a large truck (gross vehicle weight rating greater than 10,000 lb) and a passenger vehicle, injuries or fatalities are much more likely to be inflicted upon the occupants of the smaller vehicle. Multiple-vehicle large truck crashes killed 4,321 people in the United States in 2000 (U.S. Department of Transportation [USDOT], 2001). Occupants of the large trucks represented 6% of those fatalities, whereas occupants of the other vehicles represented 94%. Virginia crash data for 2000 indicate that large trucks were involved in 6.4% of all crashes but accounted for 13% of fatal crashes. These fatal crashes resulted in 127 fatalities, of which 83% (105 fatalities) were not occupants of large trucks (Virginia Department of Motor Vehicles [DMV], 2001).

The rear end of a typical van semi-trailer is 12 ft tall and 8 ft wide and is usually equipped with reflective tape and lighting equipment. Nevertheless, in 2000, 18% of fatal crashes involving a large truck and a passenger vehicle in the United States were the result of the passenger vehicle striking the rear of the large truck (USDOT, 2001). The Virginia DMV submits information regarding fatal crashes of this kind to the National Highway Traffic Safety Administration (NHTSA) to be included in the Fatality Analysis Reporting System (FARS), a national database NHTSA maintains on all fatal crashes.

Because rear-end crashes are among the most serious types of crashes between passenger vehicles and large trucks, this configuration has attracted international attention. In an effort to understand this type of crash on Virginia's highways and reduce its number and severity, the Honorable Robert G. Marshall, Member of the Virginia House of Delegates from the 13th District, sponsored House Joint Resolution No. 23 (HJR 23) during the 2002 Session of the Virginia General Assembly. Appendix A provides the text of HJR 23.

HJR 23, enrolled by the Virginia General Assembly in April 2002, requested that the Virginia Transportation Research Council and the Crash Investigation Team of Virginia Commonwealth University's Transportation Safety Training Center conduct a study of ways to reduce the number and severity of highway crashes involving trucks and other large vehicles stopped on the roadway or shoulder and struck in the rear.

Two types of crashes are addressed in HJR 23: (1) crashes involving a large truck stopped in a traffic lane and struck in the rear by a passenger vehicle (i.e., lead vehicle stationary [LVS] rear-end crashes), and (2) crashes in which a passenger vehicle runs off the road and strikes a large truck parked on the shoulder (i.e., single vehicle roadway departure [SVRD] crashes into parked vehicles). These types of crashes often involve what is known as underride. *Underride* is defined as the sliding of a motor vehicle at least partially under a large truck at some time during a crash. When a passenger vehicle strikes the rear of a large truck, it is possible for the smaller and lighter vehicle to underride the rear structure of the large truck. Underride greatly increases the possibility that the passenger compartment will be intruded upon, which in turn raises the risk of injury or fatality for the occupants of the passenger vehicle that strikes the truck.

The large trucks described in HJR 23 include those illustrated in Figure 1 and for the purposes of this study are defined as follows:

- *straight truck:* a truck with the engine and body mounted on the same chassis
- *tractor-trailer:* a combination vehicle consisting of a truck-tractor and a semi-trailer.

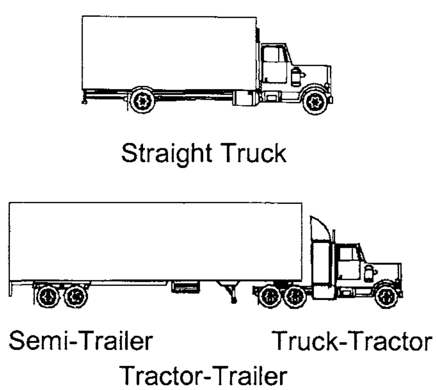

Figure 1. Vehicles Included in Category of Large Trucks

In Virginia during the 5 years from 1997 through 2001, there were 209,655 rear-end crashes, representing 30% of all crashes and 5% of all fatal crashes. In the same period, there were 153,132 SVRD crashes, representing 20% of all crashes and 50% of all fatal crashes. Large trucks were involved in 11,159 rear-end crashes and 7,145 SVRD crashes.

The passage of HJR 23 by the Virginia General Assembly signaled the legislature's resolve that state resources be committed to investigate Virginia's crashes involving large trucks struck in the rear by passenger vehicles.

PURPOSE AND SCOPE

This study addressed three questions posed by the Virginia General Assembly in HJR 23 with respect to reducing the number and severity of highway crashes involving trucks and other large vehicles stopped on the roadway or shoulder being struck in the rear by passenger vehicles:

1. What spatial perception factors, physiological elements, and psychological ingredients combine to cause or materially contribute to these crashes?

2. What are the characteristics of crashes of this type?

3. What useful and practical countermeasures have the potential to reduce the number and severity of these crashes?

METHODS

To answer the three questions, the researchers pursued seven avenues of investigation: (1) the formation of a project steering committee: (2) a literature review of pertinent issues; (3) a review of applicable federal and state law; (4) a determination of the magnitude and severity of the problem, both nationally and in Virginia; (5) a survey of selected states; (6) factors contributing to the problem; and (7) a determination of appropriate countermeasures.

Steering Committee

A steering committee was established to assist in the direction and tone of the research effort. The committee included representatives from the Virginia DMV, Virginia State Police (VSP), Virginia Department of Transportation (VDOT), Federal Motor Carrier Safety Administration, Commercial Vehicle Safety Alliance, Virginia Trucking Association, and Insurance Institute for Highway Safety. The membership of the Steering Committee included:

Delegate Robert Marshall, Virginia General Assembly
Dale Bennett, Virginia Trucking Association
Debra Wood Whittington, Virginia Trucking Association
Sandra Alexander, Virginia Trucking Association
Elisa Braver, Insurance Institute for Highway Safety
Craig Feister, Federal Motor Carrier Safety Administration
Colonel W. Gerald Massengill, VSP
Lt. Colonel J. B. Scott, VSP
Capt. Dennis Robertson, VSP
Lt. H. B. Bridges, VSP
Lynwood Butner, Virginia DMV
Vincent M. Burgess, Virginia DMV
David Mosely, Virginia DMV

Carl Hewlin, Virginia DMV
Lawrence Caldwell, VDOT
Phebe P. Greenwood, VDOT
Cyndi Ward, VDOT.

Literature Review

The literature review began with a search of the Transportation Research Information Service (TRIS) and the Internet. In addition, experts in the field of heavy truck safety, particularly authors of national studies on rear-end and underride crashes involving commercial vehicles, were contacted concerning additional references.

The literature review included the following issues: rear-end crashes, SVRD crashes, and underride crashes; perceptual and psychological factors causing or contributing to crashes; large truck visibility and conspicuity; commercial vehicle parking; and rear-end crash countermeasures.

Review of Applicable Federal and Virginia Law

The legal review began with a Lexis/Nexis search of federal legislation concerning commercial vehicles and a search of the *Code of Virginia* (COV), the *Code of Federal Regulations* (CFR), and the *Virginia Administrative Code* (VAC). In addition, Virginia's Office of the Attorney General was contacted to ensure that all pertinent information had been included.

An important component of the review was legal clarification concerning the kind of interventions the Commonwealth could consider to reduce the number and severity of rear-end crashes and remain within the boundary of federal preemption regulations.

In addition, a review of large truck registrations in Virginia was conducted to determine the number of trucks that are not included under the federal requirement for rear-impact guards.

Magnitude and Severity of the Crash Problem

This analysis was directed specifically at the crashes described in HJR 23: crashes involving a large truck stopped in the traffic lane and struck in the rear by a passenger vehicle (i.e., LVS rear-end crashes) and crashes in which a passenger vehicle runs off the road and strikes a large truck parked on the shoulder (i.e., SVRD crashes into parked vehicles). The analysis provided statistical descriptions of the number and type of crashes. Any vehicle on the shoulder presents a target that otherwise would not be there, and in the case of SVRD crashes, represents an additional dimension for consideration.

The data for this analysis were supplied by VDOT in the form of an Access file that contained all Virginia crash records contained in Virginia's Highway Traffic Records

Information System (HTRIS) from 1997 through 2001. The file included 691,877 crash records identified by the 9-digit crash record document number. Each crash record contained 93 data fields describing all aspects of the crash. The data fields contained information coded by the Virginia DMV from the police accident report (Form FR 300), along with data coded by VDOT concerning the physical characteristics of roadway segments. The final data set used in the analysis was prepared in two stages.

In the first stage, LVS rear-end crashes and SVRD crashes into parked vehicles were extracted from the Access file containing all crashes. The subject crashes were contained under two crash types in the Access file coded as rear-end and fixed-object-off-road. Within each crash type, a further subset coding was required to identify LVS crashes where the stationary vehicle was a large truck and fixed-object off-road crashes where the fixed object struck was a large truck. The first stage in data preparation was to identify the individual records for each type of crash and subset.

Neither HTRIS nor the Access file contained a data field classifying the vehicles involved as striking or struck. In order to capture all large truck LVS and SVRD crashes, it was necessary to query the Access file first for "vehicle 1" as the large truck and "vehicle 2" as the passenger vehicle and then correspondingly for "vehicle 2" as the large truck and "vehicle 1" as the passenger vehicle. The two results were then combined.

Each crash record was retrieved from HTRIS by document number, and a copy of the FR 300 was printed. This provided the original data and the reporting officer's narrative describing each crash. (The officer's narrative and crash diagram are not included in the Access file.) Each of the hard copies was then reviewed to determine if the crash met the criteria for the study. This review indicated that a large number of the identified crashes were not appropriate (i.e., both vehicles were moving, both vehicles were large trucks, both vehicles were cars, etc.). This was addressed by using a second Access query.

In the second stage, the Access query was performed and yielded 1,630 appropriate crash records that were used to develop the statistical descriptions of LVS rear-end crashes and SVRD crashes used as the data set of this report. Applying the two Access queries yielded the subsets of crashes used in the analysis.

The analysis of Virginia crash data also provided the opportunity to review FR 300 reports to determine if fatal rear-end or SVRD crashes involving underride were being underreported by Virginia to FARS.

Survey of Selected States

Highway safety, transportation, and enforcement officials in Maryland, North Carolina, West Virginia, Kentucky, and California were contacted by telephone to determine if they had experienced problems with rear-end underride crashes and crashes on the shoulder involving large trucks.

Factors Contributing to Rear-End and SVRD Crashes

The psychological and perceptual factors contributing to these crashes were identified in the literature review. National factors related to truck parking were also identified in the literature review, and those specific to Virginia were determined through a review of all motor vehicle-related convictions in Virginia for the years 1998 through 2001.

Determination of Countermeasures

The determination of useful and practical countermeasures involved several avenues of research. The literature review uncovered actions taken or recommended by others. The survey of selected states provided useful information as well. The review of federal and state commercial motor vehicle safety legislation provided clarification concerning the kind of interventions the Commonwealth could consider to reduce the number and severity of LVS rear-end and SVRD crashes.

RESULTS

Review of Applicable Federal and Virginia Law

Federal Law

The ability of the Commonwealth to enact legislation governing commercial vehicles is limited by federal jurisdiction. The federal government has preempted the jurisdiction of the 50 states over these standards by enacting 49 USC § 30103(b). The Federal Motor Vehicle Safety Standards (FMVSS) preempts state legislation up to the point where a state can "prescribe or continue in effect a standard applicable to the same aspect of performance of a motor vehicle or motor vehicle equipment only if the standard is identical to the standard prescribed under this chapter." Therefore, Virginia cannot curtail or add to these federal standards. Nevertheless, state-owned motor vehicles are exempted from this rule. For these vehicles only, the Commonwealth can prescribe higher safety standards than those that are federally mandated.

The FMVSS, covering commercial vehicles, mandates appropriate lighting, reflective tape, and rear-impact guards. Commercial vehicles are vehicles with a combined weight of 4536 kg (10,000 lb) or more as defined in the CFR. Commercial vehicles parked along the roadside are governed by federal regulations. A summary of federal standards is provided in Table 1.

Although additional regulation of vehicles that are not state owned is limited by federal preemption, there is no mandate that the Commonwealth must rely on federal *enforcement* of these federal safety standards. The Commonwealth may enact legislation to enforce safety standards more strictly as long as the safety standards are identical with the standards prescribed by federal legislation. This state legislation could focus additional attention on the prevention of rear-end crashes and the attendant injuries and fatalities.

Table 1. Federal Statutes, Regulations, and Rule Making Associated With Commercial Vehicle Equipment and Conspicuity

Topic	Provisions
Federal Preemption	
49 USC § 30103(b)	Preempts Virginia legislation up to the point where the Commonwealth could "prescribe or continue in effect a standard applicable to the same aspect of performance of a motor vehicle or motor vehicle equipment only if the standard is identical to the standard prescribed in this chapter."
Retroreflective Tape	
FMVSS No. 108. Lamps, Reflective Devices, and Associated Equipment (amended September 1992)	Commercial trailers with a gross weight greater than 10,000 pounds manufactured on or after December 1, 1993, not designed exclusively for living or office use to be equipped with reflective tape
49 CFR 571.108. FMVSS lighting devices	Standards for the application of reflective tape
FMCSR 49 CFR Part 393 [FMCSA Docket FMCSA-1997-2222], Parts and Accessories Necessary for Safe Operation; Trailer Conspicuity (amended March 31, 1999)	Trailers and semi-trailers manufactured *before* December 1, 1993, to be retrofitted with reflective tape or reflex reflectors on their sides and rear by June 1, 2009
NHTSA Rule Making, August 8, 1996	Truck-*tractors* manufactured on or after July 1, 1997, to be equipped with the same reflective tape markings as trailers
Rear-Impact Guards	
FMVSS 223 and 224	Minimum standards for the geometry, configuration, strength, and energy absorption capability of rear-impact guards on trailers and semi-trailers with a gross weight greater than 10,000 pounds manufactured on or after January 26, 1998 (exclusive of pole or pulp trailers, special purpose or wheels back vehicles, or temporary living quarters). (Trailers manufactured before January 26, 1998, are equipped with smaller rear guards.)

The federal requirements for lighting and reflectors on commercial vehicles set standards for color, position, and required lighting fixtures by type of vehicle. Motor vehicles, including those placed into commercial operation, must comply with the FMVSS concerning lighting devices (49 CFR 571.108). These standards are designed to ensure that motor vehicles meet the minimum requirements for lighting at the time of their manufacture. The Commonwealth is preempted from enacting legislation that would require large trucks to increase lighting and reflectors that might reduce rear-end crashes because the FMVSS sets the standard.

In September 1992, NHTSA amended FMVSS No. 108, "Lamps, Reflective Devices, and Associated Equipment," by adding a conspicuity systems provision that required heavy trailers (i.e., those 80 or more inches in width with a gross vehicle weight rating over 10,000 lb) manufactured on or after December 1, 1993, to be equipped with reflective material (Morgan, 2001). Title 49, Part 571, Section 108 of the CFR outlines specifications for the application of the tape. These standards for retroreflective tape configurations do not apply to trailers designed exclusively for living or office use (Federal Motor Carrier Safety Administration [FMCSA], 2002).

On March 31, 1999, the Federal Motor Carrier Safety Regulations (FMCSR) were amended to require semi-trailers and trailers manufactured before December 1, 1993, to be retrofitted with retroreflective tape or reflex reflectors on their sides and rear. By June 1, 2009, all older trailers must be retrofitted and have conspicuity treatments identical with those mandated for new trailers (FMCSA, 2002). Going further, NHTSA published a final rule on August 8, 1996, that required all truck-tractors manufactured on or after July 1, 1997, to be equipped with red-and-white retroreflective tape similar to that required on trailers.

Two primary federal standards relate to rear-impact guards, which are designed to prevent a passenger vehicle from underriding the rear of a trailer or semi-trailer during a rear-end crash. FMVSS 223 and 224 set minimum standards for the "geometry, configuration, strength and energy absorption capability" of rear-impact guards applicable to trailers and semi-trailers. The stated purpose of the legislation is to reduce the number of deaths and serious injuries that occur when light-duty vehicles collide with the rear end of trailers and semi-trailers. These requirements apply only to trailers and semi-trailers with a gross vehicle weight rating of 4536 kg (10,000 lb) or more that were manufactured on or after January 26, 1998, and do not apply to pole trailers, pulpwood trailers, special purpose vehicles, wheels back vehicles, or temporary living quarters. Prior to this enactment, trailers and semi-trailers were regulated federally by the FMCSR, which mandated substantially smaller rear guards (NHTSA, 2000). Because pre-1998 trailers and semi-trailers are not governed by the current standards, they continue to pose a substantial risk to passengers of vehicles involved in rear-end crashes. To close this loophole, advocates have argued for an update of the federal standard to correct this omission (Truck Underride, 2002a).

Although this problem remains unaddressed, it does not appear that the Commonwealth can take action at the state level to require improved rear guards on commercial vehicles without being preempted by federal jurisdiction. As with reflective devices, the Commonwealth's options at this time are to enforce federal standards rigidly and to consider improved rear guards on state-owned vehicles.

Federal safety regulations concerning commercial vehicles parked along the roadway rest predominantly upon the requirement that "whenever a commercial motor vehicle is stopped upon the traveled portion of a highway or the shoulder of a highway for any cause other than necessary traffic stops, the driver . . . shall immediately activate hazard lights" (49 CFR § 392.22(a)). These hazard lights are to remain activated until the driver deploys warning devices such as flares or reflective triangles. This deployment must occur within 10 minutes of stopping. Virginia has adopted similar legislation but currently mandates deployment of flares only when the vehicle is disabled (COV § 46.2-111).

One of the concerns expressed in HJR 23 is crashes that occur while a commercial vehicle is stopped on the shoulder. In an attempt to address this issue, a question was raised by the project steering committee concerning a possible state mandate to require the installation of an electronic onboard recorder designed to measure the amount of time a commercial vehicle has been pulled off to the side of the road. This device would assist law enforcement in issuing citations by providing an accurate measurement of the time that a commercial vehicle has been stopped along the roadside. In Europe a mechanical tachograph, which monitors vehicle activities including vehicle motion, is mandatory for all large trucks (European Union, Council Regulations No. 2135/98).

Under 49 USC § 30103(b), which preempts states from curtailing or increasing FMVSS, it appears that the Commonwealth could require a tachograph or some other recording device on a commercial vehicle traveling in the state. Section 30103(b) applies to safety standards in effect under Chapter 301, Motor Vehicle Safety, and requirements for recording devices are not mentioned. Would this requirement stand up to a challenge brought under the Commerce Clause of the U.S. Constitution? The federal government maintains jurisdiction over interstate commerce, including the instruments of trade such as trucks and trains; therefore, such legislation might not stand up to a challenge of restricting interstate trade (*Houston, E. & W. T. R. Co. v. United States,* 234 U.S. 342). Nevertheless, the Commonwealth may not need to enact such legislation, as there seems to be a trend within the commercial trucking industry of installing global positioning systems or other monitoring systems on their vehicles to track the movements of their drivers. As this practice grows and the question of data ownership is addressed, Virginia law enforcement officials may be able to use the readings from these devices to determine whether drivers are acting in accord with both federal and state codes concerning vehicles parked on the roadside.

Virginia Law

Regarding Stopped Vehicles

The Commonwealth has mandated that "no person shall stop a vehicle in such a manner as to impede or render dangerous the use of the highway by others, except in the case of an emergency, an accident, or a mechanical breakdown" (COV § 46.2-888). Currently, violation of the statute can result in a fine of up to $48. Further state regulation requires that vehicles illegally parked or stopped (whether attended or not) on the highway "shall display at least one light projecting a white or amber light visible in clear weather from a distance of 500 feet to the front of such vehicle and projecting a red light visible under like conditions from a distance of 500 feet to the rear" (COV § 46.2-1037). Currently there is a $48 fine for a violation of this regulation. Similarly, the Commonwealth requires

> whenever any ..., truck, trailer ... is disabled and stops on any roadway in the Commonwealth, except in corporate limits of cities or on highways which are artificially lighted at night, at any time during which lights are required on motor vehicles by § 46.2-1030, the operator of such vehicle shall place ... on the roadway red flares or torches ... in the center of the traffic lane occupied by the vehicle and not less than 100 feet from the vehicle in one direction and not less than 100 feet in the other direction and one not less than ten feet from the rear of the vehicle on the traffic side of the vehicle (COV § 46.2-111).

COV § 46.2-111 requires the placement of warning devices only during the time when vehicle lights are required to be lit and applies only to disabled vehicles on the roadway. Amending COV § 46.2-111 to reflect the requirements in CFR § 392.22 would provide Virginia law enforcement personnel with the means to issue citations for illegally parked commercial vehicles. Such a proposed amendment is presented in Appendix B.

Regarding Truck Parking

The control of vehicle parking in Virginia is vested with the Commonwealth Transportation Board, which has general authority to make regulations governing traffic on the highways, including parking. In practice, the board's authority to regulate and control parking has been delegated to local government jurisdictions (COV § 46.2-1220) with certain controls when local ordinances deal with parking on interstate or arterial highways.

However, specifically granted under COV § 33.1-12, COV 33.1-218, and 24 VAC 30-50-10 is the authority for VDOT to establish time limits for parking in public rest stops. The time limit is clearly posted by sign and applicable to all vehicles using the rest stop. Currently, VDOT policy is to limit parking in rest areas to a maximum of 2 hours. The citation for exceeding the time limit for parking in a public rest area is issued under COV § 46.2-830, Failure to Obey a Highway Sign. More discussion concerning the use of this statute is provided in the section on factors regarding truck parking later in this report.

Prevalence of Rear-Impact Guards in Virginia

A review of large truck registrations in Virginia was conducted in an attempt to answer two questions: (1) How many straight trucks, all of which are exempt from FMVSS 224 (not required to have rear-impact guards), are registered in Virginia? (2) How many Virginia-registered semi-trailers were manufactured before FMVSS 224 took effect in 1998 and thus are not required to have rear-impact guards?

Straight Trucks

Straight trucks are currently exempt from the impact guard requirement of FMVSS 224 but certainly not from being involved in rear-end crashes. In Virginia's LVS rear-end crashes, straight trucks are struck more often than tractor-trailers. Straight trucks are struck by passenger vehicles in 63% of truck-involved LVS crashes, and tractor-trailers are struck in 35%. For this reason, it was important to identify the number of straight trucks registered in Virginia.

Data were extracted from the Virginia DMV's TTTR (Virginia DMV, 2001a) and the IRP (Virginia DMV, 2001b). The total number of straight trucks identified was 207,446. Included in this figure were 203,406 trucks and 4,040 tow trucks. In an attempt to validate the number of straight trucks identified in the report, the number was compared to that in the 2001 *Virginia Crash Facts* (Virginia DMV, 2002). The number identified from the TTTR and IRP includes about 95% of the registered straight trucks indicated in the *Crash Facts.*

Truck-Tractor Semi-Trailer Combinations

Data were also extracted from the Virginia DMV reports to determine the number of truck-tractors and semi-trailers registered in Virginia. In total, 37,989 truck-tractors and 24,197 semi-trailers were identified.

This appears to be a very low number of registered semi-trailers when compared to the total number of truck-tractors at 37,989. Usual operating practice would dictate that there are from two to three semi-trailers for each truck-tractor.

The age or year of manufacture of the semi-trailers identified could not be determined from the data provided by the Virginia DMV. Without the vehicle age, it is not possible to quantify the number of semi-trailers licensed in Virginia that were manufactured before the rear-impact guard mandate in FMVSS 224. This being the case, it was necessary to estimate the number of subject semi-trailers using available statistics of new trailer production and total fleet size. Trailer production figures were obtained from the U.S. Census (U.S. Census, 2001) and ACT Research Co. LLC, a private research company that is now the only source of trailer manufacturing data since the U.S. Census no longer collects these data (Vieth, K., 2002, unpublished data). The total national semi-trailer fleet figure was based on industry estimates.

The estimate presented here is based on the following assumptions.

1. Any complete trailer or chassis manufactured after 1994 was considered to be under the FMVSS 224 mandate.

2. All trailers in the "Tank" and "Other" categories were considered to meet one or more of the criteria for exemption under FMVSS 224, such as wheels back design, low chassis construction, pole trailers, etc.

3. The total national semi-trailer fleet was estimated to be 2.7 million units.

In January 1992, NHTSA published a Supplementary Notice of Proposed Rulemaking on Rear-impact Guards and Rear-impact Protection (*Federal Register,* 1992). In April 1994, the Truck Trailer Manufacturers Association (TTMA) issued a voluntary Recommended Practice RP92-94, Rear-impact Guard and Protection, which included all the essential elements subsequently included in FMVSS 223 and 224 except the energy absorption requirements. The result of the Recommended Practice is that from April 1994 all trailers manufactured by TTMA members would have been fitted with a rear-impact guard that essentially complied with the requirements of FMVSS 224 (NHTSA, 2000).

Semi-trailers manufactured after January 25, 1998, and not meeting the exemptions were required by NHTSA to be equipped with an FMVSS 224 rear-impact guard. Since production figures are available on only an annual basis, any unit manufactured after 1994 was considered here. Trailer production figures for 1995 through 2001 were used to develop the estimate figures. In preparing these figures, a conservative approach was taken. Only van trailers, platform trailers, and chassis units were considered to be equipped with an impact guard. This resulted in an estimated total of 1,693,332 units equipped with a rear-impact guard.

Using the figure of 2.7 million for the national fleet, simple division yielded an estimate that 63% of all semi-trailers in operation today are equipped with an impact guard essentially complying with the requirements of FMVSS 224. NHTSA reported that based on observations of rear-impact guards made by their staff at weigh stations, it was anticipated that by 2002, approximately 69% of semi-trailers would be equipped with a rear-impact guard complying with either the TTMA or FMVSS 224 requirements (NHTSA, 2000). Given the estimate calculated in the report and NHTSA's observations, it is estimated that 30% to 40% of Virginia's registered semi-trailers are not equipped with a rear-impact guard complying with the requirements of FMVSS 224.

Magnitude and Severity of the Crash Problem

National Rear-End Crash Problem

Rear-end crashes are commonly divided into two groups: rear-end crashes where the lead vehicle is stationary (i.e., LVS) and rear-end crashes where the lead vehicle is moving. This study deals only with LVS rear-end crashes. To address the situation in Virginia, it is helpful to understand the national characteristics of these crashes.

Four studies were reviewed concerning rear-end crashes (Knipling et al., 1993; Knipling, Wang, and Yin, 1993; Misener et al., 2000; Wiacek and Najm, 1999). Each of these studies used one or both of two national crash databases compiled by NHTSA: FARS and the National Accident Sampling System (NASS) General Estimates System (GES). The most important result pertaining to the current study is that LVS crashes represent 70% of all rear-end crashes and 55% of all fatal rear-end crashes (Knipling, Wang, and Yin, 1993).

Knipling, Wang, and Yin (1993) included a breakdown of commercial vehicles in their problem analysis. Of particular interest was the finding that rear-end crashes where the struck vehicle was a combination truck (truck-tractor and semi-trailer) represented 1.1% of all rear-end crashes but accounted for 23.4% of the fatalities in rear-end crashes. The figures presented also indicate that the struck vehicle involvement rate per 100 million vehicle miles traveled was lower for combination trucks than for any other vehicle category. Using FARS and GES, the authors also found descriptive statistics of environmental, roadway, driver actions, and causal factors for all LVS rear-end crashes, not just those involving a passenger car and a truck. The authors found the following:

- More than 70% occurred on straight, level, dry roadways.
- More than 80% occurred in the daytime—between 6 a.m. and 6 p.m.
- Approximately 54% were intersection related, and 35% were not.
- Approximately 58% occurred on a divided roadway, and 33% did not.
- Approximately 53% of drivers received no citation.
- Approximately 72% were caused by driver inattention.
- Approximately 24% were caused by following too closely.

Barr (2001) presented an analysis of the 1998 GES crash database to compare the rear-end crashes of commercial vehicles and passenger vehicles. According to Barr, in 1998 there were 1.79 million police-reported rear-end crashes, and in approximately 29,000 crashes (1.6%), a commercial vehicle was struck in the rear. LVS crashes occurred during daylight and clear weather 65% of the time. The majority of crashes, 77%, were not intersection related, with 19%

on freeways and 58% on non-freeways. For the purpose of the roadway characteristics, a freeway was defined as any divided highway with a posted speed limit of 55 mph or greater. When a commercial vehicle was struck in an LVS crash, the striking vehicle was a passenger vehicle 72% of the time. The contributing factors for the driver of the striking vehicle, regardless of vehicle type, indicate that driver distraction and speed-related actions were involved more than 40% of the time and alcohol was involved in 1.9% of crashes.

The author also presented statistics for passenger vehicle rear-end crashes. In 1998, there were 3.5 million passenger vehicles involved in rear-end crashes, about evenly divided between the striking and struck vehicles. A passenger vehicle struck a commercial vehicle in less than 1% of LVS rear-end crashes. This makes such a crash a rare event.

National SVRD Crash Problem

HJR 23 specifically addresses crashes involving a passenger vehicle striking the rear of a large truck parked on the shoulder. Such a crash, although it appears to be an off-roadway rear-end crash, is technically not a rear-end crash but rather an SVRD crash into a parked vehicle. This review found only one study that dealt directly with SVRD shoulder crashes involving parked vehicles. However, four studies touched on this subject. These four studies indicated that crashes involving large trucks stopped on the shoulder and struck by another vehicle of any kind are rare but tend to be over-represented in terms of fatalities.

Wang and Knipling (1994) used FARS and GES data for 1991 to document the number of this class of crashes and provide statistical descriptions. They found that 1.27 million SVRD crashes representing 20.8% of all police-reported crashes in 1991 were responsible for 37.4% of all vehicle crash fatalities. There were 315,000 crashes involving frontal impact into a parked vehicle, representing 23.5% of SVRD crashes. Although this is a significant portion of SVRD crashes, it represents only 5% of all police-reported crashes and includes all categories of parking location and struck vehicle. There were 41,000 crashes involving a heavy truck either striking or struck. This represents 3% of all SVRD crashes and 0.70% of all police-reported crashes in 1991. The authors did not further analyze the crashes to provide descriptive statistics of the striking and struck vehicle. However, even at 0.70%, an SVRD crash involving a large truck and a passenger vehicle is a rare event.

Agent and Pigman (1989) conducted a study of crashes involving vehicles on the shoulder of interstate highways and parkways. They reviewed data for all crashes occurring from 1985 through 1987 on interstates and parkways in Kentucky. The identified crashes represented 1.8% of all crashes on Kentucky interstates and parkways but were responsible for 11.1% of fatal crashes. The majority, 71%, of these crashes involved a vehicle parked on the shoulder. Tractor-trailers were over-represented in these crashes, accounting for 25% of the vehicles struck on the shoulder, whereas tractor-trailers were involved in only 2.8% of vehicle crashes statewide. The authors did not present data on the number or percentage of tractor-trailers stopped on the shoulder struck by passenger vehicles but did report that the striking vehicle was an automobile in 74% of shoulder crashes. The fatality rate for shoulder crashes was greater than the rate for crashes statewide. More than 5% of shoulder crashes resulted in a fatality compared to 0.50% for crashes statewide. Shoulder crashes were twice as likely to have alcohol involvement.

Wegmann, Chatterjee, and Clarke (1999) reviewed large truck crashes on interstate highways in Tennessee between January 1990 and April 1996 and found a total of 12,723 crashes, resulting in 240 fatalities and 5,829 injuries. During these 64 months there were 69 SVRD crashes where a large truck on the shoulder was struck by a passenger vehicle. This represented 0.50% of the large truck interstate crashes during the period.

Agent and Pigman (2002) analyzed all crashes involving large trucks on Kentucky's interstate highways for 1998 through 2000. Of particular interest was the analysis of crashes occurring on the shoulder. The authors found that crashes occurring on the shoulder with a parked vehicle represented 3.1% of total interstate crashes and 3.7% of truck interstate crashes. Fatal crashes occurring on the shoulder with a parked vehicle represented 7.4% of total interstate fatal crashes, 15.5% of fatal interstate truck crashes, and 5.6% of all fatal truck crashes regardless of roadway classification. An additional review was completed of 144 police crash reports representing all fatal truck crashes occurring on Kentucky's interstate highways for the years 1994 through 2001. The results indicated that during the 7-year period, 11 crashes, or 7.6%, of all fatal truck crashes involved a large truck stopped on the shoulder and struck by a passenger vehicle.

Analysis of Virginia Crash Records: 1997-2001

In Virginia from 1997 through 2001 there were 209,655 rear-end crashes, representing 30.3 % of total crashes, and 212 fatal rear-end crashes, representing 5 % of the total fatal crashes. These figures are in line with national database studies presented in the literature review that place rear-end crashes at approximately 25% to 30 % of total crashes and 5% of fatal crashes (Knipling et al., 1993; Knipling, Wang, and Yin, 1993; Misener et al., 2000; Wiacek and Najm, 1999). SVRD crashes are represented by the collision categories of Fixed-Object Off-Road and Non-Collision as shown in Figure 2. The total of these two categories is 153,132 crashes, representing 22.1% of total crashes but 50% of fatal crashes. These figures closely reflect the 21% of total crashes from the national database study done by Wang and Knipling (1994), but the percentage of fatal Virginia SVRD crashes is 12% higher. The percentage of rear-end or SVRD crashes in Virginia is not substantially different than the percentage in national database studies, but the percentage of fatal SVRD crashes is higher.

Two of the crash types are of particular interest. The 121,080 LVS rear-end crashes represent 17.5% of total crashes and 58% of the rear-end crashes. The 5,908 SVRD crashes into parked vehicles represent 0.9% of total crashes. Passenger vehicles were the striking vehicles in 3,743 SVRD crashes into parked vehicles. It is important to note that 5,658 of those SVRD crash records contained no indication of the struck vehicle type. Reporting officers indicate that they include these data elements when they fill out the FR 300 but the elements are not contained in HTRIS.

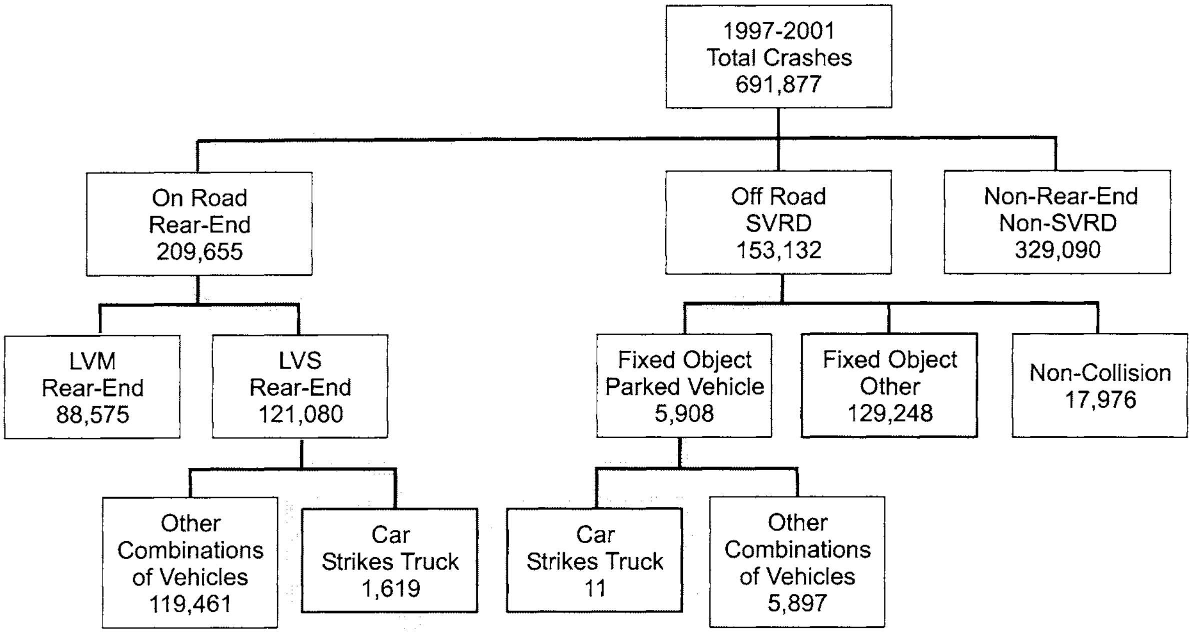

Figure 2. Determination of Data Sets for LVS and SVRD Crash Analysis

Characteristics of LVS and SVRD Crashes in Virginia

This portion of the crash analysis presents descriptive statistics for LVS rear-end crashes and SVRD crashes involving large trucks struck in the rear by passenger vehicles.

The statistics for the analyzed data fields describing LVS rear-end crashes and SVRD crashes into parked vehicles are presented in Tables 2 through 11. It is important to note that the sample size is very small for three categories of crashes: there were 16 fatal LVS crashes, 11 SVRD crashes into parked trucks, and 5 fatal SVRD crashes into parked trucks. In general, the percentage indicated in the tables is of the number of data entries in the crash records, not the total number of crash records in the sample. The exception is in cases where the data field contains a variable indicating "not stated." The sample size is indicated in the column heading for each crash category and represents the total sample size, not the number of data entries analyzed. As a result of the small sample sizes, caution must be attached to the results. The small sample size in the case of fatal LVS and fatal SVRD crashes is an indication that these types of crashes occur very infrequently. It should be noted that all of the fatal SVRD crashes were actually coded in the VDOT Access file as rear-end crashes. This suggests that there may be confusion on the part of reporting officers concerning the distinction between a rear-end crash and an SVRD crash. The small sample size for SVRD crashes is the result of incomplete data elements in a number of the data fields for the SVRD crashes.

Time and Day of Crash

The descriptive statistics for time of day and day of week are presented in Table 2. The majority of LVS crashes, 85%, occurred during daytime hours from 6:00 a.m. to 5:59 p.m., with

Table 2. Time and Day of Crash for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Time of Day				
6:00 a.m.-5:59 p.m.	85.0	81.3	54.5	40.0
6:00 p.m.-11:59 p.m.	10.6	6.3	18.2	20.0
12:00 a.m.-5:59 a.m.	4.4	12.5	27.3	40.0
Day of Week				
Monday	16.5	18.8	9.1	
Tuesday	18.5	31.3		
Wednesday	15.9	6.3	27.3	20.0
Thursday	19.5	18.8	18.2	20.0
Friday	18.5	12.5	27.3	20.0
Saturday	7.2	12.5	9.1	20.0
Sunday	3.9		9.1	20.0

only 4.4% occurring between midnight and 5:59 a.m. However, 40% of fatal SVRD crashes occurred between midnight and 5:59 a.m. All LVS crashes were evenly distributed during the weekdays, with a substantial reduction on Saturday and Sunday. Fatal LVS crashes spiked on Tuesday and decreased substantially on Wednesday. Fatal SVRD crashes did not decrease on Saturday or Sunday, and no crashes occurred on Monday and Tuesday, but this is largely the result of the very small sample size.

Environmental Factors

The environmental factors of weather and light conditions are presented in Table 3. For each category, a majority of crashes occurred in clear weather. LVS, fatal LVS, and SVRD crashes occurred mainly during daylight. This supports the NHTSA finding that retroreflective tape on trailers appears to offer no benefits during daylight hours (Morgan, 2001) and illustrates the need to improve large truck conspicuity during daylight. In contrast, 60% of the 5 fatal SVRD crashes took place on a dark street with no light and involved a tractor-trailer. These crashes represent those that could possibly benefit from the increased nighttime conspicuity offered by additional retroreflective tape or tape in more effective patterns.

Table 3. Environmental Factors for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Weather				
Clear	67.4	75.0	63.6	100.0
Cloudy	15.8	12.5		
Fog	1.2			
Raining	10.7	6.3	9.1	
Snow	2.2		18.2	
Other	2.7	6.3	9.1	
Lighting				
Dawn	2.7			
Daylight	82.3	68.8	54.5	40.0
Dusk	1.7			
Dark-Street Lighted	7.5	12.5		
Dark-Street No Light	5.8	18.8	45.5	60.0

Roadway Factors

Roadway factor descriptive statistics for the highway system and junction type are provided in Table 4. The majority of all LVS and fatal LVS crashes occurred on a primary highway. A majority of SVRD crashes and all fatal SVRD crashes occurred on interstate highways. This may be due in part to the higher speed limits on interstate highways. Interstates also have higher concentrations of large trucks. In all categories, a majority of crashes occurred on segments of the roadway having no junctions. This agrees with the national study of LVS rear-end crashes involving commercial vehicles done by Barr (2001).

Table 4. Roadway Factors, Highway System, and Junction for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Highway System				
Interstate	18.8	37.5	72.7	100.0
Primary	54.7	50.0	18.2	
Secondary	13.3	6.3	1	
City Street	36	6.3		
County Road	1.0			
Interstate Ramp	0.5			
Junction				
Signalized	14.0			
Crossing	5.7			
T Junction	9.6	12.5		
Interchange	7.1	6.3	18.2	40.0
Other	1.1			
Non-junction	62.6	81.3	81.8	60.0

Roadway factor descriptive statistics for road alignment and surface condition are provided in Table 5. In all categories, the majority of crashes occurred on straight, level, dry roadways.

Table 5. Roadway Factors, Alignment, and Surface Condition for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Road Alignment				
Straight-Level	72.0	68.8	72.7	80.0
Curve-Level	3.2		9.1	
Straight-Grade	17.7	31.3	9.1	20.0
Curve-Grade	3.3		9.1	
Other	3.8			
Roadway Surface				
Dry	78.7	81.3	63.6	100.0
Wet	18.4	18.8	18.2	
Other	2.9		18.2	

Vehicle Factors

Vehicle factors for LVS and SVRD crashes are presented in Tables 6 and 7. Descriptive statistics are provided for the striking vehicle and the struck vehicle. Vehicle type is presented in Table 6. The striking vehicles represented are all passenger categories by study design. For all LVS crashes, pickup trucks and vans were over represented in relation to their percentage of registered vehicles. Fatal LVS, SVRD, and fatal SVRD crashes also involved a higher percentage of pickup trucks in relation to their share of vehicle registrations. However these three crash categories have very small samples.

Table 6. Vehicle Type for LVS and SVRD Crashes

Vehicle Type	Striking				Struck			
	% All LVS N=1619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5	% All LVS N=1619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Passenger Car	67.9	68.8	45.5	40.0				
Pickup/Jeep/SUV	23.3	31.3	54.5	60.0				
Van	8.8							
Straight Truck					62.5	56.3	27.3	
Tractor-Trailer					34.7	43.8	72.7	100.0
Tractor-Trailer Double					0.2			
Motor Home					1.3			
Oversized Vehicle					1.4			

Table 7. Maneuvers of Striking and Struck Vehicles for LVS and SVRD Crashes

	Striking				Struck			
Vehicle Maneuver	**% All LVS N=1619**	**% Fatal LVS N=16**	**% All SVRD N=11**	**% Fatal SVRD N=5**	**% All LVS N=1619**	**% Fatal LVS N=16**	**% All SVRD N=11**	**% Fatal SVRD N=5**
Going Straight	72.6	87.5	18.2	20.0	8.5			
Right Turn	2.3				1.8			
Left Turn	1.9				3.5			
U Turn					0.1	6.3		
Slowing/Stopping	14.8							
Starting/Traffic Lane	2.5							
Starting/Parked Position	0.2							
Stopped/Traffic Lane					83.6	87.5	18.2	
Off Road Right			72.7	80.0				
Off Road Left			9.1					
Parked					1.4		36.4	40.0
Backing								
Passing	0.7							
Changing Lanes	4.5	12.5						
Other	0.2				0.8	6.3	45.5	60.0
Not Stated	0.4				0.3			

The struck vehicles were all large trucks by study design. The majority of all LVS crashes and fatal LVS crashes involved a straight truck. Straight trucks are more likely to be used on primary roads and in urban environments with heavy traffic where the majority of LVS and fatal LVS crashes occurred. In contrast, the majority of all SVRD crashes and fatal SVRD crashes involved passenger vehicles striking tractor-trailers. This also is not unexpected given that tractor-trailers log more operating mileage on interstate highways, where the majority of SVRD crashes occurred.

Vehicle maneuvers for the striking and struck vehicle are presented in Table 7. Not surprisingly the majority vehicle maneuver for striking LVS and fatal LVS crashes was "going straight." In the majority of SVRD and fatal SVRD crashes, the striking passenger vehicle maneuver was "off road to the right." SVRD crashes are off-roadway events, and the right shoulder is adjacent to the normal traffic lane. The struck truck maneuver for the majority of struck LVS and fatal LVS crashes was "stopped in the traffic lane." Fatal SVRD crashes indicated 40% parked" and 60% "other." In fact, in all 3 of the 5 fatal SVRD crashes coded under "other" for struck vehicle maneuver, the truck was actually parked on the shoulder. This could indicate that reporting officers are unsure of how to classify this type of crash, as it is a rare event.

Driver Factors for Striking Vehicles

It is a general presumption for this study that in LVS and SVRD crashes it is the striking vehicle that is at fault. For this reason, only driver actions for the striking vehicle were analyzed. The descriptive statistics for driver sex and age are presented in Table 8.

Table 8. Driver Sex and Age for Striking Vehicle Driver Only

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Driver Sex				
Male	60.1	93.8	81.8	80.0
Female	38.6	6.3	18.2	20.0
Unknown	1.3			
Driver Age				
< 15	1.3			
15-19	12.2		36.4	60.0
20-24	14.6	6.3	18.2	
25-54	56.0	62.5	45.5	40.0
55-64	7.4			
65-74	4.7	12.5		
>74	3.9	18.8		

Male drivers make up the majority of drivers of the striking vehicles in all crash categories. In fatal LVS crashes, a man was driving 14 times more often than a woman. The age group 25 to 54 represents a majority of drivers for LVS and fatal LVS crashes and the largest group for SVRD crashes. However, the combined age groups of 15 to 19 and 20 to 24 make up a majority for SVRD crashes. Fatal SVRD crashes indicate 60% (3 of 5) in the 15 to 19 age group and 40% in the 25 to 54 age group.

The descriptive statistics for driver action and seat belt use are presented in Table 9. The major driver action identified for all crash types was "driver inattention." Other major contributors to this factor were "following too close," "speed related," and "none."

One or more persons in 33% of fatal crashes did not use a seat belt. No seat belt statistics were generated for injury and property damage crashes. Seat belt use is not a data field in either the HTRIS or Access file. Normally that would prevent the generation of descriptive statistics. However, in this case, the number of fatal crashes was small, allowing seat belt use to be manually determined.

Table 9. Driver Action and Seat Belt Use for Striking Vehicle Driver Only

Driver Action	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
None	5.9	18.8		
Exceed Speed	1.7	18.8	9.1	20.0
Exceed Safe Speed	4.6	12.5	18.2	
Follow Too Close	28.7			
Inattention	44.3	50.0	63.6	80.0
Avoid Other Vehicle	1.2			
Other	12.4		9.1	
Not Stated	1.1			
Seat Belt Used (% Individuals, Not Crashes)				
Yes	UNK	43.8	UNK	50.0
No	UNK	43.8	UNK	33.3
Unknown	UNK	12.5	UNK	16.7

Major Contributing Factors

The descriptive statistics for major contributing factor are presented in Table 10. The major factor for all crash types was "driver inattention." When the prominent major factor recorded presents such a general description, it is difficult to determine the cause of the crash and formulate meaningful countermeasures. "DUI alcohol or drugs" was a factor for all crash categories. However, with the exception of fatal SVRD crashes, alcohol involvement in the crashes analyzed was below 7.8%, which is the level of alcohol involvement for all Virginia crashes during 2001 (Virginia DMV, 2001). Again, it is important to note that the sample size for fatal SVRD crashes is very small, and the 20% alcohol involvement represents only one crash.

Table 10. Major Contributing Factors for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Miscellaneous	0.6			
Driver Handicap or Ill	2.0	12.5		
DUI Alcohol or Drugs	2.3	6.3	9.1	20.0
Driver Speeding	2.4	6.3	18.2	
Driver Inattention	85.1	62.5	63.6	80.0
Vehicle Defective	1.2	12.5		
Weather/Visibility	3.9		9.1	
Road Defect	0.1			
Road Slick	2.2			
Not Stated	0.2			

The descriptive statistics for driver condition and driver drinking are presented in Table 11. Driver condition was "no defects" or "not stated" for more than 94% of all crash types. The driver had not been drinking in 93.8% of LVS, 68.8% of fatal LVS, 63.6% of SVRD, and 20% of fatal SVRD crashes. This factor was "not stated" in 31.3% of fatal LVS crashes, 27.3% of SVRD crashes, and 60% of fatal SVRD crashes. Here again, a substantial number of crash records contained "not stated" as an entry for the factor, which provides no information concerning the driver's use of alcohol.

Table 11. Driver Condition and Driver Drinking Factors for LVS and SVRD Crashes

Factor	% All LVS N=1,619	% Fatal LVS N=16	% All SVRD N=11	% Fatal SVRD N=5
Driver Condition				
No Defects	94.6	62.5	72.7	40.0
Eyesight Defective	0.4			
Hearing Defective	0.1			
Other Body Defects	0.2			
Ill	0.4			
Fatigued	0.7			
Apparently Asleep	0.7			
Other	0.6			
Not Stated	2.2	37.5	27.3	60.0
Driver Drinking				
Not Been Drinking	93.8	68.8	63.6	20.0
Drinking-Drunk	2.0		9.1	20.0
Drinking-Impaired	0.7			
Drinking-Not Impaired	0.7			
Not Known	0.7			
Not Stated	2.0	31.3	27.3	60.0

Identification of Virginia's Fatal Underride Crashes

Blower and Campbell (1999) examined data on underride crashes collected in 1997 by the University of Michigan Transportation Research Institute for National Truck Statistics as part of its Trucks Involved in Fatal Accidents (TIFA) Survey. Virginia was cited as a prime example of a state that incompletely reported underride crashes. FARS data for 1997 indicate that Virginia submitted 1 reported underride fatality crash, but the analysis of the TIFA data identified 13 Virginia underride crashes, 7 by directly contacting the reporting officer and six by projecting those results based on the sample size. The analysis of Virginia crash data provided the opportunity to review FR 300 reports to determine if fatal rear-end or SVRD crashes involving underride were being underreported by Virginia to FARS.

To classify a crash as underride, it was necessary to review the corresponding FR 300 report. These were available for each fatal crash as a result of the data analysis effort already described. The four methods used to evaluate the fatal crashes for underride are presented here.

Table 12. Underride by Classification Method for Fatal LVS and Fatal SVRD Crashes

Method	Yes Underride		No Underride	
	LVS	SVRD	LVS	SVRD
FR 300		1		
Reporting Officer	1	1	3	1
Review Criteria	2			
Blower and Campbell	1			
No Contact			3	
Unknown			6	2
Total	4	2	12	3

Of the 21 fatal crashes reported, 6 crashes were underride crashes. The results of the evaluation are presented in Table 12.

1. *Officer Narrative.* The FR 300 does not provide a means to code underride directly. The only method of determining underride directly from the FR 300 is to review the reporting officer's narrative. Only one FR 300 contained a description of underride in the narrative.

2. *Officer Contact.* An attempt was made to contact the reporting officer for each of the remaining crashes to determine if underride was involved. Three of the reporting officers could not be located. Of those contacted, six responses were received and confirmed that two of the crashes involved underride and four did not.

3. *Study Criteria.* Section V22 of the *FARS Coding and Validation Manual* directs that underride information should be obtained from the police accident report in either the narrative section or the vehicle damage scale (NHTSA, 2002a). Damage to the roof of the vehicle must be indicated on the vehicle damage scale before underride is confirmed. For the remaining FR 300 reports, a conservative interpretation of the FARS manual was used to classify the crashes. If the damage scale included front-end damage and roof damage, the crash was classified as underride. Only two crashes met these criteria and were classified as underride. All of the remaining nine crashes would have been classified as no underride if Blower and Campbell had not identified them through direct contact with the reporting officer.

4. *Blower and Campbell Study.* Blower and Campbell (1999) described an effort to document underride crashes that were underreported to FARS for 1997. Blower was contacted and provided FARS case numbers for seven crashes reported to FARS by Virginia in 1997 that did not indicate underride but were documented during their study as underride crashes by direct contact with the reporting officer. Five of the FARS case numbers represented rear-end crashes where both vehicles were moving and, as such, were outside the scope of this study. The two remaining were included in the group of FR 300 reports that were reviewed. In fact, one of the two FARS case numbers provided by Blower had already been classified as underride using the study criteria.

The FARS system was queried for crashes in Virginia with any underride for the years 1997 through 2001. There was one crash reported in 1997, one in 1998, none in 1999, two in 2000, and none in 2001, for a total of four. Table 13 presents the comparison of the FARS queries with the underride crashes identified during the FR 300 review.

The review identified additional underride crashes in 3 of the 5 years. However, the number of crashes involved is extremely small, and the reader is cautioned from making any inferences. The existing Virginia crash reporting system is inadequate for identifying underride crashes, and it is possible that more of the crashes reviewed could have involved underride. Some of the reporting officers who responded stated that they were not certain what constituted an underride. In a review of the *Police Officer's Instruction Manual for Investigating Traffic Accidents* (Virginia DMV, 1995), no mention of underride or how it should be addressed, i.e., how it should be included in the narrative and identified on the vehicle damage scale, was found. Discussions with a Virginia DMV FARS analyst indicated that underride is rarely contained in the narrative portion of the FR 300, and there is no attempt to interpret the vehicle damage scale when coding from the FR 300 to the FARS database.

Two modifications to the current practice could improve the situation. One is to provide additional training to reporting officers on what constitutes underride involvement in a crash. Another is to add an underride-coding block to the FR 300. This would be in line with the Model Minimum Uniform Crash Criteria being developed by NHTSA, which includes underride as a vehicle data element that should be collected at the crash scene (NHTSA, 2002a). These changes would clarify and simplify the situation for the reporting officer and for the FARS analyst coding data from the FR 300.

It is important to note that underride crashes need not be fatal. In fact, during the previous analysis of Virginia crash records, two documented examples of non-fatal LVS crashes involving underride were found. In both examples, the reporting officer had included the underride involvement in the narrative.

Table 13. Number of Underride Crashes: FARS Reported and FR 300 Review by Year

Year	FARS	Review
1997	1	2
1998	1	0
1999	0	1
2000	2	0
2001	0	3
Total	4	6

Survey of Selected States

Highway safety, transportation, and enforcement officials in Maryland, North Carolina, West Virginia, Kentucky, and California were contacted by telephone to determine if they had experienced problems with rear-end underride crashes and crashes on the shoulder involving large trucks. California was included because it is only one of two states (the other is Kentucky) that had recent legislative activity related to this study. In each state, the Governor's Representative for Highway Safety was contacted first. In all cases, the representatives provided contact details for individuals they felt might provide useful information. (A list of contacts is available from the Safety, Planning & Legal Team of the Virginia Transportation Research Council.) The questions asked in the survey are provided in Appendix C.

Underride and Shoulder Crashes

None of the states contacted considered either underride crashes or shoulder crashes involving large trucks to be a priority problem, but each mentioned that when such crashes occur they often seem to be severe and highly publicized. Two states, California and Kentucky, provided limited statistical information on shoulder crashes for 2001. California reported 522,562 total crashes, of which 1,491 (0.3%) involved large trucks stopped on the shoulder. The breakdown for these California crashes is 30 fatal, 516 injury, and 945 property damage only (Johnson, B., unpublished data, 2002). Kentucky reported 130,190 total crashes, the number of shoulder crashes into trucks was 17 (0.01%), with a breakdown of 6 injury crashes and 11 property-damage-only crashes (Pratt, M., unpublished data, 2002).

Current Countermeasures

Maryland and North Carolina indicated that they use “No Parking” signs on ramps and shoulders as countermeasures against shoulder crashes. None of the states has considered any countermeasures specifically targeted at underride crashes other than enforcing the FMCSR. West Virginia moves heavy trucks to the right traffic lane on steep grades as a general countermeasure to prevent rear-end crashes.

Current Statutes

No existing state statutes dealing specifically with truck underride or shoulder crashes were identified, other than those contained in the FMCSR. California is the only state to have considered a requirement for onboard recorders (Speier, 2001).

Legislation was introduced twice in the Kentucky General Assembly to increase the fine for failing to have a rear-impact guard or rear-end protection as provided for in 49 CFR, Parts 393 and 571, and prohibit the motor vehicle in question from being operated until adequate rear-end protection is provided (Jones, 2001). The Kentucky legislators did not adopt this legislation. The Kentucky Vehicle Enforcement Division of the Department of Vehicle Regulation did not support the bill as it would have caused a deviation from the uniform inspection procedures of the Commercial Vehicle Safety Alliance, which is the cooperative organization of federal and state commercial vehicle enforcement agencies (Powers, G., unpublished data, 2002).

Three of the states (California, Maryland, and North Carolina) have adopted the FMCSR into their state codes. West Virginia and Kentucky enforce existing federal regulations by administrative regulation. None of the states was concerned about federal preemption in the area of motor vehicle safety and had not taken any steps to address it as an active issue.

Truck Parking Policy

Each of the states contacted had concerns about large truck parking. Several states indicated the actions they had taken in this area. Maryland instituted a program of notification signs at public rest stops to inform truck drivers where to find additional parking in the direction they are traveling if the rest area parking is full. This was done in an attempt to decrease the number of trucks parked on the ramps of the rest stops. Kentucky enlarged several rest stop facilities and opened weigh stations for truck parking 24 hours a day with no time limit for parking. North Carolina is concerned about rest stop capacity in the western part of the state and is reviewing the situation.

Kentucky is the only other state contacted that has a time limit (4 hours; twice as long as Virginia's 2-hour limit) for parking in public rest areas. Two other states, North Carolina and West Virginia, have no time limit, but both "discourage" overnight parking.

Vehicles that are legitimately broken down on the ramps or shoulders are handled in a similar fashion in all the states contacted. The vehicle is tagged or marked in some manner and towed from the scene after a prescribed period of time. California allows 4 hours for the removal of breakdowns, and West Virginia allows 6 hours. The remaining states allow "a reasonable amount of time" for the removal of the vehicle, after which it is towed.

Each of the states has a policy to discourage parking on ramps and shoulders of interstate highways, which is reinforced by specific statutes. This includes issuing citations for illegal parking and requiring the driver to move the vehicle off the ramp or shoulder. The actual operating situation is somewhat different. All states indicated that enforcement is at the discretion of the law enforcement officer. In general, citations are not issued unless the area is clearly posted as "No Parking." Whether the driver of a stopped vehicle is directed to move on also remains at the discretion of the officer. Although all the states have specific statutes relating to parking, it is not uncommon for law enforcement officers to issue a citation for "Failure to Obey a Traffic Sign" instead of citing the appropriate parking statute.

Factors Contributing to Rear-End and SVRD Crashes

Psychological and Perceptual Factors in the Literature

Driver Inattention

Traffic crashes are relatively low-probability events that result from the interaction of many factors, including highway geometry, traffic control, pavement condition, weather, visibility, vehicle condition, roadside and in-vehicle safety equipment, and driver error, to name just a few. All of these factors can come together to create the potential for a crash, although they do not ensure that a crash will occur. The first, and usually the hardest, question asked in terms of any particular crash is: Why did this happen? In relation to rear-end crashes, the most common causal factor noted in the police accident reports included in the crash analysis previously described was driver error and in particular, driver inattention (63%). This factor and others were described in the literature.

Several aspects of what is called inattention could contribute to involvement in crashes:

- *Lack of Vigilance.* In the human factors literature, *vigilance* is defined as the prolonged ability to detect particular environmental signals. In cases of over-learned tasks such as driving, drivers often feel comfortable devoting less than full attention (Readinger et al., 2002) and to some degree may operate in "automatic pilot." Driving on highways without traffic controls (such as stop signs and traffic lights) or driving on familiar roadways often seems to drivers to make fewer demands on them, and they devote less attention to the driving task than they would under different circumstances. This lower level of vigilance leaves them vulnerable when something out of the ordinary occurs.

- *Driver Distraction.* As opposed to lack of vigilance, distracted drivers are paying attention, but their attention is distracted away from the roadway ahead where the hazardous situation is being created. This distraction may be physical, as when a driver "rubbernecks" when passing a traffic crash, or mental, as when a driver is talking on a cellular telephone and not processing the information in his or her visual field.

- *Steering Toward a Target.* In this form of selective attention, drivers will often steer in the direction of objects at which they are looking. Small deviations in the drivers' direction of gaze can lead to significant impairments in their ability to drive a straight course (Readinger et al., 2002). If the driver's gaze remains on the object, as it would if the object or scene were ambiguous, or if the driver needed more information to interpret the situation, then it would be possible for the driver to steer into the object, as was the situation in Case Study 3 of the CIT investigations. Readinger et al. (2002) noted that drivers who are admonished to "look where you're going" should take that advice, because in most cases, they will "go where they're looking."

- *Insufficient Visibility or Too Few Visual Cues.* Drivers may be looking directly at the target vehicle or the hazardous situation but not see it because it is physically impossible to do so. They may also see all or a portion of the situation but not have sufficient visual cues to be able to assess their danger of collision. In the case of underride crashes, they may see the large truck as moving in their lane of travel rather than on the shoulder, and they may misjudge the truck's speed or their own closing speed or distance in relation to the truck.

Driving is a complex multi-tasking activity that requires simultaneous processing of many visual and auditory cues. Level of attention and driving ability are affected by age, fatigue, some illnesses, and the use of alcohol or drugs. In a meta-analysis of 112 studies, NHTSA noted that drivers impaired by alcohol exhibited reduced vigilance and poorer performance in divided attention tasks at BACs of 0.039 and higher (NHTSA, 2001b). Older drivers tend to have longer in-vehicle "glance times," or the time it takes to see and process information before returning to a forward gaze. These age effects are generally due to deterioration of vision and slowing of cognitive processes (Wierwille, 1988). Overall vigilance is not necessarily reduced in older drivers, but vigilance is reduced when visual stimuli are degraded (Parasuraman and Giambra, 1992). In terms of illness, drivers with motion sickness can experience its earliest symptom, i.e., fatigue, long before they become nauseated.

Drivers impaired by alcohol/drugs, fatigue, illness, or in some instances age sometimes adopt a strategy to reduce the complexity of the driving task by restricting the number of stimuli they receive and the number of operations they must perform based on those stimuli. One such strategy is simply following the vehicle in front of them. An underride crash can occur if the impaired driver becomes aware of the vehicle's proximity too late to prevent the crash. (Interestingly, for these individuals, a lower visibility for the truck would probably result in fewer crashes.)

Sleep Deprivation

Sleep deprivation is endemic among Americans, with nearly one third of adults getting fewer than 6.5 hours of sleep per night, and two thirds getting less than the recommended 8 hours (Johnson, 1999). Among commercial drivers, 38% reported sleeping less than 4 hours on at least one night during the previous week, and 20% reported sleeping less than 6 hours before starting their current trip (Arnold et al., 1998). NHTSA estimated that at least 100,000 crashes per year are attributable to driver fatigue, representing 1.5% of all crashes and 4% of fatal crashes (Knipling et al., 1995). These figures are higher for freeways and interstates where attention demands are lower than on many primary and secondary roads. Fatigue may also contribute to one million crashes each year by increasing inattention, reducing perception-reaction time, and negatively affecting judgment (Charlton and Baas, 2001; Knipling, 1999).

Drivers of large trucks are more likely to be involved in fatigue-related crashes than are drivers of passenger cars due to their increased hours of exposure and the high percentage of nighttime hours they drive. However, according to the FMCSA (2000), when annual miles of travel are controlled, commercial and non-commercial drivers have similar fatigue-related crash rates.

Considering the prevalence of fatigue among commercial drivers and the relationship between fatigue and traffic crashes, the need for drivers of large trucks to be able to stop and rest as needed is apparent. At this point, the number of trucks stopping on shoulders, the amount of time they remain stopped, and percentage of stops due to fatigue is unknown.

Perceptual Factors Affecting the Visibility of Parked Trucks

Although vigilance, distraction, and steering toward an object are based on a driver's state of awareness, the fourth category, visibility, is based on the physical properties of the parked truck. Assuming that a driver is attentive while operating a motor vehicle, truck characteristics must be such that a driver is physically able to see the vehicle and correctly interpret its actions in relation to his or her vehicle. This section of the report discusses factors affecting the visibility of a stationary object such as a parked truck, drivers' determination of distance and speed, and how drivers determine time-to-collision.

- *Brightness:* the subjective experience related to visible light. Descriptions such as "dim" or "blinding" are subjective measures of brightness (Werner, 1994). The objective measurement of brightness is *luminance,* a measured quantity directly related to the power of the electromagnetic radiation emitted from a surface. At night, the luminance of a truck parked on the shoulder depends on the truck's lights and retroreflective tape.

- *Conspicuity:* the property of an object such that it is not only visible but also draws the attention of the observer and could be identified. This term differs from visibility in its cognitive characteristics. Whereas the visibility of an object depends highly on its brightness, the conspicuity depends on the color and brightness in relation to the color and brightness of the surrounding environment. An ant, for example, may be visible but not conspicuous when viewed in its colony because the surrounding ants make identifying a particular ant difficult. Conspicuity depends largely on the environment, whereas visibility does not.

In order to determine what safety measures are most likely to increase the visibility, conspicuity, and speed judgment information of a vehicle, it may be helpful to review some of the relevant literature on the perceptual and psychological phenomena that drivers encounter.

Brightness/Luminance

There is little doubt that increased luminance of objects correlates directly with improved reaction times to that object (Forbes, 1960; Plainis et al., 1999). Although an attempt to increase the luminance or visibility of an object will likely result in improved reaction times (up to some limit beyond which reaction times cannot be improved), the question remains as to what form this luminance should take and what other factors might increase reaction time. In addition, laboratory experiments that record reaction times where subjects are told to react may not apply to real driving conditions where not only visibility but also conspicuity are factors. *Conspicuity* includes the characteristics of an object such that it can attract one's attention in addition to being seen once pointed out. This is the role largely played by the retroreflective tape applications on trailers and semi-trailers.

In addition, vehicle color can affect brightness. It is important, during both daytime and nighttime conditions, that the vehicle color chosen for commercial vehicles reflect as much light as possible. The amount of light reflected from a vehicle distinguishes it from the generally dark or unlit background at night and makes it more visible at greater distances. Increased reflectivity results directly in an increase in luminance, which generally, if all other factors are kept constant, increases the sensation of brightness among observers, although this is not a one-to-one relationship (Werner, 1994). A National Bureau of Standards report (Howett et al., 1978) relating to emergency vehicle conspicuity indicates that light-colored vehicles are more visible at nighttime. Large trucks have something of an advantage over smaller vehicles in that as objects shrink, their colors become less distinct. Dark colors, such as blue, converge on black, whereas bright, desaturated colors, such as yellow, become whiter. Thus, truck colors may appear brighter than corresponding passenger vehicle colors, and light-colored trucks would be more visible than dark-colored ones.

Detection Size and Illumination

Plainis et al. (1997) noted that the size of the visual angle extending across an object plays a critical role in the detection of that object up to a certain critical visual angle. Objects extending across different visual angles were presented at different illuminations to different parts of the eye. As noted previously, when an object approaches the eye, there is an increase in the size of the angle of that object on the retina. The results show that for centrally located objects, the critical angle is 2 degrees, above which no additional detection advantages were noted. This means that an object extending across 10 degrees will require approximately as much luminance to be detected as an object extending across 2 degrees. For items smaller than 2 degrees of visual angle, however, the luminance must be higher as the angle decreases for the object to be detected. For a peripherally located object (30 degrees from center), the critical angle is 5 degrees of visual angle. For reference purposes, a car extends across 5 degrees of visual angle at 68 feet and 1 degree at 338 feet. If it is difficult to increase the luminance of an object, then increasing its size will also increase detection up to a certain limit. Conversely, if retinal image size cannot be adjusted, additional luminance will have the same effect (also noted by Olson et al., 1992). This would support the use of retroreflective tape to frame an outline on the rear of a semi-trailer either on the rear doors or on the cargo itself in the form of cargo tarps incorporating retroreflective material. Such an outline makes the retinal size of the trailer larger and thus increases the conspicuity at a distance.

The current federal trailer retroreflectivity requirements are largely a result of a NHTSA-sponsored study conducted by the University of Michigan Transportation Research Institute (Olson, 1992). This extensive research analyzed tractor-trailer data to determine whether conspicuity was a factor in a significant percentage of the accidents. Conspicuity was determined to be a significant factor in many two-vehicle accidents involving tractor-trailers.

There is evidence from studies cited by Ford, Richards, and Hungerford (1998) that increasing the horizontal and vertical vision angles of a retroreflective surface resulted in quicker detections of speed differential. The rates of angular expansion may be more easily noticed when the areas expanding are larger. This also lends support to the notion that outlining the rear of a trailer increases conspicuity at a distance.

There is widespread agreement on at least one fact: retroreflective tape *always* increases the detection distance and visibility of the treated surface (Ford et al., 1998; Hildebrand and Fullerton, 1997; Olson et al., 1992), except in fog (Hildebrand and Fullerton, 1997).

A recent report done for NHTSA (Morgan 2001) presented the results of a study to evaluate the effectiveness of retroreflective tape in enhancing the visibility of heavy trailers. The major finding was that retroreflective tape significantly reduces side and rear impacts into heavy trailers in the dark. Other findings and conclusions include:

- Retroreflective tape did not significantly reduce daylight crashes.
- Retroreflective tape is effective in both clear and rainy weather.
- Retroreflective tape is especially effective in preventing injury crashes.
- Retroreflective tape is more effective when the viewing driver is young.
- Dirty tape significantly diminished the overall effectiveness.

Perceptual Factors Affecting Determination of Distance and Speed

The human eye and brain perceive distance and speed in several ways. Distance can be perceived as a result of two main types of visual cues: monocular cues, those that can be used with only one eye, and binocular cues (Goldstein, 1999). The size of an image on the eye is measured in degrees, with 180 degrees being the maximum. Some of the most important depth cues are listed in Table 15.

Table 15. Factors Affecting Distance Perception

Depth Information	0-6 feet	6-100 feet	Above 100 feet
Occlusion	X	X	X
Relative size	X	X	X
Accommodation and convergence	X		
Motion	X	X	
Disparity	X	X	
Height		X	X
Atmospheric perspective			X

In truck underride situations, the most important distance discriminations are made prior to coming within 6 ft of the truck. The following describes the impact of each of the medium- and long-distance depth cues (as adapted from Goldstein, 1999):

- *Occlusion:* refers to the fact that if one object is in front of another, the closer object obstructs the view of the farther object. This cue does not indicate the absolute distance to an object, only which object is closer.

- *Relative Size:* refers to the fact that if two objects are the same size, the farthest one will have a smaller visual angle.

- *Motion:* in this case refers to two separate cues, motion parallax and accretion and deletion, which are available only when the observer is in motion.

  — *Motion parallax:* describes the apparent motion of objects as a person moves relative to them. Close objects appear to move quickly, whereas objects far away appear to move slowly or not at all. The classic example is when a person looks out the side window of a moving car; the street signs and guardrail move quickly past the visual field, whereas the trees and clouds in the background move more slowly.

  — *Accretion and deletion:* occurs when two surfaces are at different distances. As the observer moves closer and farther from two surfaces, the closer surface will appear to cover up and reveal, respectively, parts of the further surface.

- *Disparity:* a binocular cue that describes the difference between the images on the retinas of the two eyes. Because the eyes are in two locations, they receive two slightly different images of the world. How different these images are for particular objects depends on the observer's distance from the objects. Objects infinitely far away will have identical images on the retina.

- *Height:* refers to the fact that objects whose bases are closest to the horizon in an image appear furthest away. For example, trees whose bases are higher up in a painting are perceived to be farther away.

- *Atmospheric Perspective:* describes the effect of haziness on distance. An object that is very far away will appear fuzzier than a near object because the object is viewed through many particles of air that disperse the light slightly. A mountain in the distance, then, appears further away than a hill nearby in part because it appears less sharp.

Perception of Vehicle Speed in Relation to a Parked Truck

The judgment of distance depends on the cues described, but driving requires not only distance judgments but also speed judgments. This section examines how drivers make perceptual decisions regarding speed.

Many of the speed-related visual cues are related to the distance cues such that a change in the distance cue indicates some sort of movement. For example, if an object previously occluded becomes visible, this would indicate movement. In addition, the observer's movement can sometimes give the observer further clues regarding the distance of objects because when an observer moves, his or her image of the world changes.

Optic flow describes the movement of visual information past an observer as he or she moves. During driving, the "visual stimulus for a driver . . . is not a static optic array but an optic flow field, a continuously changing optic array" (Lee, 1976, p. 438). Lee and others (McLeod and Ross, 1983; Schiff and Detwiler, 1979) found that *the key information used by the visual system to determine the time-to-collision with an object is the rate of dilation of the retinal image.* This is also termed *the rate of angular expansion* (Goldstein, 1999). The relative movements of the points on an object as one approaches it are termed *optic flow.* Lee pointed out that noting the separation of any two points on an object and registering the rate at which the separation is increasing are sufficient to calculate the rate of dilation of the retinal image and the time-to-collision with an object. Figure 16 shows the principle of angular expansion and optic flow.

Judging the distance of a single light by the rate of angular expansion is difficult. The light is small and causes glare, making it hard to determine the actual size of the light itself. Judging the distance by the brightness of the light might seem reasonable, since the light will become brighter as one approaches it, but the distance to the light cannot be judged. If someone has no idea of the absolute brightness of a particular light, then judging that the light is getting brighter tells the person that the light is getting closer, but not how close. Multiple lights on a single object would provide several points of reference such that the rate of angular expansion could be calculated. The visual system needs constant information to calculate speed and time-to-collision.

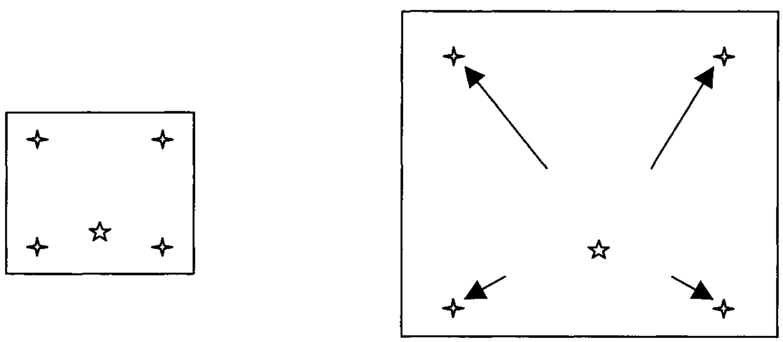

Figure 16. Illustration of Optic Flow: An Image Approaching the Observer

Perceptual Factors in Determining Time-to-collision

Drivers often find themselves on a collision course with another vehicle. This occurs whenever drivers are gaining on another vehicle in their lane or are approaching a vehicle that is stopped. One might suspect that in order to plan for the time of arrival, the perceptual system would have to compute the difference between the vehicles' speeds and the distance between them; however, this turns out not to be the case. In determining time to contact, there exists an optical variable, *tau*, which can be accurately predicted by drivers and does not require that the driver first determine object speed or distance.

Introduced by Lee (1974), *tau* relates the optical size of an object to its rate of expansion in a manner that specifies time to contact. *Tau* is defined as follows:

$$\text{tau} \approx \theta \,/\, \delta\theta/\delta t,$$

where θ is the angular expansion of the object in radians, and $\delta\theta/\delta t$ is the rate of its expansion. *Tau* specifies time to contact with vehicles under the assumption that they are moving with constant velocities. This relationship holds for approaching a parked vehicle so long as the velocity of the approaching vehicle is approximately constant.

To provide an example, suppose that a driver is approaching a parked vehicle and first notices it at a distance of 1,000 ft. As this distance is halved from 1,000 to 500 ft, the image size of the back of the parked vehicle will double. Halving the distance again from 500 to 250 ft will again double the image size. This progress will continue such that the image size of the parked vehicle doubles with every halving of the distance (Olson and Farber, 2002). Drivers make multiple determinations of time-to-collision as they approach a stationary object, such as a parked truck, without consciously determining speed and distance in relation to the object.

In ideal laboratory conditions, people are quite accurate in making time-to-contact judgments (Schiff and Oldak, 1990; Todd, 1981). Todd's data show relative time-to-contact judgments to be sensitive to less than 0.01-second time differences.

Factors Regarding Truck Parking

National Data

Forward impacts into parked vehicles comprise a significant portion of SVRD crashes. HJR 23 focuses attention on vehicles striking the rear of large trucks stopped on the shoulder. Six interstate highways, i.e., I-64, I-66, I-77, I-81, I-85, and I-95, pass through Virginia and provide considerable opportunity for large trucks to be stopped temporarily or parked on the shoulder, which in turn increases the possibility that these vehicles will be struck in an SVRD crash.

Substantial research has been conducted concerning large truck parking. It has been proposed that the increasing numbers of large trucks parked on the shoulders and ramps of interstate highways pose a significant safety hazard:

> When truck drivers are unable to locate available safe parking in a lot, they often unsafely park on the road shoulders of entrance and exit ramps and at highway interchanges. Parking illegally on the shoulders of entrance and exit ramps is not safe for several reasons. First, it limits the acceleration rate of the drivers who are parked on the exit ramp shoulder, creating the possibility that their trucks' speed may be significantly lower than that of the traffic on the main roadway. Second, it creates a dangerous dilemma between high-speed vehicles decelerating into or accelerating out of the public rest area. Finally, the shoulders are not protected from errant vehicles (National Transportation Safety Board, 2000).

A Tennessee study found that on a typical weekday night approximately 1,200 trucks were parked along 964 miles of interstate highways and that 40% of these were illegally parked on the shoulders of ramps and through lanes (Wegmann, Chatterjee, and Clarke, 1999). The study reported that observations of commercial truck stops during the same period indicated that 30% of private parking spaces were not used. The authors pointed out that trucks parked on the shoulders and ramps pose a risk to other traffic and accelerate the deterioration of shoulder pavement as a result of fuel and lubricant leaks.

A 1996 FHWA study of a 200-mile segment of I-81 from Radford, Virginia, to Knoxville, Tennessee, reported large numbers of trucks illegally parked on the ramps and shoulders of public rest areas even when there were empty spaces in the adjacent rest stop (FHWA, 1996). The study estimated that Virginia had a shortfall of 1,322 large truck parking spaces at public rest facilities and cited I-95 and I-81 as major corridors where a serious problem existed. This study found that many states are reluctant to enforce laws against parking on interstate shoulders and ramps because they prefer that truck drivers rest rather than create a moving hazard for motorists. A submission by the National Association of Truck Stop Operators (NATSO) to the FHWA in response to this study characterized the problem as one that could be solved by commercial truck stops if truck drivers planned their trips better (NTSB 2000). In fact, the lack of information available to truck drivers concerning parking availability is a recurring theme in large truck parking studies. A study done for NATSO concluded that increasing truck-parking capacity at public rest stops is an ineffective and inefficient method of addressing highway safety and reducing crash rates for heavy trucks (Egan and Corsi, 1999).

Two studies indicated that trucks were parked on the ramps and shoulders even though there were open spaces in the adjacent public rest area (FHWA, 1996) or in nearby private truck stops (Wegmann, Chatterjee, and Clarke, 1999). These studies also support the view that truck drivers, for whatever reason, do not view public and private parking places as completely interchangeable.

A 2002 report by the FHWA to Congress evaluated large truck parking resources on a state-by-state basis. The evaluation for Virginia indicated a shortage of parking spaces at public rest facilities but a surplus of commercial parking spaces and projected an annual increase in large truck parking demand of 1.4% each year for the next 20 years (FHWA, 2002). On a statewide basis the FHWA considers Virginia to be a "sufficient" state, meaning that statewide the supply of large truck parking spaces nearly meets the demand. It should be noted that the state-by-state evaluation was an overall look at truck parking and did not address the specific large truck-parking situation in any particular location. The report also detailed the future actions recommended by each state to address any parking shortfalls in their state identified in recent studies. Those attributed to Virginia include expanding public facilities, expanding private facilities, and improving information to truck drivers. Information supplied to the study team by VDOT indicates that two rest areas are under construction, one for a new building to replace the existing structure and one for utility improvements. In addition, three more rest area projects for utility improvements have been advertised. A recent study by Garber, Wang, and Charoenphol (2002) used I-81 in Virginia as a case study for developing a method to estimate the supply and demand for commercial truck parking. The authors found a shortage of parking for large trucks in both the public and private facilities along I-81.

Truck Parking Trends in Virginia

The study team planned to review conviction data for illegal parking convictions issued to commercial truck drivers on I-81 in Virginia from 1997 through 2001. Data for all motor vehicle convictions from 1998 through 2001 were received from the Virginia DMV. No conviction data for 1997 were available. Conviction data relating to parking and heavy truck safety statutes were extracted from the Virginia DMV material to construct the conviction information for 1998 through 2001 as presented in Table 16.

Unfortunately, the data compiled by the Virginia DMV do not indicate the issue location of the citation, and this prevented any further comparative use of the data. In addition, the number of convictions for commercial vehicles appeared to be low. Subsequent discussions with the VSP provided an answer for the low number of convictions. It is usual practice for law enforcement officers to issue citations for several parking offenses under COV § 46.2-830, Failure to Obey a Highway Sign. The Virginia DMV data were again analyzed for convictions under this section, and the results are presented in Table 16. The total number of convictions for this offense in 1998 through 2001 was 437,680, with commercial vehicle convictions of 3,143 representing 0.70% of the total. This number of convictions also appears low, given that commercial vehicles make up approximately 4% of registered vehicles nationwide and 6% of Virginia-registered vehicles, and it is unlikely that all the citations issued under this statute were for parking violations.

The statistics provided by the Virginia DMV might establish a pattern of information that could prove helpful in determining the Commonwealth's success in avoiding SVRD crashes into parked vehicles through current legislation. Nevertheless, if citations for illegal parking continue to be issued under "Failure to Obey a Highway Sign," accurate data classifying parking infractions will never be available. In addition, the statistical data represent only those individuals who were convicted and do not quantify those whose citations were dismissed, nor do they reflect the number of commercial vehicle operators who were given verbal warnings instead of a citation. A directed effort by law enforcement officers to issue citations under the best descriptive statute would provide an accurate means to evaluate the current situation.

Table 16. Number of Convictions in Virginia for Illegal Parking by Statute for 1998-2001

Section of the Code of Virginia	Commercial Vehicle	Total Convictions	% Of Total
46.2-111 Failure to use proper warning device when vehicle disabled in highway	13	27	48.1
46.2-830 Failure to obey highway sign	3,143	437,680	0.7
46.2-888 Vehicle improperly stopped or parked on highway	402	12,292	3.3
46.2-1037 Vehicle parked or stopped on highway without lights at night or during low visibility	3	24	12.5
46.2-1040 Failure to use flashing signals when stopped on highway	50	124	40.3

Determination of Countermeasures

Roadway Solutions: Continuous Shoulder Rumble Strips

The use of rumble strips is targeted specifically at SVRD crashes and has proven to be effective in reducing SVRD crashes. Harwood (1993) reported that SVRD crashes can be reduced 20% systemwide and up to 70% on long, isolated sections of rural highways. Four recent studies (FHWA, 1998; Hickey, 1997; NYSDOT, 1998; Perrillo, 1998) credit rumble strips with reducing SVRD crashes from 34% to 70% during periods when vehicle miles traveled were increasing. The FHWA reports that 85% of states now use shoulder rumble strips as a countermeasure against SVRD crashes (Perrillo, 1998).

Chen (2001) analyzed the effectiveness of milled rumble strips at 25 sample sites, representing a total of 390 roadway miles of rural interstates in Virginia. A comparison of run off the road (ROTR) crashes before and after the installation of milled rumble strips showed that the application of the rumble strips:

- reduced fatal ROTR crashes by 42%
- reduced fatalities from ROTR crashes by 48%
- reduced injury ROTR crashes by 32%
- reduced injuries from ROTR crashes by 32%
- reduced property damage only ROTR crashes by 19%.

Chen concluded from the comparison that every 17 miles of milled rumble strips have saved one life and 22 crashes and estimated that Virginia's application has saved 52 lives and prevented 1,150 ROTR crashes since 1997.

VDOT, in response to a request by the General Assembly in Senate Bill 30 (2002), is engaged in an effort to report the progress of installing rumble strips on the shoulders of interstate and other limited access highways in Virginia. This effort also includes investigating other means to identify roadway shoulders clearly such as paint striping or alternative surface treatments.

Intelligent Transportation System Solutions: Vehicle Solutions

ITS applications that will warn a driver of possible danger include collision warning systems (CWS) and adaptive cruise control (ACC). CWS applications use various visual and audible signals to warn drivers that they must take appropriate action to prevent an impending crash. An ACC system detects slower traffic to the front and acts to decrease vehicle speed by reducing throttle and applying the brakes. However, these systems work within a specified range and any further vehicle speed reduction requires direct driver action.

NHTSA has for some time been involved in an effort to promote solutions for the reduction and mitigation of the major categories of vehicle crashes including rear-end crashes and SVRD crashes. Research and demonstration efforts are underway for radar-controlled rear-lighting systems, rear-end crash driver warning systems, and vehicle road departure avoidance systems that contain longitudinal and lateral components aimed at reducing SVRD crashes (USDOT, 1999).

Radar-Controlled Rear Lighting

Lee, Wierville, and Klauer (2001) described efforts funded by NHTSA to evaluate various rear lighting concepts and identify promising candidates for further consideration in a lighting optimization process. A trade study was used to identify which rear signaling concepts merited further research and testing. This involved the use of experts to develop criteria for judging each alternative and, in turn, use of the criteria to rank the alternative systems. The expert panel was asked to rate the lighting concepts and provide comments. The survey results were analyzed, and three concepts were recommended for further testing:

1. *Closed-loop, radar-activated high-intensity strobe lights.* For this concept, the vehicle would be fitted with rear-directed radar that would detect the range, range rate, and angle of the following vehicle. These variables would then be processed by a control system to determine when the four high-intensity strobe lights would be activated. The lights would be in a horizontal array of two pairs with a clear gap in the center between the pairs. When a vehicle following too closely activated the system, the inner strobes would flash first, followed by the outer strobes. This flash cycle would continue until the control system determined that there was no further danger.

2. *Closed-loop, radar-activated horizontal array of lights.* For this concept, the vehicle would be fitted with rear-directed radar that would detect the range, range rate, and angle of the following vehicle. These variables would then be processed by a control system to determine when a horizontal array of lights would be activated in a pattern that spread out from the center. The inside lights would activate first and then spread out to each outer edge of the display. Once all the lights were activated, they would turn off and the cycle would repeat until the system determined that there was no further danger.

3. *Open-loop horizontal array of lights activated by two levels of braking.* This concept uses the same horizontal array of lights as in the previous example, but is an open-loop system with no radar detection. When the driver applies the brakes, the horizontal array of lights is activated and stays on continuously, similar to a conventional brake light. If the driver puts additional force on the brake pedal and exceeds a predetermined limit, the horizontal array begins to cycle from the inside lights to both edges of the display. When the force on the brake pedal exceeds the system limit, the flashing array again becomes continuous and remains lit until the driver stops depressing the brake pedal.

These lighting concepts are undergoing further testing, and a report detailing the results is in preparation.

Rear-End Crash Warning System

This system tracks the forward motion of the equipped vehicle and is designed to warn drivers if the distance (headway) to a vehicle located to their front (lead vehicle) has decreased to an unsafe level. A graphical visual display and an audio signal provide the warning. As the equipped vehicle moves closer to the lead vehicle, the visual display increases in color and intensity until the headway has decreased to a critical point, at which time an audible warning is relayed to the driver.

General Motors and Delphi-Electronic Systems are working with other contractors to develop and test a prototype system consisting of a heads-up warning display, a forward vision sensor, and radar sensors all combined with an adaptive cruise control (NHTSA, 2002b).

Road Departure Crash Warning System

This system is a combination of longitudinal and lateral components working together to prevent road departure crashes.

The longitudinal component analyzes data concerning vehicle speed and acceleration, vehicle position, roadway geometry, pavement surface condition, and vehicle-specific characteristics to determine if the vehicle speed is unsafe for the forward section of roadway. When the system senses unsafe speed, it alerts the driver.

The lateral component warns when the vehicle is in danger of leaving the roadway. This is accomplished by collecting dynamic vehicle data and geometric data concerning the forward roadway with onboard sensors. The data are analyzed and processed to provide a probability that the vehicle position and orientation could result in a roadway departure. When the system encounters a probability high enough to indicate a possible crash, it issues a warning to the driver.

The University of Michigan Transportation Research Institute (2001) in partnership with Visteon Corp. and AssistWare Technology Inc. is developing a road departure system. Development will be followed by field tests in a fleet of 11 passenger vehicles. This effort is funded by the FHWA.

The systems discussed here will primarily be developed by the private sector. The USDOT sees its role as one of defining the specifications for on-board vehicle safety systems. USDOT is supporting research and development for generation 0, 1, and 2 systems, with each generation representing a higher level of capability and integration. Generation 0, 1, and 2 systems are expected to enter production planning in 2003, 2008, and 2012, respectively. The USDOT recognizes that the private sector has and will continue to produce products to address the problem areas without federally funded support (USDOT, 2000).

Adaptive Cruise Control

ACC is an extension of the conventional cruise control system familiar to most drivers. A conventional system maintains vehicle speed through a link to the vehicle's power train and accelerator, which regulates the speed at a level set by the driver. ACC adds several important components to the conventional system: (1) forward-looking radar to detect vehicles to the front, (2) an actuator to apply the vehicle's brakes, and (3) a control mechanism to allow the driver to select a comfortable headway. When the ACC is engaged, the radar scans to the front of the vehicle. If it detects a vehicle in the pre-determined distance, the system reduces the throttle and, if necessary, applies the brakes until the system senses that the lane to the front is again clear. Once the radar determines that the lane is clear, the system returns to the speed set by the driver. Some newer ACC applications also warn the driver with an audible tone that further application of the brakes is necessary (NHTSA, 2002b).

A recent Special Investigation Report pointed out that ACC and rear-end collision warning system technology is available commercially and has been for some time (NTSB, 2001). In Japan and Europe, ACC systems have been offered on luxury model passenger cars since 1997 and 2000, respectively. In 2001, Mercedes Benz and Lexus were the first to offer ACC systems on passenger cars in the United States. Heavy truck manufacturers in the United States offer a collision warning system manufactured by Eaton Inc. as original equipment.

Intelligent Transportation Systems Solutions: Infrastructure Warning Systems

Infrastructure warning systems can use a multitude of technologies including variable message signs, cellular telephones, pagers, wireless e-mail, and highway advisory radio to provide drivers with timely information concerning traffic conditions. These systems could decrease the risk of rear-end crashes by warning drivers that traffic ahead is slowing or stopped.

Several examples of infrastructure systems are operating in Virginia, including 511 Virginia and Truck Fleet Support, an adjunct of 511 Virginia. 511 Virginia is part of the Commonwealth of Virginia Intelligent Transportation Systems Advanced Traveler Information Systems Project. It offers a toll-free service that provides travel information for users of Virginia's I-81 corridor. Information available currently includes real-time travel alerts, traffic conditions, food and lodging information, and travelers' services.

This system operates a central database maintained by the Virginia Tech Transportation Institute that continuously receives and updates information concerning weather, road conditions, and traffic conditions from the National Weather Service, VDOT, and the VSP. Travelers can access the information by toll-free telephone or Internet connection, and plans are to expand the delivery of information to changeable message signs and highway advisory radio on interstate routes and commercial or public radio stations.

Truck Fleet Support provides information and services for commercial vehicle drivers using the I-81 corridor:

- real-time travel alerts
- road and traffic conditions
- winter road conditions
- truck stop locations and services
- parking availability
- service locations
- oversize and overweight permitting
- all other information generally available through 511 Virginia

Information is made available to drivers and dispatchers 24 hours a day, 7 days a week, by automatic alerts using e-mail and pager alerts, an Internet site (www.truckfleetsupport.com), and toll-free telephone service.

An infrastructure-based ITS such as Truck Fleet Support operated under 511 Virginia could be expanded to include real-time information for truck drivers concerning the availability of public and private parking.

Countermeasures Concerning Illegal Parking of Large Trucks

Several studies (FHWA, 1996; FHWA, 2002; Wegmann, Chatterjee, and Clark, 1999) provide recommendations for addressing the parking situation for large trucks. In general, the recommendations fall within three categories:

1. *Expand or Modify Public Rest Areas*
    - Construct new public rest stops.
    - Open existing weigh stations to long-term truck parking.
    - Open Park-and-Ride facilities to large trucks during evening hours.
    - Modify existing public rest stops for drive-through truck parking.
    - Increase truck parking in rest areas during evening hours by reducing car-only areas.
    - Convert closed public rest areas into truck-only parking facilities.

2. *Expand or Improve Commercial Truck Stops*
    - Encourage local government and business support for commercial truck stop expansion.
    - Create public/private working groups to explore options for truck parking development.
    - Consider large truck parking requirements as part of the building permit process.

3. *Educate and Inform Drivers About Parking Supply*
    - Develop ITS applications to provide drivers with real time information about parking availability.
    - Produce and distribute maps correctly locating existing parking facilities.

Enforcement of Regulations on Ramp or Shoulder Parking

One issue voiced by the VSP deals with the inability to know how long a driver has been parked on a ramp or shoulder. The requirements for placing warning devices when a commercial motor vehicle is stopped on the traveled portion or shoulder of a highway are enumerated in 49 CFR 392.22. The warning devices must be placed as soon as possible, but in any event no later than 10 minutes after the truck is stopped. It has been suggested that local courts and law enforcement officers have rarely enforced CFR 392.22 as a result of vague legal language and the ambiguous position of USDOT (Truck Underride, 2002b).

Due to operating time constraints, law enforcement officers do not observe every parked truck for an extended period or return to a previous location to determine if the warning devices required by FMCSR are set out. In Europe, traffic police have an ally in this situation. Since 1985, all large trucks operating within the European Union must be fitted with a mechanical tachograph that records driving speed and time (European Union Council Regulations No. 3821/85). Such devices make it possible to determine how long a vehicle has been stopped. New European Union regulations expected to take effect in 2005 require the use of electronic digital tachographs that are much more tamper proof than the mechanical version and record large truck operating times within an accuracy of 1 minute (European Union Council Regulations No. 2135/98).

The required use of digital tachographs or some other electronic on-board recorder (EOBR) to provide vehicle-operating history is not under the FMVSS umbrella but is being considered. In May 2000, the Federal Motor Carrier Safety Administration (FMCSA) proposed that regulations concerning hours of service for drivers of commercial vehicles be revised. The proposed regulations would have required commercial vehicles used in long haul and regional operations to be equipped with an EOBR to monitor the drivers' hours of service. A subsequent bill in the U.S. House of Representatives (HR 1008, 2001) stopped any further activity on this proposed rulemaking:

> Neither the Secretary of Transportation nor the Administrator of the Federal Motor Carrier Safety Administration may take any action or use any funding to finalize, implement, or enforce the proposed rule entitled "Hours of Service of Drivers" published by the Federal Motor Carrier Safety Administration in the Federal Register on May 2, 2000 (65 Fed. Reg. 25539 et seq. and Docket No. FMCSA 97-2350-953) and issued under the authority delegated to the Administrator under section 113 of title 49, United States Code.

These recorders could also provide an electronic indication of how long a vehicle has been stopped and thereby provide law enforcement officers with a method to determine if warning devices should have been set out as required by FMCSR.

Absent FMVSS inclusion, a requirement for commercial vehicles in Virginia to be equipped with an EOBR would not be successfully challenged based on federal preemption regarding FMVSS. However, it is possible that a successful challenge could be raised under the Interstate Commerce clause of the U.S. Constitution.

Several manufacturers produce digital tachographs that could provide information concerning how long a vehicle has been stopped. The initial cost of these units varies from $300 to $500 and does not include installation or annual maintenance expense. The FMCSA presents an analysis of the costs associated with an EOBR in the proposed rulemaking and uses $1,000 for initial cost and $100 for annual maintenance. However, later in the proposed rulemaking, the FMCSA clearly states that an "EOBR will cost the average small long haul motor carrier $2850 to purchase and $282 annually to maintain" (*Federal Register,* 2000).

An additional possibility for determining how long a truck is stopped is the use of data collected by the electronic engine control systems. These systems control various aspects of the engine combustion process such as pressurization of the fuel, injection of the fuel, and timing. Their use by manufacturers of heavy-duty diesel engines became standard practice in 1994. This was followed in 1998 by controls for all medium-duty engines. This was not an attempt on the part of engine manufacturers to collect operating data from the vehicles but rather a means to meet emission standards for heavy and medium duty engines. The previous mechanical control systems for fuel injection did not allow for the precise adjustments necessary for the engines to meet clean air standards. A wide range of data elements are captured by electronic engine controls, depending on the engine manufacturer's design. However, these are proprietary systems, and each requires a unique set of testing equipment to read and collect data from the equipped vehicles. The possession and daily use of this type and amount of testing equipment would appear to be an unlikely scenario for any mobile law enforcement officer.

The major unanswered question concerning the collection and interpretation of data from any EOBR concerns the ownership of the stored data. Existing commercial operators who collect and analyze data stored in any number of EOBRs believe that the data are the sole property of the vehicle owner. NHTSA takes the position that the owner of the vehicle owns any data captured by an Event Data Recorder (NHTSA, 2001a). This is a type of EOBR installed by an original equipment manufacturer or by the vehicle owner and is used to collect vehicle and occupant-based crash information. Clearly, the FMCSA did not intend that the ownership of data should rest with the vehicle owner. If that were the case, a court order would be required every time an enforcement officer wanted to inspect the hours of service data. NHTSA's current position would seem to complicate the use of data collected by an EOBR monitoring hours of service for any other purpose without the vehicle owner's consent.

A bill introduced in 2001 to the California Senate but not adopted provides an example. Senate Bill 1048 (Appendix D) introduced on February 23, 2001, by Senator Jackie Speier would have required commercial vehicles with a gross vehicle weight over 26,000 pounds and registered in California to be equipped with an EOBR to monitor the driver's hours of service. However, the bill specifically prevented the use of the data collected for any purpose other than to monitor hours of service. To date, no clear legal precedent has been established concerning the data collected in an EOBR.

Enforcement of Other Statutes and New Legislation

The federal regulations concerning commercial vehicles parked along the roadway rest predominantly upon the requirement that "whenever a commercial motor vehicle is stopped upon the traveled portion of a highway or the shoulder of a highway for any cause other than necessary traffic stops, the driver . . . shall immediately activate hazard lights" (49 CFR 392.22(a)). These hazard lights are to remain activated until the driver deploys warning devices such as flares or reflective triangles. This deployment must occur within 10 minutes of stopping. Virginia has similar legislation (COV § 46.2-111) but mandates deployment of those devices only when the vehicle is disabled on the roadway. This does not cover any vehicle, disabled or roadworthy, stopped on the shoulder. Virginia's legislation could be changed to include vehicles stopped on the shoulder that are not disabled.

The Commonwealth may want to require that its own commercial vehicles be equipped with improved safety devices, ranging from the digital tachograph to additional lighting and conspicuity treatments.

Further, the Commonwealth may want to attempt to convince USDOT to change the FMVSS to include increased safety requirements in areas such as conspicuity and rear-impact guards for prevention of underride in rear-end crashes.

FINDINGS AND CONCLUSIONS

Legal Review

- Virginia may not modify any provision of the Federal Motor Vehicle Safety Standards in its attempts to reduce rear-end or SVRD crashes. However, the Commonwealth may set standards for state-owned vehicles and may work to ensure that federal standards and regulations concerning commercial vehicles are fully enforced.

- Since truck-parking citations are rarely issued under the statute dealing specifically with that infraction, it is difficult to assess the extent of illegal large truck parking or its level of enforcement in Virginia.

- Although the mandatory use of electronic on-board recorders would allow law enforcement officers to determine how long a truck had been parked on the roadside, this has not been successfully legislated in any state and would likely be constitutionally challenged if enacted in Virginia.

Magnitude and Severity of the Crash Problem in Virginia

- The percentages of on-road LVS rear-end and off-road SVRD crashes in Virginia are similar to those of other states and nationwide. However, Virginia has a higher percentage of fatal SVRD crashes than nationwide.

- On-road LVS rear-end crashes involving a passenger vehicle striking the rear of a large truck are rare and represent less than 0.25% of the total Virginia crashes analyzed and 0.40% of total fatal crashes.

- Off-road SVRD crashes involving a passenger vehicle striking a large truck stopped on the shoulder are also rare and represent 0.002% of the total Virginia crashes analyzed and 0.10% of the total fatal crashes.

- The LVS rear-end crashes are more numerous, but the SVRD crashes are more severe.

- In LVS rear-end crashes, straight trucks are struck by passenger vehicles more often than are tractor-trailer combinations. All straight trucks registered in Virginia are exempt from being equipped with a rear-impact guard meeting the requirements of FMVSS 224. In comparison, this study estimates that 30% to 40% of Virginia-registered semi-trailers are not equipped with a rear-impact guard meeting the requirements of FMVSS 224.

- SVRD crashes into parked vehicles are routinely coded as "rear end" instead of "fixed object off road," with the struck vehicle maneuver coded as "other" instead of "parked vehicle." This suggests confusion on the part of reporting officers where a vehicle on the shoulder is struck. This is likely due to the infrequent nature of this type of crash.

- The current Virginia crash reporting system is inadequate for capturing underride involvement data. The *Police Officer's Instruction Manual for Investigating Traffic Accidents* contains no mention of underride or how it should be addressed. The FR 300 does not provide a means to code underride directly.

- Virginia has under reported underride crashes to FARS in the past, but they are rare by all indicators. The review of the FR 300 reports for fatal crashes identified six crashes involving underride that represented additional crashes involving underride in 3 of the 5 years reviewed.

- Interviews with selected officials in surrounding states indicate that Virginia's neighboring states do not consider underride crashes on the roadway and shoulder to be a major problem. These crashes tend to be serious, but the limited number of occurrences does not warrant priority treatment.

Factors Causing and Contributing to Crashes

- The most common cause of rear-end crashes is driver inattention. However, this term is so general that it is difficult to design countermeasures to increase attention. Inattention may be affected by lack of vigilance, driver distraction, steering toward a target, insufficient visibility or misjudged visual cues, alcohol impairment, fatigue, illness, and effects attributable to age.

- Because of their size and unique profile, it is likely that parked trucks are brighter and more conspicuous than other parked vehicles, making them more visible to passing motorists. However, they are still struck in the rear by other vehicles even in daylight and clear weather. To prevent SVRD crashes into trucks parked on the shoulders, the trucks must be moved from the shoulders as quickly as possible.

- The practice of large truck parking on the ramps and shoulders of roadways is documented to be widespread in other states and the focus of concern for both motorists and transportation officials alike. This practice continues, in spite of federal and state regulations that expressly prohibit such activity, mainly due to a shortage of large truck parking spaces in public rest areas.

- Each of Virginia's neighboring states has an official position to discourage parking on ramps and shoulders by statute and enforcement. However, in each state, implementation of parking policy is left to the discretion of the law enforcement officer at the scene.

- The position of the commercial truck stop industry is that private truck stops offer an adequate supply of parking spaces to meet current demand but truck drivers do not plan well enough to use them.

- A common finding in large truck parking studies is that there is a lack of information available to truck drivers about alternative parking in locations where the demand for public rest area parking purportedly exceeds the supply.

- In-depth crash investigations were conducted by Virginia's Crash Investigation Team. The rear-end and SVRD crashes that they studied involving large trucks as the struck vehicle were often associated with driver inattention, driver impairment (fatigue/medications), and failure to activate appropriate lighting on the struck vehicle.

Countermeasures

- Two of Virginia's neighboring states have taken direct action to confront the issue of inadequate large truck parking spaces in public rest areas. Maryland uses information signs at rest areas indicating the location of additional parking for commercial vehicles, and Kentucky opens weigh stations 24 hours a day for commercial vehicle parking. Virginia could investigate implementing such actions.

- It is necessary to increase driver vigilance and make drivers aware that a parked truck may constitute a danger to them, requiring a higher level of attention. Two known methods to alert drivers are the use of rumble strips and reflective objects. Research should be expanded to identify other methods that may promote driver vigilance. Rumble strips have decreased SVRD crashes from 34% to 70% on the sections of roadway investigated. In Virginia, their use is estimated to have saved 52 lives and prevented 1,150 SVRD crashes since 1997.

- NHTSA is investigating improved rear lighting systems for passenger vehicles that could be adapted for large commercial vehicles if the tests prove successful. However, any such improvement would be strictly controlled by NHTSA under FMVSS 108.

- ITS countermeasures including collision warning systems and adaptive cruise control have considerable potential but are not expected to be widely implemented for some time. The former will not be available in passenger vehicles before 2008, and the latter is available now but only in particular luxury passenger vehicles.

- Infrastructure warning systems such as 511 Virginia provide real-time information. This approach could be expanded to include information about the availability of large truck parking facilities.

Issues for Further Research

- A substantial number of Virginia crash records have unrecorded data elements for SVRD crashes into parked vehicles. This resulted in a very small sample for these crashes.

- The crash record sometimes provides inexact information specifying the cause of the crash, making it difficult to formulate effective countermeasures.

- The extent to which large trucks park on ramps and shoulders in Virginia has not been documented.

- The FHWA has reported that Virginia has a shortage of parking spaces for large trucks in public rest areas and a surplus in private truck stops. The situation at any given location in Virginia could be considerably different. A detailed statewide assessment has not been undertaken.

- VDOT is engaged in an effort to report on the progress of installing rumble strips in Virginia to the General Assembly. This will include a review of other means to clearly identify roadway shoulders, such as paint striping or alternative surface treatments.

RECOMMENDATIONS

Countermeasures Involving Federal and State Regulations

1. *The Commonwealth should amend COV 46.2-111 (Flares and Other Signals Relating to Disabled Vehicles) so that it applies to both disabled and roadworthy vehicles on any roadway and the shoulders of any roadway.* Appendix B provides suggested wording.

2. *The Commonwealth should strictly enforce all state regulations and Federal Motor Carrier Safety Regulations enumerated in 49 CFR, Parts 390 through 397 (included by reference in 19 VAC 30-20-80).*

3. *If COV 46.2-111 is amended, enforcement officials should issue all citations for illegal truck parking on the shoulder under the new violation if it applies.* CRF 392.22 restricts truck parking on ramps and shoulders, but it is difficult to determine how completely this regulation is enforced since a large number of truck parking citations are combined with citations in the category of "failure to obey a highway sign."

Countermeasures Involving Large Truck Parking

4. *Since the number of truck parking places in public rest areas on I-81 is insufficient to meet the demand according to FHWA (2002) and Garber et al. (2002), VDOT should develop in conjunction with Truck Fleet Support and 511 Virginia a pilot application for a real-time information system designed to track the number of nearby commercial parking spaces available and make this information available to truckers, either in vehicle, at the rest areas, or on interactive highway signs.*

5. *The Virginia DMV should investigate the feasibility of opening Virginia's weigh stations for truck parking 24 hours a day.*

Issues Involving Accident Reporting

6. *The Virginia DMV and the interagency group amending the FR 300 report form should consider making provisions to include underride information in the new report form and coordinate the coding of SVRD and on-road rear-end crashes to improve the consistency of data collection.*

7. *To improve the quality of crash data captured by the FR 300, enforcement officials should receive more training on accident reporting procedures focusing on SVRD crashes and underride* involvement. Further, the *Police Officer's Instruction Manual for Investigating Traffic Accidents* should be modified to provide additional information concerning SVRD crashes and underride involvement.

Issues for Further Research

8. *An investigation of Virginia's existing crash database should be undertaken to determine the precision and reliability of the data elements and to allow recommendations for amended coding procedures.*

9. *To gain a more accurate picture of the number of commercial motor vehicles illegally parked, a study should be conducted to determine the extent of large truck parking on ramps and shoulders of Virginia's limited access highways.* Such a study might also help focus law enforcement efforts and indicate areas where the Commonwealth might want to target enforcement efforts.

10. *A feasibility study should be conducted on methods (other than rumble strips) to clearly identify shoulders, including their cost-effectiveness.*

11. *A statewide study should be conducted to assess the adequacy of large truck parking spaces in Virginia and to prioritize locations with the greatest need for public and private development.*

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APPENDIX A

HOUSE JOINT RESOLUTION NO. 23

Requesting the Crash Investigation Team of Virginia Commonwealth University's Transportation Safety Training Center and the Virginia Transportation Research Council to study ways to reduce the number and severity of highway accidents involving trucks and other large vehicles stopped on the roadway or shoulder.

Agreed to by the House of Delegates, February 12, 2002
Agreed to by the Senate, March 5, 2002

WHEREAS, year after year, motor vehicle crash statistics for Virginia and other states as well, show that an alarming number of crashes occur when drivers of other vehicles on the highway mistake trucks and other large vehicles that are stopped either on the roadway or on the shoulder of the highway for moving vehicles and collide with them, sometimes at considerable speed, and often with tragic consequences; and

WHEREAS, if it could be determined what spatial perception factors, physiological elements, and psychological ingredients combine to cause or materially contribute to this dangerous and often deadly misperception, many lives and even more injuries could be avoided and property damage reduced; and

WHEREAS, two entities in Virginia, the Crash Investigation Team of Virginia Commonwealth University's Transportation Safety Training Center and the Virginia Transportation Research Council have years of experience and a wealth of training and skills that may be able to afford valuable insights into how and why crashes of this type happen and make useful and practical recommendations as to how their number and severity may be reduced; now, therefore, be it

RESOLVED by the House of Delegates, the Senate concurring, That the Crash Investigation Team of Virginia Commonwealth University's Transportation Safety Training Center and the Virginia Transportation Research Council be requested to study ways to reduce the number and severity of highway accidents involving trucks and other large vehicles stopped on the roadway or shoulder.

All agencies of the Commonwealth shall provide assistance to this study, upon request.
The Crash Investigation Team and the Transportation Research Council shall complete their work by November 30, 2002, and shall submit their findings and recommendations to the Governor and the 2003 Session of the General Assembly as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents.

APPENDIX B

PROPOSED AMENDMENT TO CODE OF VIRGINIA § 46.2-111.

§ 46.2-111. Flares and other signals relating to ~~disabled~~ *stopped* vehicles.

A. Whenever any bus, truck, trailer, house trailer, or manufactured home is ~~disabled and stops~~ *stopped* on any roadway *or shoulder of any roadway* in the Commonwealth *at any time for any cause other than necessary traffic stops,* ~~except within the corporate limits of cities or on highways which are artificially lighted at night, at any time~~ ~~*unless*~~ ~~during~~ ~~*the time*~~ ~~which lights are required on motor vehicles by § 46.2-1030~~ the operator of such vehicle shall, *immediately activate the vehicular hazard warning signal flashers and as soon as possible, but in any event within 10 minutes of stopping,* place or cause to be placed on the roadway *or shoulder,* three red *reflectorized triangular warning devices* ~~flares or torches~~ of a type approved by the Superintendent. One of the *red reflectorized triangle warning devices* ~~flares or torches~~ shall be placed in the center of the lane of traffic *or shoulder* occupied by the ~~disabled~~ *stopped* vehicle and not less than 100 feet therefrom in the direction of traffic approaching in that lane, a second not less than 100 feet from such vehicle in the opposite direction and a third at the traffic side of such vehicle not closer than ten feet from its front or rear. However, if such vehicle is ~~disabled~~ *stopped* within 500 feet of a curve or crest of a hill, or other obstruction to view, the *red reflectorized triangle warning devices* ~~flares or torches~~ in that direction shall be so placed as to afford ample warning to other users of the highway, but in no case less than 500 feet from the ~~disabled~~ *stopped* vehicle. *Vehicular hazard warning signal flashers shall continue to flash until the operator has placed the three red reflectorized triangle warning devices required in this subsection. The placement of red reflectorized triangular warning devices is not required within the corporate limits of cities unless during the time which lights are required on motor vehicles by § 46.2-1030 the street or highway lighting is insufficient to make such vehicle clearly discernable at a distance of 500 feet to persons on the street or highway.* ~~Red reflectorized triangular warning devices~~ *Flares or torches* of a type approved by the Superintendent may be used in lieu of *red reflectorized triangular warning devices* ~~flares or torches~~. *In the event that the operator of the stopped vehicle elects to use flares or torches in lieu of red reflectorized triangle warning devices, the operator shall ensure that at least one flare or torch remains lighted at each of the prescribed locations as long as the vehicle is stopped.*

The exception provided in this subsection with respect to highways within the corporate limits of cities ~~or on streets or highways which are artificially lighted at night~~ shall not apply to any portion of any interstate highway within the corporate limits of any city.

B. If any such vehicle is used for the transportation of flammable liquids in bulk, whether loaded or empty, or for transporting inflammable gases, red *reflectorized triangle warning devices* ~~flares~~ or red electric lanterns of a type approved by the Superintendent of State Police shall be used. Such reflectors or lanterns shall be lighted and placed on the roadway in the manner provided in subsection A of this section.

~~C. During such time as lights on motor vehicles are not required, red flags not less than twelve inches both in length and width shall be used in the place of flares, torches, or lanterns. The flags shall be placed on the roadway in the manner prescribed in subsections A and B of this section for flares, torches, and lanterns, except that no flag shall be required to be placed at the side of~~

~~such vehicle. If the disablement of such vehicle continues into the period when lights on motor vehicles are required, flares, torches, reflectors, or lanterns shall be placed as required by~~ subsections ~~A and B of this section. Red reflectorized triangular warning devices of a type approved by the Superintendent may be used in lieu of flags.~~

APPENDIX C

QUESTIONS FOR SURVEY OF SELECTED STATES

Crashes

- Do you consider underride crashes a major problem in your state?
- Have you implemented countermeasures targeted at underride crashes?
- Do you consider crashes involving cars running into the rear of trucks on the shoulder a major problem in your state?
- Have you implemented countermeasures targeted at shoulder crashes?

Current Statutes

- Do you have any current statutes specifically targeted at underride crashes?
- Do you have any current statutes specifically targeted at shoulder crashes?
- Does your state enforce the Federal Motor Carrier Safety Regulations by statute or administrative regulation?
- Has your state ever considered requiring electronic on-board recorders for commercial vehicles?
- Is your state concerned that federal preemption regulations limit the improvement of commercial vehicle safety standards? If so, what steps has your state taken to address this?

Truck Parking

- What is your state policy concerning large truck parking on ramps?
- What is your state policy concerning large truck parking on shoulders?
- Is enforcement of large truck parking uniform throughout your state? Who does it and how effective is it?
- Does your state limit vehicle time in public rest stops?
- Does the law enforcement officer on the scene have complete discretion concerning large truck parking?

APPENDIX D

SEC. 5 OF PROPOSED CALIFORNIA SENATE BILL 1048

SEC. 5. Section 34501.25 is added to the Vehicle Code, to read:

34501.25. (a) On and after January 1, 2005, every motor carrier operating trucks or truck tractors set forth in subdivision (a), (b), (f), (g), (j), or (k) of Section 34500, that are registered in this state, shall require every driver of those vehicles to document drivers' hours of service using an automatic onboard recording device meeting requirements set forth in the regulations of the department. A vehicle that is used to operate solely within a 100-mile radius of its terminal or a vehicle whose primary function is the rendering of aid to, and removal of, disabled vehicles is not subject to the requirements of this section.

(b) This section shall not be construed to mean that compliance with the requirement to use the equipment establishes compliance with the drivers' hours of service requirements of this division or of the regulations of the department. If the software of an automatic onboard recording device miscalculates a driver's eligibility to continue driving, resulting in a violation of the hours of service regulations, the violation is not mitigated by the miscalculation. No driver, unless the driver is a motor carrier, shall be cited or otherwise held responsible for the failure of any onboard recording device to be maintained in accordance with this section.

(c) Motor carriers shall ensure that all drivers of their vehicles required by this section to be equipped with automatic onboard recorders are trained in the proper use of each model of recorder the driver will be required by the motor carrier to use, and that training is documented and retained on file at the carrier's office or terminal where the driver is based. Those records of training shall be presented to any authorized employee of the department for inspection upon request, and shall be retained with the driver's time records for as long as the driver is employed by the motor carrier, plus the amount of time that drivers' hours of service records are required to be kept on file by the regulations of the department. If a recording device is replaced with a different model requiring new training, the driver's training records relating to the replaced recorder model shall be retained at least until the last record it produced for that driver is no longer required to be on file.

(d) Motor carriers shall ensure that each driver is provided with the means to document his or her hours of service in the event of failure of an automatic recording device, as those means are set forth in the regulations of the department. Motor carriers shall make available to drivers, or their designated representatives, upon demand, a copy, free of charge, of the record of the automatic onboard recording device.

(e) Subdivision (a) shall apply only to vehicles with a gross vehicle weight rating of greater than 26,000 pounds, and to combinations of vehicles with a gross combination weight rating of greater than 26,000 pounds, except that it shall apply to truck tractors regardless of gross vehicle weight rating and whether or not a truck tractor is drawing another vehicle when operated upon the highway.

(f) The department shall by regulation establish standards for automatic onboard recording devices. The standards shall ensure that automatic onboard recording devices meet all of the following criteria:

(1) Operate without being activated.
(2) Operate at all times.
(3) Be readable at roadside by law enforcement personnel.
(4) Identify individual drivers.

(g) The information derived from an automatic onboard recording device may only be used by the department for hours of service enforcement.