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Heavy-Vehicle Crash Data Collection And Analysis to Characterize Rear and Side Underride and Front Override in Fatal Truck Crashes

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16. Abstract

This study was conducted by the University of Michigan Transportation Research Institute (UMTRI) to collect and analyze crash data on rear underride in fatal truck crashes, 2008-2009. The underride data was collected as a supplement to UMTRI's Trucks Involved in Fatal Accidents survey, which in turn supplements NHTSA's Fatality Analysis Reporting System file.

Data was collected on the rear geometry of the rear-most unit of all trucks involved in fatal crashes, 2008-2009. For all collisions in which the rear of the truck was struck, data was collected on the extent of underride, damage to the underride guard (if any), and whether the collision was offset.

In addition, two other tasks were accomplished: Impact speeds were estimated for fatal rear-end crashes by light vehicles where there was sufficient information; and the incidence of front override and side underride was estimated through a clinical review of all appropriate cases in the Large Truck Crash Causation Survey (LTCCS).

Overall, accounting for the rear geometry of the vehicles and exemptions for certain cargo body types, it is estimated that about 38 percent of straight trucks in the crashes were required to have underride guards, and about 66 percent of tractor/trailers were required to have them. Rear underride was noted in about 75 percent of rear-end struck crashes where the striking vehicle was a light vehicle. The underride was to the windshield or beyond in 36 percent of light-vehicle impacts. Vehicles with lower front geometry tended to experience more underride than vehicles with a higher front geometry. Offset impact was not associated with greater damage to the underride guard. There were 934 total fatalities to the occupants of vehicles that struck the rear of a truck. Considering light vehicles only, there were 724 fatalities in the crashes, and some underride occurred in 70 percent of the fatalities.

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Rear underride, side underride, front override, truck, fatal crashes	Document is available to the public from the National Technical Information Service www.ntis.gov

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Executive Summary

For crash years 2008 and 2009, the Trucks Involved in Fatal Accidents (TIFA) survey, conducted by the University of Michigan Transportation Research Institute (UMTRI), collected a set of information related to underride guards and rear underride in the crashes. The information covered two areas. The first area covered the physical dimensions of the rearmost unit of all the trucks in the crashes. For straight trucks, this is for the rear of the truck itself. For combination vehicles, the dimensions collected were for the back end of the last trailer in the combination. The information collected characterizes the physical structure of the rear of the vehicle, to determine the opportunity for underride. The second area covered information about the nature and extent of any underride that may have occurred in cases where the rear of the truck was struck in the crash.

In addition, two other tasks were accomplished. The first additional task was to estimate impact speeds for fatal rear-end crashes by light vehicles where there was sufficient information. The data collected here includes estimated relative velocity, the mass of the striking vehicle, and the front geometry of the striking vehicle. These data were collected for crashes in 2008 and 2009.

In the second additional task, the incidence of front override and side underride was estimated through a clinical review of all appropriate cases in the Large Truck Crash Causation Survey (LTCCS). LTCCS material including scene diagrams, the researcher's narrative, and photographs of the involved vehicles were used to estimate override/underride, passenger compartment intrusion (PCI), and other dimensions related to frontal and side impacts of trucks with light vehicles.

This report provides results from all three of these activities. It includes:

- A discussion of existing underride guard standards;
- A description of the survey methodology and data collected;
- Results of the survey of rear underride, providing detailed descriptions of the rear dimensions of trucks involved in fatal crashes in 2008 and 2009;
- A description of the outcomes of rear-end crashes in which the truck was struck, including the incidence of rear underride, the extent of underride, offset impacts, and counts of the fatalities and injuries that occurred in the striking vehicle;
- Estimates of impact speeds and collision energies in light-vehicle rear-end fatal crashes with trucks;
- A description of the front dimensions of light vehicles that struck the rear of a truck in fatal crashes; and
- Results of a clinical review of truck crashes in the LTCCS in which the front or side of a truck was struck by a light vehicle.

Underride guards on medium and heavy trucks are governed by two standards in the United States. The first standard was issued in 1953 by the Bureau of Motor Carriers, and applied to motor vehicles manufactured after December 31, 1952, covering straight trucks and trailers. The rule required underride guards with a minimum guard height of 30 inches from the ground, on trucks with cargo beds 30 or more inches off the ground and rear tires 24 or more inches from the rear of the cargo bed. Certain vehicle/body types were exempted. The underride guard standard for trailers and semitrailers was updated and strengthened in 1998. Guard height was lowered to 22 inches, and the wheel setback dimension was shortened to 12 inches. Strength and testing standards were also added.

For the present project, rear underride data was collected as a supplement to UMTRI's TIFA survey, by means of a telephone survey. Interviewers used the same respondents, identified from police reports, as for the main TIFA data. Data collected included rear overhang, cargo bed height, the presence of an underride guard, and if the truck was struck in the rear, whether there was underride and how far the vehicle underrode the truck. Impact speeds and the relative velocity in rear impacts was estimated from travel speed, skid distance, and angle of impact, using information from police reports, including scene diagrams, police narratives, and crash reconstructions, where available. Data on front and side override/underride was collected in a clinical review of case materials from the Large Truck Crash Causation Study (LTCCS), including scene diagrams, researchers' narratives, and photographs of the scene and the vehicles.

Characterization of trucks in fatal crashes relative to underride guards

The number of trucks involved in fatal crashes decreased from 4,202 in 2008 to 3,321 in 2009, a decline of over 20 percent in just one year. This decrease was probably largely related to the economic recession in the period. Straight trucks accounted for 28.7 percent of the trucks, while tractor/trailer(s) accounted for 62.7 percent, and straight trucks pulling a trailer accounted for 4.3 percent. (As used here, tractor/trailers include tractor-semitrailers, tractors with two trailers [doubles], and tractors with three trailers [triples].) Only 1.7 percent of the trucks were bobtail tractors (truck-tractors operating not pulling a trailer), and other truck configurations accounted for 2.6 percent.

About 55.4 percent of the trucks involved in fatal crashes from 2008-2009, were reported with rear underride guards. The presence of a guard could not be determined for 11.2 percent of the trucks. If it is assumed that guard presence in the unknown cases is distributed in the same way as where guard presence is known, an estimated 62 percent of trucks in fatal crashes had underride guards.

Tractor/trailer combinations are much more likely to have rear underride guards than straight trucks. Almost 77 percent of tractor/trailer combinations were reported with underride guards, compared with only about 23.4 percent of straight trucks with no trailer. Reported guard heights—the vertical distance from the ground to the bottom of the guard—were somewhat surprising. Overall, mean and median guard heights were 21.1 and 20 inches, respectively. These are actually lower than the 1998 standard's 22-inch requirement for guards on trailers. Straight trucks are still governed under the 30-inch standard established in 1953, but reported guard heights for straight trucks were effectively identical to those for tractor/trailer combinations. This finding is reasonably compatible with previous work.

Classifying the trucks by whether the 1953 or the 1998 standard applied was challenging because knowledge of trailer year of manufacture is needed. Trailer year was not collected in the 2008 supplemental data and could not be determined for about a quarter of the trailers in the 2009 data collection. However, two different analyses showed that about three-quarters of the trailers with unknown manufacture year probably fell under the 1998 standard.

Table 14 shows the results of classifying the trucks involved in fatal crashes by the appropriate standard: the 1953 rule for straight trucks; the 1953 or 1998 for trucks with trailers, depending on year of manufacture; or the 1998 rule for trailers where year is unknown. Trucks with insufficient data to classify were excluded from the calculations of the percentages. An estimated 55.2 percent of the trucks in fatal crashes, from 2008-2009, were required to have underride guards. For those not required to have guards, the most common reason was that the rear axle is set back far enough to meet the wheels-back exemption. Only about 37.9 percent of straight trucks were required to have guards, but almost two-thirds (66.4%) of tractor/trailer combinations were required to have guards. Only about 4.2 percent of trucks of all configurations met the cargo bed exemption, and only about 5.9 percent, mostly straight trucks, were exempt because of rear-mounted equipment.

Table ES-1. Percent Distribution of Rear Guard Status by Truck Configuration, Unknown Truck Configurations and Rear Dimensions Excluded, TIFA 2008-2009

Truck Configuration	Guard Required	Reason Guard Not Required:					Total
		Exempt Type	Low Bed	Wheels Back	Low Bed and Wheels Back	Equipment Below	
Row percentages							
Straight	37.9	8.3	8.6	27.0	1.9	16.4	100.0
Straight and Trailer	44.0	4.6	30.1	16.2	0.8	4.2	100.0
Bobtail	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Tractor/Trailer	66.4	5.4	0.5	26.4	0.1	1.2	100.0
Other	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Total	55.2	8.6	4.2	25.5	0.7	5.9	100.0

Truck underride in fatal rear-end crashes

From 2008-2009, 977 trucks were struck in the rear in fatal crashes. These 977 trucks represent 13 percent of all truck fatal involvements. Most of the striking vehicles in these fatal rear-end crashes were light vehicles—passenger cars, minivans, SUVs, and light duty pickups—but many were other trucks and motorcycles. Almost 18 percent of the striking vehicles in the rear-end crashes were other trucks, and 7.4 percent were motorcycles. Along with buses (negligible at 0.2%), 25.3 percent of the vehicles hitting the rear of a truck in a fatal rear-end crash were not the light vehicle types, which the underride guard standards were designed to protect. However, since the standard is directed at light vehicles, the results in this section focus on the underride of light vehicles.

At least some underride occurred in about 75 percent of rear-end crashes involving light vehicles. In about 18.3 perent of the crashes, the underride was less than halfway up the hood of the striking vehicle, but in over half the crashes, the striking vehicle underrode the truck past the halfway point of the hood, and in almost 36 percent, the underride went into the light vehicles' greenhouse (defined as the windshield, side windows, and rear windows of a light vehicles, along with the pillars that separate them). Tractor/trailer combinations exempted from the requirement to have an rear underride guard, either because of a low cargo bed or wheels-back axle configuration, experienced less underride than tractor/trailer combinations required to have a underride guard. Over 50 percent of light vehicles striking the latter group underrode the trailer to and past the windshield on the light vehicle, compared with only 17 percent of light vehicles hitting a tractor/trailer not required to have a guard.

In the 977 fatal involvements, 2008-2009, in which a vehicle struck the rear of a truck, there were 934 fatalities in the striking vehicle.[1] Light vehicle occupants accounted for 724 of the fatalities. Almost 500 of the light vehicle fatalities occurred with some underride. There was no underride for 150 of the fatalities. The proportion of fatalities that occurred with underride (70%) is about the same for tractor/trailer combinations and straight trucks.

Impact speed estimation

Impact speeds and relative speed of trucks and light vehicles at impact were estimated for 193 light vehicles that struck the rear of a truck in fatal crashes. The mean velocity of trucks at impact was estimated at 16.3 mph, but almost 41 percent were stopped at impact and 52 percent were estimated to be going 5 mph or less (including stopped). For striking vehicles, mean speed was 59.8 mph at impact, with a range of 15 mph to 110 mph. Relative velocity is more

[1] Counts are adjusted for cases where either the striking vehicle could not be identified with certainty or where there was no injury information for the occupants of the vehicles. This adjustment was done by assigning to those cases the average number of deaths and injuries across all vehicle types. The numbers in the tables are rounded to the nearest whole number.

meaningful in terms of impact however. Overall, the mean relative velocity at impact was estimated at 44.0 mph. About 32 percent of the impacts occurred at relative velocities less than 35 mph, and in 43 percent, the relative velocity was 40 mph or less. However, many impacts were at very high relative velocities, and probably not survivable. In over 25 percent of the cases, relative velocity was over 55 mph and in 13 percent it was more than 60 mph.

Estimates were also made for light vehicles where the front seat occupants used seat belts and the vehicle was equipped with front air bags. This set represents striking vehicles using currently available and required frontal impact protection. Results for this group were similar to those for the whole population of light vehicles for which impact speed estimates could be made. For trucks, the mean speed at impact was 18.1 mph, and for light vehicles, it was 61.1 mph. Relative velocity was estimated at 43.6 mph. About 34 percent of the impacts in this group were at 35 mph or less; about 44 percent of the relative velocities was 40 mph or less. On the other hand, about one-third of the impacts were greater than 50 mph, and 10 percent were greater than 60 mph. All these results are very similar to the earlier results for all striking light vehicles.

Available data was also used to calculate impact energies involved in light vehicle striking crashes. Impact energy may be considered more meaningful in evaluating underride guard standards because they account for differences in the masses of the striking vehicles. Estimates were made in kilojoules (kJ). Overall, the average impact energy was 354.4 kJ, with a range between 34.9kJ and 1,206.3kJ. Impacts up to 100kJ account for 17 percent of the cases, and impacts up to 200kJ account for 34 percent. Almost a third were over 400kJ.

Key front dimensions for the light vehicles in this analysis were extracted from a proprietary database. The dimension were the height of the front bumper top, height of the front hood top, height of the base of the windshield, and the length of the hood from the front bumper to the base of the windshield. Mean front bumper height for light vehicles was estimated at 23.6 inches, with a median of 22 inches, measured statically. For almost 51 percent of light vehicles in this set, the top of front bumper was at or below the bottom of the 1998 standard. Almost 95 percent are under the 1953 standard guard height. Mean and median hood lengths for the striking light vehicles are close to the mean and median rear cargo body overhangs on tractor/trailer combinations. About half of the light vehicles could underride half of the tractor/trailer combinations at least up to the base of the windshield before the front bumper of the light vehicle would encounter the rear face of trucks' rear tires.

Front and side underride in the LTCCS

LTCCS cases to review were selected based on the geometry of the crash. Cases were selected from crash types in which the front or side of a truck was struck. Only cases involving collision with a light vehicle were selected for review. Front and side override/underride was reviewed in a total of 411 crashes.

Overall, in front and side impact crashes, some underride was identified in 53.9 percent of the crashes, and passenger compartment intrusion (PCI) was coded in 44.2 percent. The rate of override/underride in side impacts is lower than the rate when the front of the truck is involved. There was some override/underride in 72 percent of front impacts, compared with 53.9 percent when the truck side is struck. Rates of light vehicle PCI are also lower in side impact crashes, with PCI identified in 65.4 percent of front impacts but only 48.5 percent of side impacts. Underride and PCI could not be determined in 7.9 percent and 7.3 percent of front and side impacts respectively.

Impacts to truck fronts and to the sides of trailers tended to result in override/underride at higher rates than impacts to the sides of truck cabs or straight truck cargo bodies. When the truck front was involved, there was identifiable override in 72 percent of the impacts. Similarly, impacts on trailer sides resulted in underride in 68.9 percent of the crashes. Side impacts to truck or tractor cabs resulted in underride in 43.5 percent of cases, and side impacts to the cargo body area of straight trucks resulted in underride in about 52.6 percent of such crashes. Front bumper height, cargo bed height, and whether the truck's axles were struck all were found to be related to the incidence of override/underride and PCI.

The review of LTCCS cases produced evidence that front override and side underride are a significant problem in serious crashes between heavy trucks and light vehicles. Front override and side underride were found in most of the crashes examined. Preliminary estimates from this review are that override occurs in almost three-quarters of crashes in which the front of the truck is involved, and in over half of the crashes when the sides of the trucks were struck. The results here are based on only a limited sample of serious crashes for which detailed investigations were available, but they clearly indicate that the safety problem of the geometrical mismatch between light vehicles and trucks as currently configured is significant.

Though preliminary, the results point to opportunities to address the damage from front and side impact crashes in some ways. Low front bumpers were associated with lower rates of override. Front axle set back may provide space for structures to help manage the energy in frontal collisions. With respect to side impacts, some crash geometries such as same direction sideswipes may be mitigated by side underride guards, if closing speeds are low enough to be managed by practical structures. Further research on these crashes may point to methods to reduce the damage in these crash types.

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List of Acronyms

Acronym	Full
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GVWR	Gross vehicle weight rating
kJ	Kilojoules
LTCCS	Large Truck Crash Causation Survey
Mph	Miles per hour
NHTSA	National Highway Traffic Safety Administration
PCI	Passenger compartment intrusion
TIFA	Trucks Involved in Fatal Accidents
TIN	Trailer identification number
UMTRI	University of Michigan Transportation Research Institute
VIN	Vehicle identification number

Heavy-Vehicle Crash Data Collection and Analysis to Characterize Rear and Side Underride and Front Override in Fatal Truck Crashes

1. Introduction

For crash years 2008 and 2009, the Trucks Involved in Fatal Accidents (TIFA) survey, conducted by the University of Michigan Transportation Research Institute (UMTRI), collected a set of information related to underride guards and rear underride in the crashes. The information covered two areas. The first area covered the physical dimensions of the rearmost unit of all the trucks in the crashes. For straight trucks, this is for the rear of the truck itself. For combination vehicles, the dimensions collected were for the back end of the last trailer in the combination. The information collected characterizes the physical structure of the rear of the vehicle, to determine the opportunity for underride. In cases where the rear of the truck was struck in the crash, data was collected about the nature and the extent of any underride that may have occurred.

In addition, two other tasks were accomplished: Impact speeds were estimated for fatal rear-end crashes by light vehicles where there was sufficient information. The data collected here includes estimated relative velocity, the mass of the striking vehicle, and the front geometry of the striking vehicle. These data were collected for both crash years, 2008 and 2009.

In the second task, the incidence of front override and side underride was estimated through a clinical review of all appropriate cases in the Large Truck Crash Causation Survey (LTCCS). LTCCS material including scene diagrams, the researcher's narrative, and photographs of the involved vehicles were used to estimate override/underride, passenger compartment intrusion (PCI), and other dimensions related to frontal and side impacts of trucks with light vehicles.

This report provides results from all three of these activities. It includes:

- Discussion of existing underride guard standards;
- A description of the survey methodology and data collected;
- Results of the survey of rear underride, providing detailed descriptions of the rear dimensions of trucks involved in fatal crashes in 2008 and 2009;

- A description of the outcomes of rear-end crashes in which the truck was struck, including the incidence of rear underride, the extent of underride, offset impacts, and counts of the fatalities and injuries that occurred in the striking vehicle;
- A description of the methodology used in estimating the speeds in light-vehicle impacts on the rears of trucks;
- Estimates of impact speeds and collision energies in light-vehicle rear-end fatal crashes with trucks;
- A description of the front dimensions of light vehicles that struck the rear of a truck in fatal crashes; and
- Results of a clinical review of truck crashes in the LTCCS in which the front or side of a truck was struck by a light vehicle.

1.1. U.S. underride guard standards

Underride guards on medium and heavy trucks are governed by two standards in the United States. The first standard was issued in 1953 by the Bureau of Motor Carriers, and applied to motor vehicles manufactured after December 31, 1952. This rule applied to straight trucks and trailers and is referred to in this report as the 1953 rule or 1953 standard. The underride guard standard was updated and strengthened in 1998 by a rule that covered trailers and semitrailers. This rule applied to trailers manufactured after January 26, 1998, and is referred to in this report as the 1998 rule or standard. Each rule is discussed in turn.

1.1.1. 1953 standard

The 1953 rule applied to both straight trucks and trailers. It required a rear underride guard on vehicles in which the vertical distance from the ground to the cargo bed was greater than 30 inches when the vehicle was empty. Certain vehicle types were exempted, including truck tractors, pole trailers, pulpwood trailers, and trucks in driveaway/towaway operations. In addition, vehicles in which the rear of the tires was less than 24 inches from the end of the cargo body (termed “wheels back”), trucks with cargo beds lower than 30 inches, and trucks with rear-mounted equipment that could provide rear-end protection comparable to a rear underride guard were also exempted. The only strength requirement was that the guard be substantially constructed, and attached by means of bolts or welding. The bottom of the guard must be no more than 30 inches from the ground, within 24 inches of the rear-most extremity of the cargo bed, and must extend within 18 inches of each side of the vehicle.[2]

[2] See 49 CFR 393.86(b)(1)

As stated, the 1953 rule applied to both straight trucks and trailers. Because the 1998 standard applies only to trailers and semitrailers, the 1953 standard continues to be the controlling rule on rear-impact protection for straight trucks. It also applies to trailers and semitrailers manufactured before January 26, 1998.

1.1.2. 1998 standard

The underride guard standard was updated for trailers and semitrailers in Federal Motor Vehicle Safety Standard (FMVSS) Nos. 223 and 224. The 1998 standard applies to trailers and semitrailers manufactured after January 26, 1998.

The 1998 standard modifies the 1953 standard in three ways. First, the cargo bed height standard was reduced from 30 inches to 22 inches. Second, the wheels back dimension was shortened from 24 inches to 12 inches. And finally, the guard height standard was lowered to 22 inches above the ground. In addition, required underride guard width was increased so that the guard must extend to within four inches of the sides of the truck. The 1998 trailer standard follows the logic of the 1953 standard by exempting certain trailers types, including pole trailers, pulpwood trailers, trailers with horizontal discharge (live-bed), special purpose vehicles, and cargo tank trailers with rear end protection conforming with 49 CFR part 178. Special purpose vehicles exempted are defined as those with work performing equipment mounted at the rear or trailers with loading platforms (e.g., liftgates) that deploy through the space where the underride guard would be mounted. FMVSS No. 223 provides strength and testing requirements and FMVSS No. 224 covers installation.[3]

[3] See 49 CFR 571.223, 224.

2. Survey of rear underride in fatal truck crashes, 2008-2009

2.1. Data collection

The underride data for this project were collected along with the 2008 and 2009 TIFA data collection. The TIFA survey covers all medium and heavy trucks (gross vehicle weight rating [GVWR] over 10,000 lbs.) involved in fatal traffic crashes in the United States. The TIFA data are collected by means of a telephone interview. It is important to note that the TIFA approach differs from many other telephone surveys in that it does not use a prescriptive survey script, in which scripted questions are asked and answers recorded. Instead, the TIFA process uses highly trained and knowledgeable interviewers to collect the data. The interviewers are trained in trucks and truck operations. They interview respondents until they fully understand the nature of the vehicle and its operations and can complete the survey form. Contacts with respondents are often highly interactive. All data collected is reviewed by an experienced editor, who may request call backs to clarify the data.

The TIFA survey methodology is as follows: Medium and heavy trucks are identified in the Fatality Analysis Reporting System (FARS) file, compiled by the National Highway Traffic Safety Administration (NHTSA). Police reports on each crash are acquired from the States. These police reports are used to identify and contact parties with direct knowledge of the truck as it was configured at the time of the fatal crash. Primary sources for this information are the driver of the truck, owner or operator of the truck, safety director, or any other party with direct knowledge of the truck configuration at the time of the crash. If all the data cannot be collected from primary sources, other sources may be contacted, including the reporting police officer, any other crash investigator, or other persons present at the scene, including tow operators and witnesses. Survey data encompass a detailed description of the configuration of the vehicle, including the type of power unit[4]; number, method of attachment, and type of each trailer; cargo body type and number of axles on each unit; and type of cargo on each unit. The survey also collects information about the operating authority, the type of trip at the time of the crash, driver hours at the time of the crash, and driver compensation for the trip. The TIFA survey has been operating continuously since the 1980 crash year, and provides a complete and detailed census of all medium and heavy trucks involved in fatal crashes.

[4] Power unit refers to the unit in a combination that is power, i.e., has the engine. There are two power unit types: a straight truck, which typically has a cargo body or other working body mounted to the same frame as the engine, and a tractor, which is designed to pull trailers and usually has no cargo-carrying capacity itself.

2.2. Method

The underride data was collected as a supplement to the TIFA data, so the collection method was a telephone survey. Interviewers used the same respondents as for the main TIFA data and attempted to complete the underride survey form. Each question was asked, along with any clarifying questions that might be needed. Interviewers typically noted any information that can help clarify responses on the forms themselves.

Each survey is reviewed by an experienced data editor. The editors examine each data element in the full context of the type of truck and trucking operation, to make sure the responses as a whole are coherent and consistent. Any cases that need clarification are returned to the interviewers for more calls. After another editor review, cases are keypunched and entered into a computer database where automated checks for consistency and outliers are applied.

2.3. Data elements

The underride data collection forms is provided in Appendix A. Certain questions were added to the 2009 data collection process. Data collected for both 2008 and 2009 includes:

- Rear overhang (back of tires to rear of cargo body);
- Cargo overhang (beyond the rear of the cargo body);
- Height of cargo bed;
- Underride guard presence;
- Underride guard height (if present);
- Width of underride guard;
- Presence of equipment mounted below the level of the cargo body;
- Description of the mounted equipment;
- Whether the rear of the truck was struck in the crash.

In cases where the rear plane of the truck was struck in the crash, interviewers asked a series of additional questions to determine whether there was underride or damage to the underride guard. These questions include:

- The level of damage to the underride guard;
- Whether the striking vehicle hit the rear tires of the truck combination;
- The extent of underride, captured in an ordinal variable;
- The extent of underride, estimated in inches.

In addition, case editors identified the specific striking vehicle so that information about that vehicle from the FARS record could be joined to the data collected. They also entered a code for the state of registration of the truck or trailer, if that could be determined, and recorded any comments about the nature of the crash or anything else that might be of interest. In the 2008 survey, the comment field was used to record whether the rear impact was "offset," defined as an impact to the outer third of the rear plane of the vehicle.

For the 2009 survey, certain questions were added. The added questions help clarify which standard (1953 or 1998) applied to the trailers, as well as adding additional detail that could be used in checking the consistency of answers received. The additional questions include:

- Trailer make, year of manufacture, and Trailer Identification Number (TIN).
- Trailer length and axle arrangement (single, spread, or together).
- A text description of the truck configuration, with details helpful to understand the application of the underride guard standards.
- Rear ground clearance.

In addition, there was a checkbox for the editors to record whether the collision was offset. This checkbox was an improvement on the process used in the 2008 data collection, where editors would write the word "offset" in the comment box.

2.4. Methodological limitations

The methodology employed here has certain limitations. Because the TIFA survey itself supplements the FARS data, it must follow the FARS data in time sequence, extending the time between crash occurrence and contacting respondents for the TIFA and supplemental underride data. The description of the dimensions of the rear of the trucks is collected primarily from truck operators themselves, who are the best source for most information, but some of the dimensions, such as rear overhang and underride guard height, may not be items that they pay much attention to. In most cases, the dimensions are estimated rather than measured.

The limitation of after-the-fact estimation also applies to the questions related to underride. In some cases, respondents provided estimates from photographs of the crashes (and provided them to the survey as well), but in many cases respondents worked from memory. It would, of course, be most reliable to extract the data from on-scene investigation, but on-scene investigation of roughly 7,500 fatal crashes across the U.S. is not feasible. Instead, the survey relied on police reports, other investigations of the crashes, and interviews with involved parties. The estimates of underride determined by the telephone interview method are reasonably consistent with estimates from photographic evidence, cited in Braver et al. and Brumbelow and Blanar (Braver, Mitter et al. 1997; Brumbelow and Blanar 2010).

3. Population statistics relative to rear underride guard standards

This section provides a description of the trucks involved in fatal crashes in 2008 and 2009, particularly focusing on the rear dimensions of the trucks. Statistics are presented on cargo bed height, rear overhang, and the presence of an underride guard or any other equipment that might serve as an underride guard. This information is then used to develop a method to classify the trucks relative to the 1953 and 1998 underride guard standards.

3.1. Introduction

The TIFA survey includes all medium and heavy trucks, with a GVWR over 10,000 lbs., involved in fatal crashes in the US. The GVWR threshold includes some pickups that are built with heavy-duty rear axles that raise their GVWR over 10,000 lbs. Some of these pickups are used for personal transportation only, meaning that they are used in the same way as light passenger vehicles. Heavy-duty pickups used only for personal transportation are excluded from the analysis. The focus in this report is on medium and heavy trucks in commercial operations. Excluding personal-use pickups identifies 7,523 medium and heavy trucks involved in fatal crashes, out of the 7,802 in the combined TIFA files for 2008 and 2009.

Rear dimensions of the trucks relative to the underride guard standards are described in detail in this section. Of course, the population described consists of trucks involved in fatal accidents, rather than a random sample of trucks intended to represent the entire truck population in the US. However, this population is probably not too far from representative of the general population of trucks, at least with respect to the rear dimensions of the vehicles. Fatal crashes tend to occur more on high speed roads, so the fatal crash population probably includes somewhat more trucks that operate on high speed roads, such as long-haul tractor/trailer combinations, and somewhat fewer of the vehicles such as work trucks that might operate at lower speeds. Yet all road types are represented, so this bias is a tendency rather than a censoring of the population.

3.2. Basic distributions

Table shows the trucks involved in fatal accidents in 2008-2009 classified into standard configurations. There were also 279 heavy duty (GVWR class 3) pickups involved in fatal crashes over those 2 years, but they are excluded here because they were operated for personal use only. The number of trucks involved in fatal crashes declined from 4,202 in 2008 to 3,321 in 2009, a decline of over 20 percent in one year. This decrease may be related to the economic recession in the period. While the total number of trucks declined significantly, the relative proportions of different truck types remained about the same. Straight trucks accounted for 28.4 percent to 29.1 percent of the trucks, tractor/trailer(s) for 60.9 percent to 64.1 percent, and straight trucks pulling a trailer for 4.1 percent to 4.5 percent. (As used here, tractor/trailers include tractor-semitrailers, tractors with 2 trailers (doubles), and tractors with 3 trailers (triples).) Tractor-trailer(s) outnumber straight trucks in fatal crashes by about 2 to 1. Bobtail tractors, which are tractors operating without a trailer, account for only 1.5 percent to 1.9 percent, and other truck configurations are a very small percentage only. (Please see Appendix D for line-drawings of standard truck configurations.) The biggest difference between the two years of data is in the number of records for which truck configuration could not be determined. This difference is accounted for by the fact that two States did not provide police accident reports in 2009.

Table 1. Comparison of Truck Configuration 2008 and 2009

Configuration	2008	2009	Total
Straight	1,192	967	2,159
Straight & trailer	174	151	325
Bobtail	79	49	128
Tractor/trailer	2,694	2,022	4,716
Tractor/other	3	2	5
Unknown	60	130	190
Total	4,202	3,321	7,523
	Column percentages		
Straight	28.4	29.1	28.7
Straight & trailer	4.1	4.5	4.3
Bobtail	1.9	1.5	1.7
Tractor/trailer	64.1	60.9	62.7
Tractor/other	0.1	0.1	0.1
Unknown	1.4	3.9	2.5
Total	100.0	100.0	100.0

As shown in Table 2, a total of 977 trucks were struck in the rear in fatal crashes, 2008-2009. These 977 trucks represent 13 percent of all truck fatal involvements. Straight trucks and tractor/trailers are the two primary configurations of trucks in fatal crashes, accounting for 28.7 percent and 62.7 percent of all, respectively. Despite differences in their operations, rear-end struck crashes accounted for about the same percentage of crashes for each. About 13.9 percent of the straight trucks were struck in the rear, and about 13.4 percent of the tractor/trailer combinations. Rear-end struck fatal crashes occur at a lower incidence for straight trucks pulling a trailer, with less than 9 percent, but there were only 29 such cases in the two years covered by the study. Bobtails also have a lower percentage of rear-end struck fatal involvements.

Table 2. Struck in Rear by Truck Configuration
TIFA 2008-2009

Configuration	Struck in rear? Yes	No	Unknown	Total
Straight	301	1,854	4	2,159
Straight & trailer	29	296	0	325
Bobtail	14	114	0	128
Tractor/trailer	633	4,068	15	4,716
Tractor/other	0	5	0	5
Unknown	0	15	175	190
Total	977	6,352	194	7,523
	Percentage by configuration			
Straight	13.9	85.9	0.2	100.0
Straight & trailer	8.9	91.1	0.0	100.0
Bobtail	10.9	89.1	0.0	100.0
Tractor/trailer	13.4	86.3	0.3	100.0
Tractor/other	0.0	100.0	0.0	100.0
Unknown	0.0	7.9	92.1	100.0
Total	13.0	84.4	2.6	100.0

3.3. Rear dimensions, guards, and equipment

This section describes the rear of trucks in fatal crashes, 2008 and 2009, relative to rear underride guard standards. Statistics are presented on the distribution of cargo bed height, rear overhang (the distance between the rear face of the tires and the end of the cargo body), mounted equipment, whether an underride guard was installed, and the height of rear underride guards from the ground.

About 55.4 percent of trucks involved in fatal crashes 2008-2009, were reported with a rear underride guard (Table 3). The presence of a guard could not be determined for 11.2 percent of the trucks. If it is assumed that the unknown cases are not biased in any way, it can be estimated that about 62 percent of trucks in fatal crashes have underride guards.

Table 3. Underride Guard Present, TIFA 2008-2009

Guard present?	N	%
Yes	4,171	55.4
No	2,508	33.3
Unknown	844	11.2
Total	7,523	100.0

Not surprisingly, the incidence of rear underride guards varies by truck configuration, in part because the standards are different for straight trucks and trailers, and in part because of the great variety of truck designs and uses. Overall, almost 77 percent of tractor/trailer combinations were reported with an underride guard, but only about 23.4 percent of straight trucks with no trailer. Most tractor/trailer combinations are subject to the requirements of the 1998 standard and so most are required to have underride guards, and actually do. Straight trucks operate under the 1953 standard, which has a broader range of exemptions.

Table 4 Underride Guard Reported by Truck Configuration, TIFA 2008-2009

	Underride guard present?			
Configuration	Yes	No	Unknown	Total
Straight	506	1,445	208	2,159
Straight & trailer	42	253	30	325
Bobtail	3	112	13	128
Tractor/trailer	3,620	693	403	4,716
Tractor/other	0	5	0	5
Unknown	0	0	190	190
Total	4,171	2,508	844	7,523
	Percentage by truck configuration			
Straight	23.4	66.9	9.6	100.0
Straight & trailer	12.9	77.8	9.2	100.0
Bobtail	2.3	87.5	10.2	100.0
Tractor/trailer	76.8	14.7	8.5	100.0
Tractor/other	0.0	100.0	0.0	100.0
Unknown	0.0	0.0	100.0	100.0
Total	55.4	33.3	11.2	100.0

Rear-mounted equipment: The TIFA supplemental data include a set of questions about the presence of equipment mounted at the back of the unit below the cargo bed. The purpose of these questions ultimately was to help determine whether the gear might be substantial enough to serve as an underride guard, under the 1953 and 1998 rules. The first question established whether there was anything mounted under the cargo bed at the rear, and the second captured a short description of the equipment. This description was used to judge whether the equipment was substantial enough and mounted such that it could serve as an underride guard. Many trucks have equipment mounted below the rear deck for various purposes. Trucks are working vehicles, and are equipped to accomplish work in addition to simply transporting freight. Table 5 shows the incidence of rear-mounted equipment by the truck configuration. All types of reported equipment and gear are included in the table, regardless of whether it was judged sufficient to serve as a guard. Some sort of equipment was reported for about 16 percent of the trucks. However, the percentage varied significantly by truck configuration. Straight trucks had the highest proportion with 39.3 percent, while only 6.6 percent of tractor combinations (the trailers thereof) were reported with any rear-mounted equipment. Many straight trucks were equipped with tool boxes, ramps, and other equipment mounted for easy access. The full list of reported equipment is included in Appendix B.

Table 5. Reported Rear-Mounted Equipment, TIFA 2008-2009

	Equipment below cargo bed?			
Configuration	Yes	No	Unknown	Total
Straight	848	1,108	203	2,159
Straight & trailer	36	261	28	325
Bobtail	10	103	15	128
Tractor/trailer	312	4,022	382	4,716
Tractor/other	0	5	0	5
Unknown	0	0	190	190
Total	1,206	5,499	818	7,523
	Row percentage			
Straight	39.3	51.3	9.4	100.0
Straight & trailer	11.1	80.3	8.6	100.0
Bobtail	7.8	80.5	11.7	100.0
Tractor/trailer	6.6	85.3	8.1	100.0
Tractor/other	0.0	100.0	0.0	100.0
Unknown	0.0	0.0	100.0	100.0
Total	16.0	73.1	10.9	100.0

Table 6 shows the presence of rear-mounted equipment by truck configuration for trucks that were reported as having an underride guard. Most trucks either had an underride guard or rear-mounted equipment but not both. However, about 5.9 percent of those with underride guards also had some sort of equipment mounted below. In most cases, the equipment was a liftgate, steps, bumpers, or ramps. Straight trucks were most likely to have both equipment and an underride guard, though only about 1 out of 5 with a guard also were reported with some sort of equipment. For tractor/trailer combinations, relatively few had both a guard and anything else mounted below the cargo bed.

**Table 6. Reported Rear-Mounted Equipment, Underride Guard Present
TIFA 2008-2009**

Configuration	Equipment below cargo bed? Yes	No	Unknown	Total
Straight	106	390	10	506
Straight & trailer	5	37	0	42
Bobtail	0	3	0	3
Tractor/trailer	137	3,431	52	3,620
Tractor/other	0	0	0	0
Total	248	3,861	62	4,171
	Row percentages			
Straight	20.9	77.1	2.0	100.0
Straight & trailer	11.9	88.1	0.0	100.0
Bobtail	0.0	100.0	0.0	100.0
Tractor/trailer	3.8	94.8	1.4	100.0
Tractor/other	-	-	-	-
Total	5.9	92.6	1.5	100.0

Table 7 shows the frequency of rear-mounted equipment for trucks that did not have a rear-underride guard. This group is much more likely to have the rear-mounted equipment, for both straight trucks and tractor-combinations. In part, this is because an underride guard could interfere with access to the equipment, such as tool boxes, pull-out ramps, and the like. Just over half (50.4%) of straight trucks without an underride guard had some sort of rear-mounted equipment. Rear-mounted equipment is much more rare (12.3%) on the trailers pulled by straight trucks. But 24.7 percent of tractor/trailer combinations had rear-mounted equipment if there was no guard. Among all tractor/trailer combinations, the proportion with rear-mounted equipment was 3.8 percent. Clearly, the presence of an underride guard is related to other equipment mounted on the back of trucks.

Table 7. Reported Rear-Mounted Equipment, Underride Guard NOT Present TIFA 2008-2009

Configuration	Equipment below cargo bed? Yes	No	Unknown	Total
Straight	729	684	32	1,445
Straight & trailer	31	216	6	253
Bobtail	9	99	4	112
Tractor/trailer	171	512	10	693
Tractor/other	0	5	0	5
Total	940	1,516	52	2,508
Row percentages				
Straight	50.4	47.3	2.2	100.0
Straight & trailer	12.3	85.4	2.4	100.0
Bobtail	8.0	88.4	3.6	100.0
Tractor/trailer	24.7	73.9	1.4	100.0
Tractor/other	0.0	100.0	0.0	100.0
Total	37.5	60.4	2.1	100.0

Equipment was flagged as “substantial” or not in a review after all the data were collected. Each response was evaluated in consultation with the TIFA editors to judge whether the equipment was substantial enough to serve as an underride guard. Table 8 shows the list and number of equipment items that were accepted as likely meeting the standard as specified in the 1998 rule: “… [O]ther parts of the vehicle [that] provide the rear end protection comparable to impact guard(s) conforming to the requirements of paragraph (b)(1) of this section shall be considered to be in compliance with those requirements.”[5] The judgment was based on the description of the equipment, the type of cargo body it was mounted on, and the reported cargo bed height. The table does not include any liftgates, which were reported on 207 trucks, because under the regulations, trucks with liftgates qualify as special purpose vehicles. Special purpose vehicles are not required to have rear impact guards, and those cases are discussed elsewhere.

[5] 49 CFR 386.86, (b)(3)

Table 8. Substantial Rear-Mounted Equipment, TIFA 2008-2009

Equipment type	N	%
Attenuator	8	1.6
Axles	6	1.2
Bumpers	130	25.2
Bumpers plus other	205	39.8
Conveyor belt; loading mechanism	4	0.8
Forklift	23	4.5
Ramps	26	5.0
Spreaders	18	3.5
Wheel lift	95	18.4
Total	515	100.0

Bumpers account for most of the equipment. Bumpers were reported most often on delivery or utility vans. "Wheel lifts," which are mechanisms on the rear of tow trucks on which the front axle of the towed vehicle rests, were also common. Other commonly reported items include forklifts, ramps, and spreaders. There were even eight cases where trucks had crash attenuators mounted on the rear. A total of 1,206 trucks were reported with some sort of rear-mounted equipment (Table 5), of which 515 were considered to be sufficiently substantial to serve as an underride guard. These 515 cases amount to 6.8 percent of all the trucks involved in fatal crashes over the 2 years of fatal crashes.

<u>Rear overhang</u>: Rear overhang is a critical dimension in determining whether a rear underride guard is required. Rear overhang is defined as the distance from the face of the rear tires to the end of the cargo bed. This measurement forms one dimension of the space available for underride, since striking vehicles that actually contact the rear tires of the truck are usually stopped right there. Under the 1953 rule, underride guards are not required if the rear wheels are within 24 inches of the end of the cargo body; under the 1998 rule, that distance was reduced to 12 inches. Respondents typically estimated the amount of rear overhang, though in some cases the distance was actually measured. The values reported varied from 0 to 2 case reported at 300 inches, 2 at 210 inches, and 4 at 180 inches. Rear overhang was unknown in 17.3 percent of the cases and reported as long but unknown in 1.8 percent. The cases reported long-but-unknown were imputed at 80 inches for the purposes of Table 9, which is the mean value of cases reported between 5 and 10 feet.

The amount of rear overhang varies with the type of truck configuration and cargo body. Table 9 shows aggregate statistics on rear overhang, organized by the high-level truck configuration and cargo body. Only straight trucks, straight trucks with trailers, and tractor/trailer combinations are relevant and shown in the table. The table shows the number of cases, mean and median overhang, the standard deviation of the distribution, and the minimum and maximum values observed. The statistics for the aggregate of each configuration include a number of minor cargo body types not shown separately in the table.

Table 9. Rear Overhang (Inches) by Truck Configuration and Cargo Body Type TIFA 2008-2009

Tractor-trailer(s)						
Cargo body	N	Mean	Median	Std Dev	Minimum	Maximum
Van	2,120	66.56	72	32.87	0	180
Livestock	43	30.63	24	23.60	4	96
Flatbed	508	40.70	36	29.67	0	210
Lowboy	66	26.52	12	26.40	0	96
Tank	398	22.53	13	21.36	0	81
Dry bulk	81	15.65	12	19.52	0	81
Dump	297	16.96	12	18.67	0	81
All tractor/trailer	3,513	51.22	48	35.84	0	210
Straight truck (no trailer)						
Cargo body	N	Mean	Median	Std Dev	Minimum	Maximum
Van	442	60.54	60	23.16	8	135
Flatbed	204	50.71	48	22.91	2	150
Tank	110	45.29	48	24.10	0	96
Dump	391	22.39	15	21.82	0	132
Refuse	189	53.84	48	25.80	0	124
Mixer	61	32.10	18	27.76	0	96
All straight trucks	1,397	45.08	48	28.09	0	150
Straight truck/trailer						
Cargo body	N	Mean	Median	Std Dev	Minimum	Maximum
Van	15	50.80	42	29.64	6	120
Flatbed	114	66.19	60	31.66	0	180
Tank	9	20.22	18	10.74	6	36
Dump	36	20.39	12	22.45	0	81
Refuse	4	24.00	18	16.97	12	48
All straight/trailer	178	52.36	48	34.95	0	180

The mean and median overhang for straight trucks overall is about six inches less than for tractor/trailer combinations, but overhang varies substantially by cargo body type, regardless of truck configuration. The placement of the rear axles with respect to the end of the cargo body depends on how trucks are used; rear overhang varies depending on the loads the truck is intended to carry and how the cargo is unloaded. Some semitrailers even have moveable rear axles, enabling the location of the axles to be varied depending on specific cargoes and where the truck is going to operate. Shorter wheel bases allow for tighter turns. In general, overhang tends to be short for livestock, tank, and dump cargo bodies, but longer for vans and some flatbeds.

Figure 1, Figure 2, and Figure 3 show boxplots for the distribution of rear overhang by cargo body type for tractor/trailers, straight trucks, and straight trucks with trailers, respectively. The shaded boxes within the plot contain the middle quartiles (the middle 50%) of the distribution, the horizontal line bisecting the box is the median, the plus sign is placed at the location of the mean, and the whiskers encompass the range of reported overhangs.

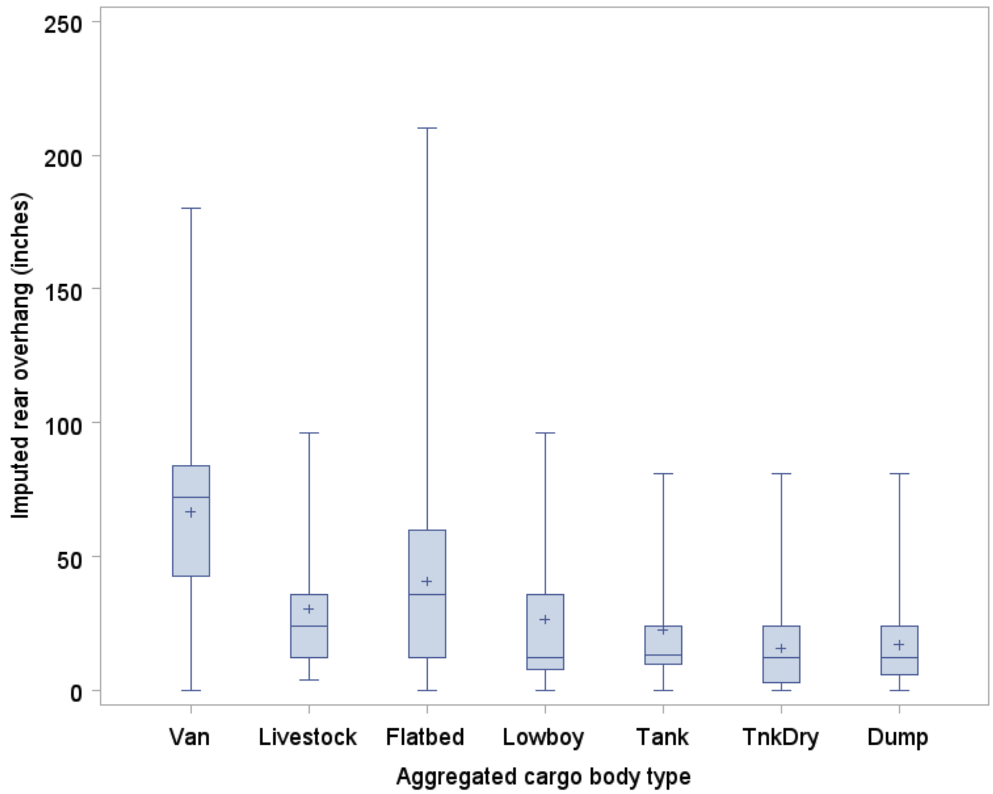


Figure 1. Tractor/Trailers, Rear Overhang by Cargo Body Type, TIFA 2008-2009

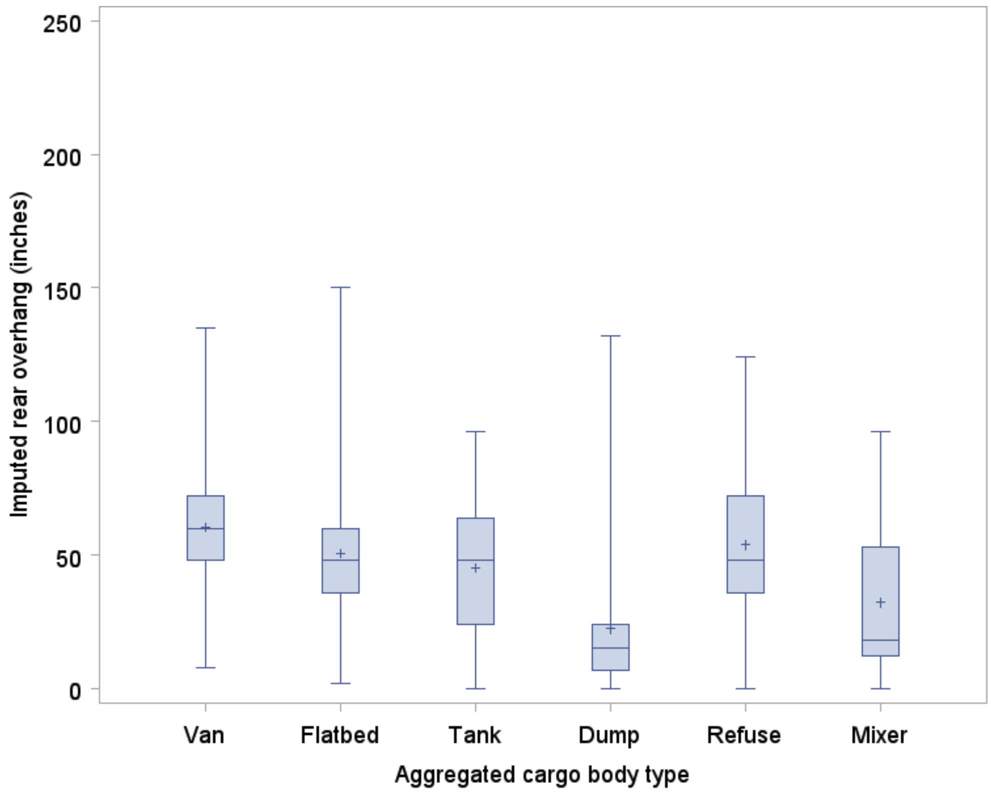


Figure 2. Straight Trucks, Rear Overhang by Cargo Body Type, TIFA 2008-2009

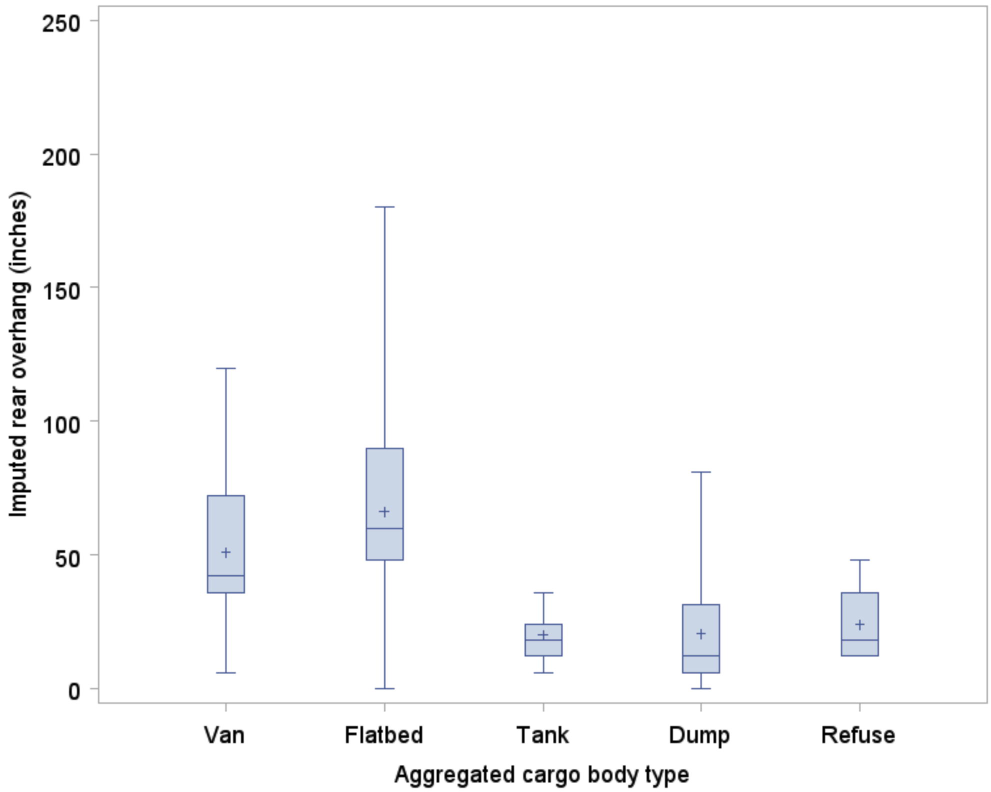


Figure 3. Straight Truck and Trailers, Rear Overhang by Cargo Body Type, TIFA 2008-2009

<u>Guard height</u>: Guard height (the distance from the ground to the underride guard) is another dimension specified in the 1953 and 1998 underride guard standards. Guard height was estimated by respondents, in some cases from actual measurements, in others by sight estimation. The guard height standard specifies maximum height from the ground, measured when the vehicle is unloaded. This condition could not be reproduced in the telephone survey, so there may be an unknown amount of variation introduced by cargo loading. However, air suspensions have been common on tractors and semitrailers for the last 15-20 years, and ride height is independent of load.

Guard height was reported for 3,894 of the 4,171 trucks that had underride guards. Table 10 provides the relevant statistics. Guard height was reported “low but unknown” for 29 cases, and “high but unknown” for 21. Underride guard height was not estimated for 277 trucks. Guard heights were imputed for low-but-unknown and high-but-unknown cases. The low-but-unknown guard heights were imputed at the median value (18 inches) for those with known values less than 22 inches. The high-but-unknown cases were imputed at the median value (30 inches) of known values greater than 24 inches. The small number of cases imputed (50) did not materially change the overall mean, median, or mode for guard height.

The results for the aggregate of 2008 and 2009 data are almost precisely the same as for 2008 alone. It had been expected that the average for straight truck underride guards would be closer to 30 inches, which is the applicable standard for straight trucks. But the mean, median, and mode are substantially identical to reported guard heights for tractors with trailers, which have a substantial number of trailers under the 1998 standard, or 22 inches.

Table 10. Reported Guard Height (Inches) by Truck Configuration

Configuration	N	Mean	Median	Mode	Std Dev
Straight	470	21.4	20	24	5.20
Straight and trailer	41	20.4	18	18	5.13
Tractor/trailers	3,380	21.1	20	24	4.20
All guards	3,894	21.1	20	24	4.35

This result should be interpreted in light of the likelihood that truck drivers, dispatchers, and others surveyed for this information generally would have no reason to pay much attention to the height of the underride guard. Frequently, the survey was performed well after the crash. For each configuration, the mode (most common response) is either 18 or 24 inches. Most responses were given in six-inch increments. There were some cases where respondents actually measured guard height, but in most instances the respondents simply estimated a value. On the other hand, the results from the TIFA survey are reasonably consistent with results from an examination of cases in the Large Truck Crash Causation Study (LTCCS), using photographs of the trucks, as summarized in Brumbelow and Blanar. These researchers found that in almost all the cases where a measurement was possible, guard height was below the minimum 1998 requirement (Brumbelow and Blanar, 2010).

Cargo overhang: Though cargo overhang does not figure into the underride standards, it can be a significant factor in rear-end crashes. Data on overhang of cargo beyond the rear of the cargo bed was collected, but cargo overhang was reported only rarely. There was no cargo overhang in 92.1 percent of the trucks, and overhang could not be determined in 6 percent. In most cases where overhang could not be determined, it was unknown whether there was any cargo overhang at all, not just the amount of cargo overhang. Of cases where overhang could be determined, there was no overhang in 98 percent of the cases. In the 2 percent where some overhang was reported, the average overhang was estimated at 77.1 inches. It should be noted that the distribution of overhang is skewed right. The median overhang is 54 inches, and the mode is 48. Very large overhangs (greater than 20 feet) were recorded for logs and a utility pole.

3.4. Evaluation of underride guard required status

The data collected describing the rear dimensions and other features of the trucks allows them to be classified in relation to the 1953 and 1998 underride guard standards. These standards are described in section 1.1.1 and 1.1.2 above. The 1953 standard applies to all trucks and trailers manufactured after December 1952, effectively all straight trucks in the 2008 and 2009 TIFA data. (The oldest truck in those two years of fatal crash data was a 1959 straight truck.) Trailer year is unknown for the 2008 data, but trailer manufacture year was collected as part of the 2009 supplemental data, which can be used to help classify trailers in that crash year. The 1998 revision of the standard applies to trailers and semitrailers (and not straight trucks) manufactured after January 1998. Straight trucks are under the 1953 standards, but trailers are controlled by the 1998 standard, depending on when the trailer was built.

Trailer model year was not captured in the supplemental data collection for 2008, so it cannot be used to determine which standard applies for that crash year. However, trailer year was captured in the 2009 TIFA survey. Table 11 shows the results, aggregated into groups by whether the 1953 or 1998 standard applies. The first thing to note, however, is that trailer year could not be determined for about one-quarter of the trailers. This is because the trailer identification number (TIN) was not available or respondents simply did not know the model year of their trailer. About 20 percent of trailers were determined to have been built in 1997 or before, but 55.1 percent were manufactured in 1998 or later.

Table 11. Trailer Manufacture Year
TIFA 2009

Trailer year	N	%
Before 1998	426	19.7
1998 to 2010	1,193	55.1
Unknown	545	25.2
Total	2,164	100.0

Two algorithms were developed to classify each truck in relation to the underride guard standards. The critical dimensions are cargo bed height and rear cargo bed overhang, as discussed above. In addition, certain cargo body types are exempt, as well as trucks with rear-mounted equipment that could serve as an underride guard. Two algorithms are needed because of the large number of trailers for which manufacture year is unknown. For trailers with unknown manufacture year, it cannot be determined positively whether the 1953 or 1998 rules apply. In the first algorithm, all trailers with unknown manufacture year are assumed to fall under the 1953 standard. In the other, all trailers with unknown manufacture year are assumed to be governed by the 1998 standard. Either one or the other rule applies, so the algorithms capture the lower bound and the upper bound of the range of applicability, within the limits of the accuracy of the data collected.

The assumption on trailer manufacture year affects the classification of 26.3 percent of the trucks that could be classified. These were cases that did not fall into one of the exempt types and rear overhang and cargo bed height were known. All that was missing was trailer manufacture year, to determine whether to apply the 1953 or 1998 rules relative to cargo bed height and overhang.

Table 12 shows the results of classifying trucks involved in fatal crashes in relation to underride guard requirements, and it also compares the results when trailers where the year of manufacture is not known, by either the 1953 standard or the 1998 standard. There was insufficient information to determine the classification of about 18 percent of the trucks. These trucks did not fall into one of the exempt types and there was insufficient information on cargo bed height and rear overhang. Certain truck types were exempted, such as logging or pole trailers, live-bed trailers, and driveaway/towaways (e.g., saddlemounts[6]). Also, trucks with cargo body beds lower than a certain amount (depending on the applicable standard) (low bed in the table) or with the rear wheels less than a certain amount (depending on the applicable standard) from the rear of the cargo body (wheels back) are not required to have a guard. Finally, trucks with rear-mounted

[6] "A saddlemount combination is a combination of vehicles in which a truck or truck tractor tows one or more trucks or truck tractors, each connected by a saddle to the frame or fifth wheel of the vehicle in front of it." 23 CFR 658.5 This configuration is often used when sets of incomplete trucks are being transported to have cargo bodies or fifth wheels mounted on them prior to sale.

equipment below the cargo body that could serve as a guard are not required to have a separate rear impact guard.

Table 12. Underride Guard Status Classification Where Unknown Trailer Year Assigned by 1953 or 1998 Standards, TIFA 2008-2009

Guard status		Classifying unknown trailer year by: 1953 rule		1998 rule	
Guard required		3,056	40.6	3,396	45.1
Reason Guard Not Required:	Exempt type	527	7.0	527	7.0
	Low bed	305	4.1	257	3.4
	Wheels back	1,870	24.9	1,570	20.9
	Low bed and wheels back	69	0.9	42	0.6
	Equipment below	344	4.6	365	4.9
Unknown if guard required		1,352	18.0	1,366	18.2
Total		7,523	100.0	7,523	100.0

Under the 1998 standard, a higher proportion of trucks are required to have a guard. This is because the 1998 rule reduced the cargo bed height exemption from 30 to 22 inches and the rear axle setback exemption from 24 to 12 inches. Note that the number of trucks classified as low bed or wheels back or both is significantly lower under the 1998 rule than under the 1953 rule.

Table 13 shows the status of trucks classified using the 1953 rear impact guard requirement by truck configuration. Trucks that could not be classified at all because of missing data are excluded from the table. Truck configuration is aggregated into categories that map to certain of the fundamental distinctions in the rear impact protection standards. The 1953 standard applies to both straight trucks and trailers, while the 1998 standard applies only to trailers known to be manufactured in 1998 or later. Thus, straight trucks and bobtails (tractors with no trailers) are shown in separate categories, while straight trucks with a trailer and all tractor/trailer combinations are shown in separate categories. Bobtails are shown separately from straight trucks because they are not required to have an underride guard under either standard, while straight trucks are governed by the 1953 standard. The tractor/other category consists of different saddlemount configurations. The columns show the status of the cases relative to the rear impact guard requirements.

Table 13. Rear Guard Status by Truck Configuration, Using 1953 Standard Where Trailer Year Unknown Unknown Truck Configurations and Rear Dimensions Excluded, TIFA 2008-2009

Truck configuration	Guard required	Reason Guard Not Required: Exempt type	Low bed	Wheels back	Low bed & wheels back	Equipment below	Total
Straight	709	155	161	505	35	308	1,873
Straight & trailer	67	12	111	53	13	5	261
Bobtail	0	128	0	0	0	0	128
Tractor/trailer	2,280	211	33	1,312	21	31	3,888
Other	0	21	0	0	0	0	21
Total	3,056	527	305	1,870	69	344	6,171
Row percentages							
Straight	37.9	8.3	8.6	27.0	1.9	16.4	100.0
Straight & trailer	25.7	4.6	42.5	20.3	5.0	1.9	100.0
Bobtail	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Tractor/trailer	58.6	5.4	0.8	33.7	0.5	0.8	100.0
Other	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Total	49.5	8.5	4.9	30.3	1.1	5.6	100.0

About 16.4 percent of straight trucks are exempt because of rear-mounted equipment that was judged sufficient to serve as an underride guard. Most of the trucks not required to have a guard because of rear-mounted equipment are straight trucks, as would be expected. About 27.0 percent of straight trucks are exempted under the wheels-back exemption, and 37.9 percent are required to have a guard. Rear underride guards are much more likely to be required for tractor/trailer combinations. About 58.6 percent are required to have guards in this classification. However, over a third are exempt because of a wheels-back setting on the trailers. Relatively few are exempt by virtue of low cargo beds or rear-mounted equipment.

Table 14 shows the results of applying the 1998 standard to combinations with trailers. The 1953 standard still applies for straight trucks, so the rows for straight trucks and bobtails are the same as in Table 13. However, the assignment of trailers with unknown manufacture year to the group known to be built after 1997 changes the distribution of the tractor/trailer classification. Almost two-thirds of tractor/trailer combinations are classified as needing an underride guard. The proportion exempt by virtue of the type of cargo body does not change, of course, but the proportion not required to have a rear guard due to a wheels back configuration decreased from 33.7 percent to only 26.4 percent. The number exempt under the low bed or low bed and wheels back criteria is even more insignificant, with only 23 trailers out of 3,876 qualifying.

Table 14. Rear Guard Status by Truck Configuration, Using 1998 Standard Where Trailer Year Unknown, Unknown Truck Configurations and Rear Dimensions Excluded, TIFA 2008-2009

Truck configuration	Guard required	Reason Guard Not Required: Exempt type	Low bed	Wheels back	Low bed & wheels back	Equipment below	Total
Straight	709	155	161	505	35	308	1,873
Straight & trailer	114	12	78	42	2	11	259
Bobtail	0	128	0	0	0	0	128
Tractor/trailer	2,573	211	18	1,023	5	46	3,876
Other	0	21	0	0	0	0	21
Total	3,396	527	257	1,570	42	365	6,157
Row percentages							
Straight	37.9	8.3	8.6	27.0	1.9	16.4	100.0
Straight & trailer	44.0	4.6	30.1	16.2	0.8	4.2	100.0
Bobtail	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Tractor/trailer	66.4	5.4	0.5	26.4	0.1	1.2	100.0
Other	0.0	100.0	0.0	0.0	0.0	0.0	100.0
Total	55.2	8.6	4.2	25.5	0.7	5.9	100.0

It is believed that the algorithm that applies the 1998 standard to trailers with unknown manufacture year provides a distribution closer to the true underlying distribution than applying the 1953 standard to those trailers. Results from the 2009 TIFA survey (Table 11) show that about 75 percent of trailers with known manufacture years were 1998 or later. Based on this, it is very likely that a substantial majority of cases for which manufacture year could not be determined were built in 1998 or later. While it is of course possible that some of the unknown years were earlier than 1998, assuming that they belong with the 1998 group probably produces a more correct representation of the population of trucks involved in fatal crashes.

Finally, Table 15 shows the cross-classification of trucks by whether they were required to have a guard under the 1998 standard and whether they actually had one. One notable finding is the number of trucks required to have an underride guard that apparently do not have one. Of trucks required to have a guard, 19.1 percent were not reported to have one. Results using the 1953 standard are not shown here, but the proportion was very similar, 18.2 percent. Most of the cases where a guard is required but not reported as present are straight trucks or straight trucks pulling a trailer. Those two configurations account for 475 of the 648 trucks reported without a guard, though they apparently should have one. These two configurations account for 73.3 percent of all such trucks. Many of these trucks are operated by intrastate private carriers, who may not have been aware of the requirement. The other primary configuration in this group is tractor/trailer combinations, which account for another 173. But since there are a total of 2,573 tractor/trailer combinations in the two years of crash data, the number that fail the requirement is only 6.7

percent of tractor/trailers. Almost 92 percent of tractor/trailer combinations required to have a guard under the 1998 standard were reported with a rear underride guard.

Table 15. Underride Guard Present by Status Relative to 1998 Standard TIFA 2008-2009

Guard status under 1998 standard	Guard present			Total
	Yes	No	Unknown	
Guard required	2,684	648	64	3,396
Exempt type	164	326	37	527
Low bed	13	241	3	257
Wheels back	771	770	29	1,570
Low bed & wheels back	3	39	0	42
Equipment below	41	322	2	365
Unknown	495	162	709	1,366
Total	4,171	2,508	844	7,523
Row percentages				
Guard required	79.0	19.1	1.9	100.0
Exempt type	31.1	61.9	7.0	100.0
Low bed	5.1	93.8	1.2	100.0
Wheels back	49.1	49.0	1.8	100.0
Low bed & wheels back	7.1	92.9	0.0	100.0
Equipment below	11.2	88.2	0.5	100.0
Unknown	36.2	11.9	51.9	100.0
Total	55.4	33.3	11.2	100.0

The number of trucks reported to have a rear impact guard even though not required is also notable. And almost all of the vehicles reported to have a guard, though not required, are because of the wheels-back exemption (438 out of the 904 with wheels back meeting the 1998 standard). It is probable that trailer manufacturers always build in underride guards for certain trailer types, such as vans, regardless of where the rear axles are located. Many such trailers have axles that can be shifted forward or back, depending on the load type and distribution.

3.5. Summary

About 55.4 percent of trucks involved in fatal crashes from 2008-2009 were reported with rear underride guards. The presence of a guard could not be determined for 11.2 percent of the trucks. If it is assumed that guard presence in the unknown cases is distributed in the same way as where guard presence is known, an estimated 62 percent of trucks in fatal crashes had underride guards. Tractor/trailer combinations are much more likely to have rear underride guards than straight trucks. Almost 77 percent of tractor/trailer combinations were reported with an underride guard, compared with only about 23.4 percent of straight trucks with no trailer.

Reported guard heights—the vertical distance from the ground to the bottom of the guard—were somewhat surprising. Overall, mean and median guard heights were 21.1 and 20 inches, respectively. These are actually lower than the 1998 standard’s 22-inch requirement for guards on trailers. Straight trucks are still governed under the 30-inch standard established in 1953. But reported guard heights for straight trucks were effectively identical to those for tractor/trailer combinations. However, this finding is reasonably compatible with estimates from the LTCCS data by Brumbelow and Blanar (2010).

Determining whether the 1953 standard or the 1998 standard applies to specific trucks is challenging, because of the number of trailers for which year of manufacture is unknown. However, analysis of the cases where trailer year is known showed that it is reasonable to think that applying the 1998 standard gives a result closer to the underlying reality than applying the 1953 rule.

In the end, an estimated 55.2 percent of the trucks in fatal crashes, 2008-2009, were required to have an underride guard. For those not required to have a guard, the most common reason was that the rear axle is set back far enough to meet the wheels-back exemption. Only about 37.9 percent of straight trucks were required to have a guard, but almost two-thirds (66.4%) of tractor/trailer combinations are required to have a guard. Only about 4.2 percent of trucks of all configurations met the cargo bed exemption, and about 5.9 percent – mostly straight trucks – were exempt because of rear-mounted equipment.

4. Rear underride in fatal truck crashes

In Table 2 it was shown that the proportion of trucks struck in the rear in fatal crashes did not significantly vary by truck configuration. The two primary truck configurations in fatal crashes are straight trucks and tractor/trailer combinations. The proportions of their fatal involvements that were rear-end struck were about the same, 13.9 percent and 13.4 percent, respectively. These two combinations also account for almost all truck rear-end fatal crash involvements. There were 977 fatal crash involvements in which a truck was struck in the rear. (Table 16). Straight trucks accounted for 301 (30.8%) of those involvements, and tractor/trailer combinations accounted for 64.8 percent, totaling 95.6 percent of all.

Table 16. Configuration of Trucks Struck in Fatal Rear-End Crashes, TIFA 2008-2009

Truck configuration	N	%
Straight	301	30.8
Straight & trailer	29	3.0
Bobtail	14	1.4
Tractor/trailer	633	64.8
Tractor/other	0	0.0
Unknown	0	0.0
Total	977	100.0

This section discusses the outcomes of fatal rear-end crashes. The outcomes are described in terms of the type of the striking vehicle, the extent of underride, and the number of fatalities and nonfatal injuries. While prior sections discussed all trucks involved in fatal crashes, this section will focus on the trucks that were struck in the rear only. The initial tables include rear-end involvements for all types of striking vehicles. But it is shown that a significant number of the striking vehicles are trucks, buses, or motorcycles. These vehicles are not relevant to the performance of rear-end underride guards, which are intended to help protect light vehicles. Accordingly, after showing the overall distribution of the types of striking vehicles, the analysis of underride extent and casualties is limited to rear-end crashes in which the striking vehicle is a light-duty motor vehicle.

4.1. Striking vehicles

The specific vehicle striking the rear of the truck was identified by the editors whenever possible. The vehicle number was transcribed from the police report, and then used to link the interview record to the vehicle record in the FARS file. This enabled the FARS classification of the striking vehicles to be established. It was not possible to identify the specific vehicle in all cases.

In crashes with only two vehicles, the identification of the other vehicle is obvious. But in multiple-vehicle crashes, particularly chain-reaction crashes, it is not always possible to determine which vehicle struck the rear end of the truck of interest, even after reviewing the narrative and scene diagrams on the crash report. Accordingly, there was a small number of cases in which either the correct vehicle number could not be determined or that vehicle was not captured in the FARS file.

Definitions of the categories used to aggregate light vehicle types are provided in Appendix C. The categories combine several similar vehicle types into the types shown in Table 17. The specific categories are selected to group together vehicles that present a similar profile. About 57.6 percent[7] of striking vehicles are light passenger vehicles such as automobiles, sport utility vehicles, minivans and compact pickups. Compact pickups are placed in a separate category from large pickups because they typically have a lower front-end geometry. About 17.9 percent of the striking vehicles are buses or trucks (GVWR greater than 10,000 lbs.), and 7.4 percent are motorcycles. Combining motorcycles, trucks, and buses, 25.3 percent of striking vehicles in rear-end, truck-struck fatal crash involvements are vehicles not relevant to requirements for rear underride guards.

Table 17. Vehicle Type of Striking Vehicle

Striking vehicle type	N	%
Auto	332	34.0
Utility	108	11.1
Minivan	67	6.9
Large van	23	2.4
Compact pickup	56	5.7
Large pickup	127	13.0
Bus	2	0.2
Truck	173	17.7
Motorcycle	72	7.4
Other/unknown	17	1.7
Total	977	100.0

For the rest of this section, only light vehicles are included in the analysis, since they are the target for rear underride guard standards. Trucks, buses, and motorcycles are excluded. Light vehicles in this section include automobiles, sport utility vehicles, minivans, large vans, compact pickups, and large pickups.

[7] There is some rounding error when summing the individual percentages shown in the table.

4.2. Underride extent

Survey respondents estimated the amount of underride in terms of the amount of the striking vehicle that went under the rear of the truck. The categories were none, less than halfway up the hood, more than halfway but short of the base of the windshield, and at or beyond the base of the windshield. Underride extent could not be determined for 75 cases, 10.5 percent of 713 fatal involvements in which a truck was struck in the rear by a light vehicle.

Smaller light vehicles tended to experience more underride than bigger or taller light vehicles, such as pickups and large vans. About 55.6 percent of passenger cars underrode the trucks past the halfway point of the car's hood and beyond. Underride past the windshield was recorded for 40.1 percent. In contrast, only 30 percent of large vans and 43.9 percent of large pickups experience such severe underride, with underride past the base of the windshield in 25 percent and 26.3 percent of the crashes, respectively. Minivans tend to stand relatively tall. About a third of minivans, large vans, and large pickups were coded with no underride at all, compared with only 20.2 percent of autos and 22.4 percent of compact pickups. It seems clear that the front geometry of the striking vehicle is related to the amount of underride. Underride amount could not be determined for 5.2 percent of the light vehicles.

Table 18. Underride Extent by Striking Vehicle Type, Unknown Extent Excluded TIFA 2008-2009

Striking vehicle type	Underride extent					Total
	None	Less than halfway	Up to halfway	Windshield or more	Unknown amount	
Auto	61	56	47	121	17	302
Utility	25	15	10	39	5	94
Minivan	20	10	10	19	0	59
Large van	7	5	1	5	2	20
Compact pickup	11	10	10	15	3	49
Large pickup	37	21	20	30	6	114
Total	161	117	98	229	33	638
Row percentages						
Auto	20.2	18.5	15.6	40.1	5.6	100.0
Utility	26.6	16.0	10.6	41.5	5.3	100.0
Minivan	33.9	16.9	16.9	32.2	0.0	100.0
Large van	35.0	25.0	5.0	25.0	10.0	100.0
Compact pickup	22.4	20.4	20.4	30.6	6.1	100.0
Large pickup	32.5	18.4	17.5	26.3	5.3	100.0
Total	25.2	18.3	15.4	35.9	5.2	100.0

The distribution of the extent of underride was relatively similar for straight trucks and tractor/trailer combinations. The percentage of straight trucks and tractor/combinations with no underride was about the same, excluding records that were unknown on extent (Table 19). Tractor/combinations and trucks with trailers tend to suffer greater amounts of underride than straight trucks, possibly because straight trucks tend to have slightly shorter rear overhangs. There were only five bobtail tractors in the data, so that distribution is not meaningful.

Table 19. Underride Extent by Truck Configuration (Light Vehicle Striking Only)

Truck configuration	Underride extent					Total
	None	Less than halfway	Up to halfway	Windshield or more	Unknown amount	
Straight	56	45	40	61	6	208
Straight & trailer	9	1	1	8	0	19
Bobtail	1	1	1	2	0	5
Tractor/trailer	95	70	56	158	27	406
Total	161	117	98	229	33	638
Row percentage						
Straight	26.9	21.6	19.2	29.3	2.9	100.0
Straight & trailer	47.4	5.3	5.3	42.1	0.0	100.0
Bobtail	20.0	20.0	20.0	40.0	0.0	100.0
Tractor/trailer	23.4	17.2	13.8	38.9	6.7	100.0
Total	25.2	18.3	15.4	35.9	5.2	100.0

It is also of interest to break out the crashes by details of the trucks' underride guard status. In Table 20, the trucks are classified in relation to what is required under the 1998 requirements and whether they actually had an underride guard. Straight trucks are classified as either having a rear underride guard or not. Tractor/trailer combinations are classified as either having a guard, qualifying as exempt from the guard requirement, or having a low cargo body bed or wheels back, as defined in the 1998 standard. Bobtails are shown separately, as are all other straight combinations (chiefly straight trucks pulling a trailer) and all other tractor combinations. Tractor/trailer combinations with an underride guard were the most common truck configuration, followed by straight trucks with no guard, and tractor/trailer combinations with trailers wheels back, within 12 inches of the rear of the cargo bed. The tractor, other/unknown combination in this table includes tractor combinations where it was unknown if the trailer had a guard or the application of the 1998 standard was unknown. In this study, trucks not required to have a guard because they fell into one of the exempt categories tended to suffer less underride than trucks required to have an underride guard. Over half of the light vehicles hitting the rear of tractor/trailer combinations with an underride guard suffered underride up to the windshield and beyond, while tractor/trailer combinations not required to have a guard were less likely to be underridden, or the underride was less than halfway up the hood of the striking light vehicle.

Table 20. Underride Extent by Truck Configuration and Guard-Required Status
Light Vehicle Striking Only

Truck type and guard required status	Underride extent					Total
	None	Less than halfway	Up to halfway	Windshield or more	Unknown amount	
Straight, guard	9	11	11	16	0	47
Straight, no guard	46	34	29	44	5	158
Tractor/trailer guard	37	30	32	115	15	229
Tractor/trailer exempt	6	4	5	4	2	21
Tractor/trailer low bed	2	1	0	1	0	4
Tractor/trailer wheels back	34	25	8	14	6	87
Bobtail	1	1	1	2	0	5
Straight, other/unknown	10	1	1	9	1	22
Tractor, other/unknown	16	10	11	24	4	65
Total	161	117	98	229	33	638
Row percentages						
Straight, guard	19.1	23.4	23.4	34.0	0.0	100.0
Straight, no guard	29.1	21.5	18.4	27.8	3.2	100.0
Tractor/trailer guard	16.2	13.1	14.0	50.2	6.6	100.0
Tractor/trailer exempt	28.6	19.0	23.8	19.0	9.5	100.0
Tractor/trailer low bed	50.0	25.0	0.0	25.0	0.0	100.0
Tractor/trailer wheels back	39.1	28.7	9.2	16.1	6.9	100.0
Bobtail	20.0	20.0	20.0	40.0	0.0	100.0
Straight, other/unknown	45.5	4.5	4.5	40.9	4.5	100.0
Tractor, other/unknown	24.6	15.4	16.9	36.9	6.2	100.0
Total	25.2	18.3	15.4	35.9	5.2	100.0

Offset impacts were recorded in both the 2008 and 2009 supplemental data collection, though in different ways. In the 2008 data collection, editors recorded offset in a Comment field. In the 2009 data collection, offset was captured as a separate categorical variable. An offset collision was defined in both as an impact with the outer third of the rear plane of the truck. Figure 4 shows a schematic of the rear of a heavy truck with an underride guard identifying the areas recorded as an offset collision areas. In offset collisions, there is not full overlap between the front of the striking vehicle and the rear of the truck. Offset was coded regardless of the angle of impact. For example, a 45 degree angle collision was coded as an offset as long as the contact point was in the offset area. If the impact was to the center of the rear plane, then offset would not be coded. Similarly, a 90-degree collision was coded as offset if the primary impact was in the offset area.

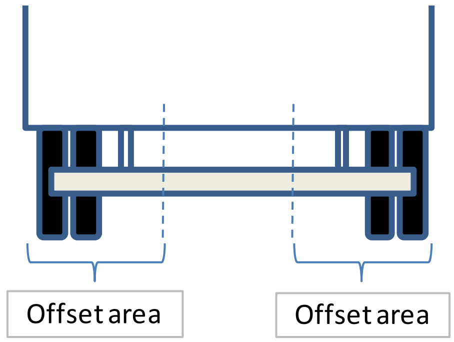


Figure 4. Diagram Illustrating Offset Collision Area

Offset impact was recorded for 41.1 percent of light-vehicle impacts on the rear end of trucks in fatal crashes. Impacts to one side or the other might be thought to increase the probability of severe damage to the underride guard, but in fact the pattern of observed damage was the reverse. Almost half of light vehicle impacts on rear guards resulted in major damage to the guard, including tearing it off, while there was major damage in only 38.7 percent of offset impacts. Table 21 shows underride guard damage by offset impact, where the striking vehicle was a light vehicle. The totals column includes cases where offset impact could not be determined. Only trucks coded with rear-underride guards are included.

Table 21 Underride Guard Damage by Offset Impact, Light Vehicles Only
TIFA 2008-2009

Underride guard damage	No offset		Offset		Total	
	N	%	N	%	N	%
None	8	3.6	20	11.9	28	6.8
Minor	50	22.2	42	25.0	95	23.2
Moderate	56	24.9	41	24.4	103	25.2
Major	111	49.3	65	38.7	183	44.7
Total	225	100.0	168	100.0	409	100.0

Maneuvering to avoid the impact can result in offset collisions. In these crashes, maneuvering to avoid the impact often included braking as well as steering maneuvers, which should have resulted in lower impact speeds. However, the result of an effort to estimate relative velocity at impact for light vehicles (reported in section 5) found that mean relative velocity was actually higher for offset impacts. Some maneuver to avoid was recorded for about 30 percent of light-vehicle strikes with offset impact, including only cases where maneuver to avoid was not unknown. In contrast, there was a maneuver to avoid in only about 20 percent of no-offset impacts. This result should be interpreted considering that maneuver-to-avoid is unknown in about a third of cases overall. In this study, it was clear that most underride guards suffer substantial damage in rear-end light-vehicle strikes, and that no-offset collisions are associated with a somewhat higher incidence of major damage.

The relationship between offset impact and underride extent is not direct, but mediated by whether a truck is required to have an underride guard or not because of one of the exemptions. Offset impacts have an effect on underride extent for trucks not required to have an underride guard, but offset does not affect underride extent for trucks required to have such a guard. In Figure 5, the top pair of bars compares the amount of underride by whether the impact was offset for all trucks required to have an underride guard and a guard was actually present. For these trucks, offset impact has no significant effect on underride extent. The two distributions are effectively identical. The next pair of bars makes the same comparison for trucks that are exempt from the underride guard requirement, either because the cargo body is an exempt type, low cargo bed, wheels back, or there is qualifying mounted equipment. In this comparison, 30.5 percent of the offset impacts resulted in underride to the windshield or beyond. The impacts without offset resulted in underride to the windshield and beyond in only 18.1 percent, but 32.9 percent of impacts had underride less than halfway up the hood of the striking light vehicle. The bottom pair of bars shows the result for all trucks struck in the rear by a light vehicle in fatal crashes, combining trucks with guard required and present and trucks meeting one of criteria to be exempt. (The column on the right shows the number of cases for the combinations of impact offset and underride guard required status.) In this comparison, it appears that offset is associated with greater amounts of underride, but separating the trucks by whether they are exempt or not demonstrates that offset impacts are more important for exempt trucks than for non-exempt trucks. This may be because the extent of underride is so high when light vehicles impact the rear of trucks required to have a guard, that offset impact does not make any difference.

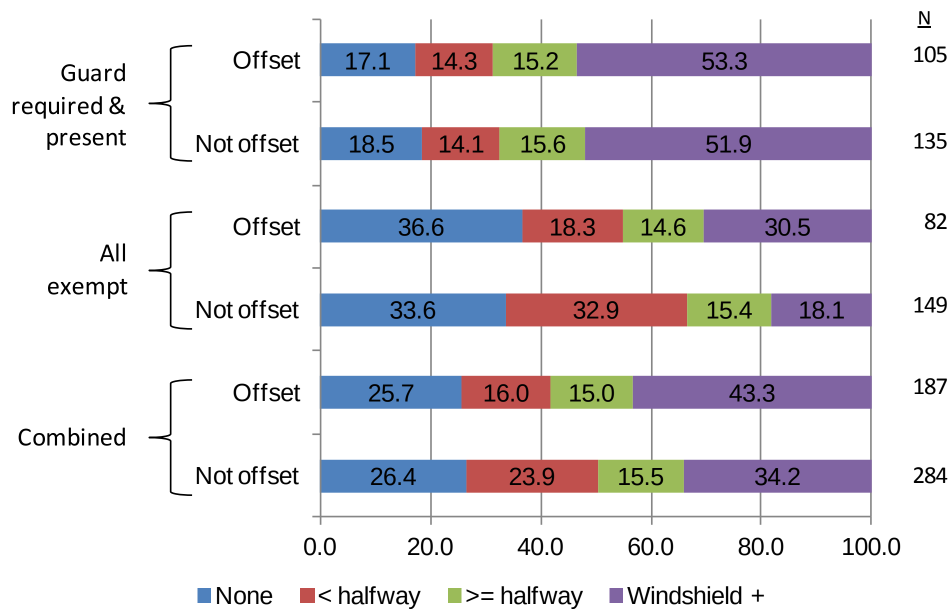


Figure 5. Underride Extent by Offset and Guard Status

4.3. Summary

A total of 977 trucks were struck in the rear in fatal crashes, 2008-2009. These 977 trucks represent 13 percent of all fatal truck involvements. Straight trucks and tractor/trailers are the two primary configurations of trucks in fatal crashes, accounting for 28.7 percent and 62.7 percent of all, respectively. Despite differences in their operations, rear-end struck crashes accounted for about the same percentage of crashes for each. About 13.9 percent of the straight trucks were struck in the rear, and about 13.4 percent of the tractor/trailer combinations.

Most of the striking vehicles in these fatal rear-end crashes were light vehicles—passenger cars, minivans, SUVs, and light-duty pickups—but it may be surprising how many were other trucks and motorcycles. Almost 18 percent of the striking vehicles in the rear-end crashes were other trucks, and 7.4 percent were motorcycles. Along with buses (negligible at 0.2%), 25.3 percent of the vehicles hitting the rear of a truck in a fatal rear-end crash were not light vehicle types that the underride guard standards were designed to protect. However, since the standard is directed at light vehicles, the results in this section focused on the underride of light vehicles.

At least some underride occurred in about 75 percent of rear-end crashes involving light vehicles. Estimates of the extent of underride showed that in about 18.3 percent of the crashes, the underride was less than halfway up the hood of the striking vehicle, but in over half the crashes, the striking vehicle underrode the truck past the halfway point. In almost 36 percent of the crashes, the underride went into the light vehicle's greenhouse. Tractor/trailer combinations had a higher proportion of catastrophic underride than straight trucks, probably because more of their crashes are on high-speed roads and because they tend to have more rear-overhang than straight trucks. On the other hand, tractor/trailer combinations exempted from the requirement to have a rear underride guard, either because of a low cargo bed or wheels-back axle configuration, suffered significantly less underride than tractor/trailer combinations required to have a underride guard. Over 50 percent of light vehicles striking the latter group underrode the trailer to and past the windshield on the light vehicle, compared with only 17 percent of light vehicles hitting a tractor/trailer not required to have a guard.

Almost 40% of the impacts by light vehicles were "offset," meaning that they occurred on the outer left or right third of a truck's rear. Offset was about equally divided between left and right. Though it might be expected that offset would be associated with greater underride, the relationship was found to be indirect, and dependent on whether the truck was required to have an underride guard. Offset mainly resulted in more underride for trucks not required to have a guard. For trucks required to have a guard, there was about the same amount of underride, regardless of whether the impact was offset. This may be because in the latter case, there is already so much underride that offset is not significant.

4.4. Fatalities and injuries in truck rear-end fatal crashes

In the 977 fatal involvements from 2008-2009, in which a vehicle struck the rear of a truck, there were 934 fatalities in the striking vehicles.[8] Light-vehicle occupants accounted for 724 of the fatalities. Some of the crashes include more than two vehicles; in some of the crashes, the fatality occurred in another vehicle in the crash, not the vehicle that struck the rear of the truck. Table 22 provides counts of fatalities and injuries by severity to the occupants of the striking vehicle in these crashes. The column for all striking vehicle types includes occupants of striking trucks, buses, and motorcycles as well as light vehicles. The column for light vehicles is provided because it is the class of vehicles that underride guard protection is designed to address. All injury severities are included, including no injury. The great majority of occupants were fatally injured, and a large number incurred serious A or B injuries.[9]

Table 22 Fatalities and Injuries in Striking Vehicle, Light Vehicles Only and All Vehicle Types

Injury severity	Light vehicles only	All striking vehicles
Fatal	724	934
A-injury	123	146
B-injury	124	152
C-injury	39	57
O-No injury	50	92
Total	1,061	1,381

Table 23 breaks down striking-vehicle injuries by injury severity and underride extent. Only occupants of light vehicles are included in this table. Note that almost three-quarters of light vehicle occupants in these crashes were fatally injured. There was at least some underride for most fatalities, though underride extent could not be determined in the case of 76 fatalities. The windshield-and-beyond category accounted for over a third of the deaths, with 253. Similarly, A and B injuries also more frequently occurred where the light vehicle underrode the rear of the truck at least to some extent. The cases where there was no underride include many where the truck's rear axles were set back or the guard prevented underride or both.

[8] Counts are adjusted for 28 cases where either the striking vehicle could not be identified with certainty or where there was no injury information for the occupants of the vehicles. This adjustment was done by assigning to those cases the average number of deaths and injuries across all vehicle types. The numbers in the tables are rounded to the nearest whole number.

[9] Injuries are classified using the KABCO scale: K means fatal injury, A means incapacitating injury, B means non-incapacitating but evident injury, C means complaint of pain, and O means no injury.

Table 23. Fatalities and Injuries in Light Vehicles by Underride Extent
TIFA 2008-2009

Underride amount	Fatal	A-injury	B-injury	C-injury	No injury	Total
None	150	32	32	18	20	252
< halfway	113	20	16	4	5	158
>= halfway	96	17	14	5	8	140
Windshield+	253	33	42	7	5	340
Unknown amount	36	12	10	1	0	59
Unknown	76	9	10	4	12	111
Total	724	123	124	39	50	1,061

Tractor/trailer combinations with an underride guard accounted for the greatest number of striking-light-vehicle fatalities in rear-end crashes, with 250 out of the total of 724. Table 24 classifies the struck trucks in relation to the 1998 underride guard requirements and whether the trucks were reported to have an underride guard. Straight trucks are categorized as either having a rear underride guard or not. Tractor/trailer combinations are aggregated as either having a guard, qualifying as exempt from the guard requirement, or having a low cargo body bed or wheels back, as defined in the 1998 standard. Bobtails are shown separately, as are all other straight combinations (chiefly straight trucks pulling a trailer) and all other tractor combinations. Straight trucks with no reported underride guard accounted for the next highest number of light-vehicle fatalities, with 160. Again, at least some underride occurred in most of these crashes. The exempt categories accounted for fewer fatalities, and in terms of underride the distribution of fatalities is shifted toward the “none” and “less than halfway” (up the hood) categories.

Table 24. Number of Light Vehicle Fatalities by Truck Configuration/Guard Status and Underride Extent, TIFA 2008-2009

Detailed truck configuration	Underride extent						Total
	None	Less than halfway	Up to halfway	Windshield or more	Unknown amount	Unknown	
Straight, guard	9	11	10	16	0	2	48
Straight, no guard	37	34	31	45	5	8	160
Tractor/trailer guard	36	28	31	130	18	7	250
Tractor/trailer exempt	7	3	4	4	2	5	25
Tractor/trailer low bed	2	1	0	1	0	0	4
Tractor/trailer wheels back	35	26	8	17	6	5	97
Bobtail	1	1	1	2	0	2	7
Straight, other/unknown	10	0	1	9	1	14	35
Tractor, other/unknown	13	9	10	29	4	33	98
Total	150	113	96	253	36	76	724

Table 25 shows the distribution of fatalities by striking light vehicle type and by whether rear underride occurred in the crash. Most of the fatalities occurred in passenger cars, in part, no doubt, because that is the most common light-vehicle type. Underride occurred in almost three-quarters of the fatal injuries to automobile occupants. The relatively high proportion of fatalities with underride for automobiles was in part because many of the other vehicle types have higher fronts and so are less likely to underride in a crash. In the utility vehicle type, primarily sport utility vehicles, about two-thirds of fatalities occurred with some underride. Minivans, large vans, and large pickup trucks all had lower rates of fatalities with underride, though even for these types of vehicles, which tend to have high front ends, a majority of the striking vehicles underrode the truck.

Table 25. Light-Vehicle Fatalities by Light Vehicle Type and Underride

Striking-light-vehicle type	Underride			Total
	None	Some	Unknown	
Automobile	56	258	31	345
Utility vehicle	21	72	16	109
Minivan	19	39	7	65
Large van	7	12	3	22
Compact pickup	10	39	7	56
Large pickup	37	78	12	127
Total	150	498	76	724
Row percentage				
Auto	16.2	74.8	9.0	100.0
Utility vehicle	19.3	66.1	14.7	100.0
Minivan	29.2	60.0	10.8	100.0
Large van	31.8	54.5	13.6	100.0
Compact pickup	17.9	69.6	12.5	100.0
Large pickup	29.1	61.4	9.4	100.0
Total	20.7	68.8	10.5	100.0

Finally, Table 26 shows counts of fatalities to light-vehicle occupants by whether there was underride and by the configuration of the truck that was struck. Straight trucks with no trailers and tractor/trailer combinations account for most of the fatal injuries to light-vehicle occupants, with 222 and 474, respectively. Only 28 of the 724 light-vehicle fatalities came in a collision with something other than these two-truck configurations. Tractor/trailers and straight trucks were more likely to permit underride, and at about the same rate. There was at least some underride for approximately 70 percent of the fatalities in rear-end crashes with the two dominant truck types. In contrast, there was at least some underride in 42.9 percent of the fatal rear-end crashes with straight trucks pulling a trailer. There were only seven bobtail rear-end crashes over the two years, too few to be statistically reliable, other than to note that the bobtail configuration does not contribute significantly to the problem.

Table 26. Light-Vehicle Fatalities by Truck Configuration and Underride

Truck configuration	No underride	Some underride	Underride unknown	Total
Straight	47	154	21	222
Straight/trailer	9	9	3	21
Bobtail	1	4	2	7
Tractor/trailers	93	331	50	474
Total	150	498	76	724
Row percentage				
Straight	21.2	69.4	9.5	100.0
Straight/trailer	42.7	42.9	14.3	100.0
Bobtail	14.3	57.1	28.6	100.0
Tractor/trailers	19.6	69.8	10.5	100.0
Total	20.7	68.8	10.5	100.0

4.5. Summary

In all 977 fatal rear-end crashes from 2008-2009, there were 934 fatalities, 146 A injuries, and 152 B injuries. Considering just light-vehicle crashes, there were 724 fatal injuries in light vehicles, 123 A injuries and 124 B injuries. About 70 percent of the occupants of the light vehicles were killed in the crashes. and 23% received serious (A- or B-) injuries. Fewer than 5% were uninjured. Almost 500 of the light vehicle fatalities occurred with some underride. There was no underride for 150 of the fatalities. The proportion of fatalities that occurred with underride (70%) is about the same for tractor/trailer combinations and straight trucks. There was some tendency for fatalities to be more highly associated with underride in smaller vehicles, but that is because smaller light vehicles such as automobiles experience more underride in the first place, likely because of the lower front ends.

Tractor/trailer combinations with an underride guard accounted for the greatest number of striking-vehicle fatalities in rear-end crashes, with 250 out of the total of 724. Straight trucks with no reported underride guard account for the next highest number of light-vehicle fatalities, with 160. Again, at least some underride occurred in most of these crashes. In this study, the exempt trucks accounted for fewer fatalities, and, in terms of underride extent, the distribution of fatalities is shifted toward the “none” and “less than halfway” (up the hood) categories.

5. Impact speed estimation

5.1. Introduction

This section discusses the process and results of estimating the relative velocity at impact of light vehicles in rear-end fatal crashes. The purpose of this effort is to construct a distribution of the speeds at impact of light vehicles striking the rear of trucks in fatal crashes. This information cannot be used to relate injury risk to impact speeds, because all of the crashes resulted in a fatal injury. However, the results do provide information about the range of impact forces seen in the most serious actual crashes. Some of these crashes are so high-speed that they are not likely to be survivable with any realistic underride guard, but there may be a subpopulation that could be made survivable with an improved underride guard.

Relative velocity estimates were made using information derived by reviewing police crash reports on the fatal rear-end crashes from TIFA in 2008 and 2009. There were 977 fatal rear-end crashes in that data, but not all of the crash reports have sufficient information to estimate impact speeds. An initial filter used to extract crash reports for review required that the data include a valid estimate of the travel speed of the truck. Records that do not include travel speed likely do not include enough information to estimate impact speed. This filter resulted in identifying 596 fatal rear-end crashes for review.

Each case was reviewed by two coders, each experienced in reading and interpreting police crash reports. Cases where the coders differed were discussed and resolved. Difficult or complex cases were reviewed and discussed with an experienced crash investigator and mechanical engineer. A random sample of 50 were also spot-checked by this expert.

Each police crash report was reviewed to estimate the following information:

- Travel speed for each vehicle.
- Skid distance, if any, for each vehicle.
- Roadway coefficient of friction, estimated from roadway condition, for each vehicle.
- Angle of impact, defined as the angle between each vehicle’s vector of motion.

Information from crash reports and any other available case material were used to collect the data. The primary sources of data on the crash reports included:

- Police estimates of travel speed;
- Crash narrative;
- Crash diagram (typically the source of angle of impact, but also frequently skid distances); and

- Witness statements.

Some of the crash reports included crash reconstructions with all the required information. The crash reports in one State recorded travel speed, skid distance, and speed at impact for both vehicles, but this level and specificity of detail is unusual. Information on speeds, skids, angle of impact, and roadway friction was used to calculate the following:

- Truck speed at impact.
- Striking vehicle speed at impact.
- Relative velocity at impact.

In addition, coders recorded the contact point of the primary impact on the rear of the truck as either left third, middle third (effectively 100% overlap), or right third.

Impact speed is computed using the following equation, derived from Clauss and Blower (1999) but based on Lofgren (1976):

$$V_{im} = \sqrt{{V_{tr}}^2 \text{-} (30Df)} \quad (1)$$

Where:
V_{im} = Impact speed, in mph.
V_{tr} = Travel speed, in mph.
D = Skid distance, in feet.
f = Coefficient of friction.

The method of estimation is simple and ignores certain complications. For example, it does not take into account braking that does not leave skid marks. Even when there are skid marks on the road, it does not account for speed loss due to braking prior to wheel lockup. Accordingly, the speeds at impact are conservative, in the sense that the vehicles were going at least as fast as the speeds estimated.

Relative velocity is computed using the following equation:

$$V_{rv} = \sqrt{(\mathrm{V_{imt}} - \mathrm{V_{ims}} * Cos(\theta * \pi/180))^2 + (\mathrm{V_{ims}} * Sin(\theta * \pi/180))^2} \quad (2)$$

Where:
V_{rv} = Relative velocity, in mph.
V_{imt} = Truck speed at impact, in mph.
V_{ims} = Striking vehicle speed at impact, in mph.
θ = Angle of impact in degrees, where 0° is same direction and 180° is opposite direction.

Speeds at impact were computed using Equation 1. Angle of impact was estimated from the crash diagram, and captures the vector of motion of the vehicles, not their orientation. That is, if a vehicle had lost control, was spinning, and struck the rear of a truck with its side, the angle would still reflect the vector of motion, and be recorded as zero. Friction levels were estimated using the following table of coefficients, reflecting variation in the coefficient of friction depending on the pavement type and road surface condition.

Table 27. Roadway Friction Coefficients

Roadway condition	Friction Level
Dry Paved Roads	0.6
Wet Paved Roads	0.4
Icy or snow packed roads	0.2
Wet or dry gravel roads	0.4

- Paved roads include asphalt, concrete, or chip-sealed surfaces.
- The ice and snow friction value of 0.2 was used for roads of all pavement types, including gravel roads.

There were a number of different situations in which useful relative velocity estimates could not be made. These situations include:

- Crashes with insufficient information on initial speed and skid distance;
- Crashes in which the rear-impact occurred after one or more prior impacts, because the uncertainty of the estimates are multiplied with each succeeding impact;
- Crashes in which the striking vehicle was being pushed by another vehicle, so that the impacting light vehicle was effectively coupled with the vehicle that was pushing it into the truck. These cases are not valid because the energy calculation (to estimate impact energies) would require both the mass of the light vehicle and of the other, coupled vehicle; and
- Crashes that do not fit the paradigm of crashes in which a light vehicle strikes the rear of a truck. These crashes are described further in the next paragraph, along with some examples.

The review of the fatal rear-impact crashes identified several cases where the harmful events were arguably not directly related to the performance or suitability of rear underride guards. These are mostly crashes in which the fatal injury in the crash, which is the threshold for inclusion in the TIFA survey data, did not stem from a light vehicle striking the rear of a truck. Seventeen crashes were excluded from the analysis of relative impact velocities because they were deemed not relevant to the performance of rear underride guards. These 17 crashes fell into the following general categories:

- The fatal injury was to a pedestrian struck by a light vehicle prior to its hitting the rear of a truck.
- The fatality was due to impact with cargo, rather than with the rear of a truck. For example, there were three cases where overhanging utility poles or logs penetrated passenger compartments of light vehicles, and the light vehicles never actually hit the truck.
- The fatality occurred due to rollover and ejection, after a minor high-speed impact with a truck resulted in loss of control for the light vehicle, which went off the road and rolled over.
- The fatality occurred elsewhere in the crash. For example, there were fatal crashes involving multiple vehicles and impacts, including a rear-end impact. But the rear-end impact was minor and the fatality occurred in some other collision in the crash.

In the end, there were 193 records with valid estimates of the relative velocity of a light vehicle striking the rear of a truck. Of the 596 total rear-end crashes reviewed, 99 were excluded because the striking vehicle was a truck or bus, 42 were excluded because the striking vehicle was a motorcycle. There was insufficient data to produce a valid estimate in 245 crashes, and 17 were excluded because the rear-impact was not related to the fatality in the crash. Excluding these cases leaves 193 light-vehicle rear-end crashes with relative velocity estimates (Table 28).

Table 28. Rear-Impact Cases Reviewed for Relative Velocity Estimates

Striking vehicle type		Number of cases
Truck, bus		99
Motorcycle		42
Light vehicle	**Valid speed estimate**	**193**
	Insufficient data	245
	Not relevant	17
Total		596

5.2. Results

5.2.1. Light-vehicle rear-end striking fatal crashes

Table 29 provides descriptive statistics for truck speed at impact, light-vehicle (striking) speed at impact, angle of impact, and the relative velocity at impact. Average truck speed at impact was only 16.3 mph, and in fact most trucks were either stopped or nearly stopped at impact. Median truck-impact speed was only 5 mph. Striking vehicles were estimated to be travelling at much greater speeds at impact. Mean light-vehicle impact speed was estimated at almost 60 mph, with a median of 58, which implies that about half of the light vehicles were travelling faster than 58 mph. Examination of the quartile distributions (not shown) showed that 25 percent of striking vehicles were going 70 mph or greater.

Table 29. Descriptive Statistics on Impact Speeds in Fatal Light Vehicle-Truck Rear-End Crashes TIFA 2008-2009

Measure	Mean	Min.	Max.	Median	Std. Dev.
Truck speed at impact (mph)	16.3	0	70	5	20.3
Light vehicle speed at impact (mph)	59.8	15	110	58	15.8
Relative velocity at impact (mph)	44.0	12	90	45	15.3
Angle of collision	5.2°	0°	80°	0°	12.0°

Figure 6 plots the speeds of trucks and light vehicles at impact. There is a positive association between the two speeds, such that higher vehicle speeds for trucks are associated with higher light-vehicle speeds. Though, of course, the light vehicles must always be going faster than the trucks. On the other hand, a substantial fraction of the trucks were stopped or going very slowly at impact. Almost 41 percent of trucks were stopped at the moment of impact, and almost 52 percent were estimated to be traveling at 5 mph or less (noted from a cumulative distribution, which is not shown here). The range of truck impact speed is from 0 mph to 70 mph, but the range of impact speeds for light vehicles is 15 mph to 110 mph (in one incident) at impact.

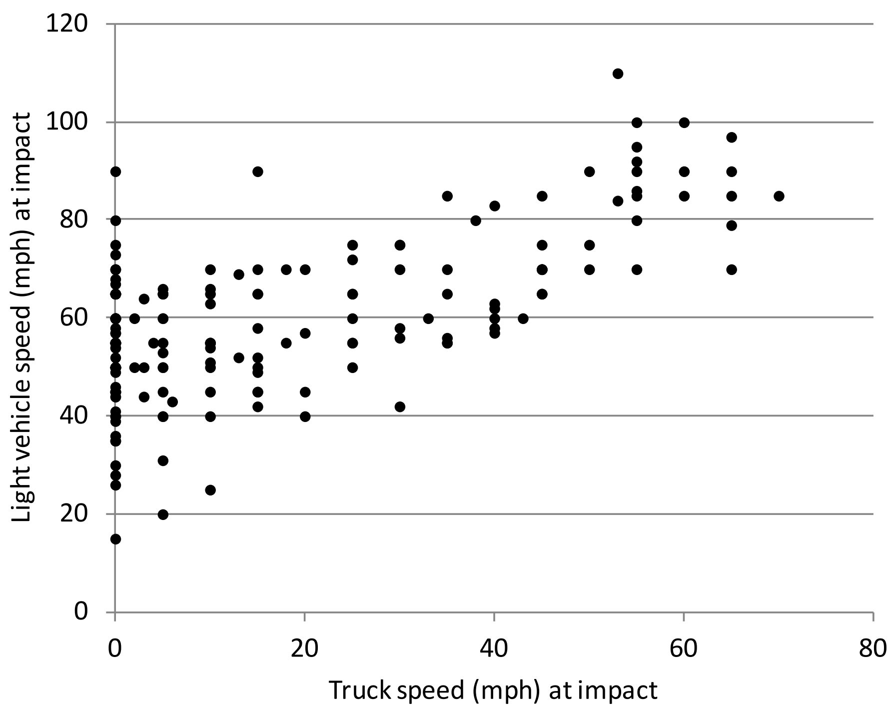


Figure 6. Scatter Plot of Light Vehicle Speed by Truck Speed at Impact

Overall, relative velocities at impact were high, though this is to be expected since the crashes all resulted in fatalities, and crashes in which the fatalities were not related to the rear-impact were excluded. The mean relative velocity at impact was 44 mph, ranging from 12 mph to 90 mph (Table 29). Some of the collisions were obviously high-speed. The mean and median are close, so the values of relative velocity are fairly well balanced on either side of the mean. Figure 7 shows a histogram of the relative velocity of light vehicles at impact into the rear of trucks. The distribution is not normal, but is reasonably symmetrical. The peak of the histogram is around 50 mph, which is the mode of the distribution.

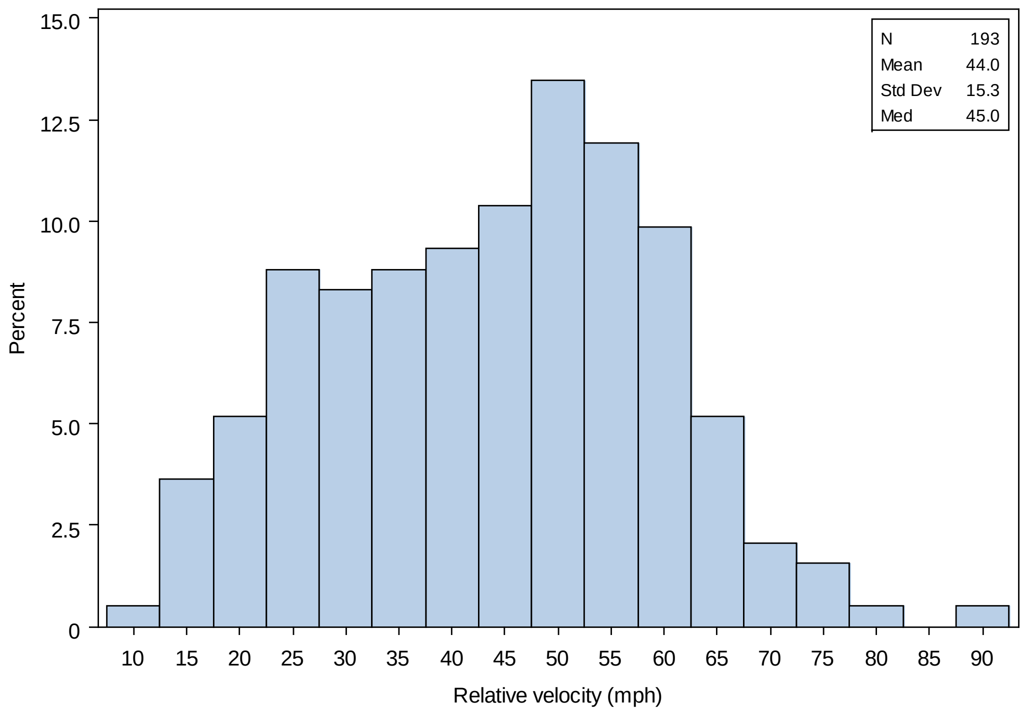


Figure 7. Estimated Relative Velocity, Light Vehicle Striking Rear of Truck

Figure 8 shows the cumulative distribution of the relative velocities of light vehicles into the rear of trucks in fatal crashes. This is a useful way to examine the results because the proportion of impacts below any given speed can be scaled from the figure. For example, the relative velocity of about 32 percent of these rear-end crashes was 35 mph or less. Impacts at 40 mph or less accounted for 43 percent of the crashes. An impact of 35 mph or less may be survivable, if the passengers are properly belted with a supplemental air bag restraint and the front of the light vehicle fully engages the rear-underride guard. On the other hand, a significant proportion of the impacts were at very high speeds. In 25 percent of the impacts, the relative velocity was greater than 55 mph, and the relative velocity was over 60 mph in one out of eight of the impacts.

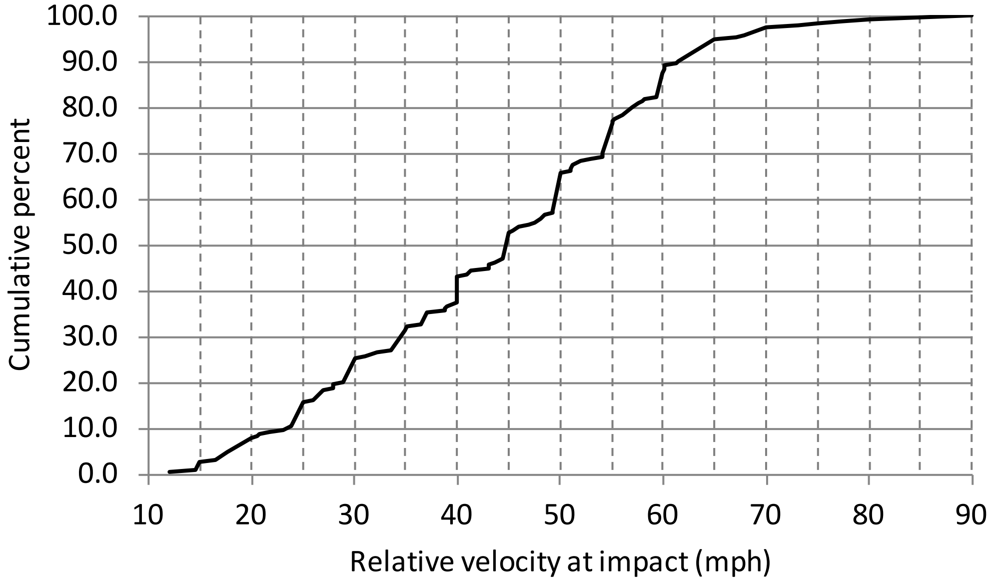


Figure 8. Cumulative Distribution of Relative Velocity, Light Vehicle Striking Truck Rear

Most of the impacts were straight into the rear of the trucks, with only a small proportion at any significant angle. Table 30 shows that in 75.1 percent of the crashes the vectors of motion of the truck and light vehicle were essentially aligned. The table shows the angle of impact in absolute value of degrees, though in the data, angle of impact was recorded as positive or negative degrees, with positive degrees arbitrarily assigned when the light-vehicle vector is pointed to the right and negative when it is pointed to the left. In the majority of crashes, the truck was in lane in front of the striking vehicle and the striking vehicle went straight into it. In almost 90 percent of the crashes, the angle of impact was 15° or less. In only about 7 percent of the crashes was the angle of impact greater than 25°. Large angles primarily occurred when a truck was hit while turning at an intersection.

Table 30. Angle of Impact on Truck Rear

Angle in degree (absolute value)	N	%
0	145	75.1
5	4	2.1
10	13	6.7
15	10	5.2
20	8	4.1
25	2	1.0
30	4	2.1
35	1	0.5
40	2	1.0
45	2	1.0
80	2	1.0
Total	193	100.0

Coders recorded the primary impact point of the rear of the truck in terms of thirds: Left third, middle third, and right third. The middle third really means that the rear of the truck completely overlapped the front of the striking vehicle. Coding left or right third means that the striking vehicle was offset either to the left or right and a substantial portion of the front of the striking vehicle did not engage the truck's rear. Figure 9 displays the diagram used by the coders. (The same diagram was used for the underride supplemental data. It is repeated here for convenience.)

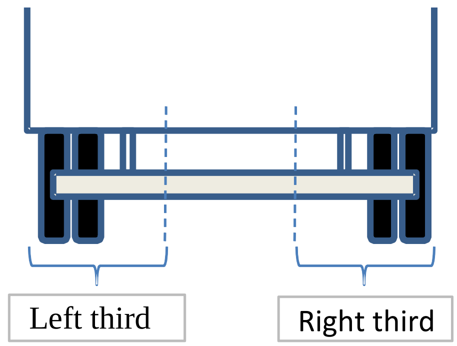


Figure 9. Diagram to Code Rear of Truck Struck

Interestingly, impacts of the trucks' rears were fairly evenly distributed. Over half were impacts where the overlap was complete, (coded "middle third"). There was about an equal number of impacts on the right and left sides of the trucks' rears. Almost 22 percent of light-vehicle strikes were on the left side, and about 23 percent were on the right side. The small difference is not significant. Given the very large proportion of crashes in which the impact was essentially straight-on, many of the impacts to the right or left of the trucks' rear are most likely due to last-second evasive maneuvers to avoid the impact.

Table 31. Contact Point on Rear of Truck, Light Vehicle Striking

Contact point	N	%
Left third	42	21.8
Middle	106	54.9
Right third	45	23.3
Total	193	100.0

Table 32 shows how angle of impact and relative velocity varied by where the light vehicle struck the truck rear in these crashes. The difference in angle of impact is the most interesting. When the middle of the truck was hit – that is, where overlap was complete – the mean angle of impact was only about 2°, though the maximum observed angle was 45°. But where the contact point was either the left or right third, the mean angle of impact was between 9° and 10°, with an observed maximum of 80°. In terms of relative velocity, the means and medians were both higher for the outside thirds, in comparison to the middle, and very similar in magnitude. The average relative velocity for the left third was 46 mph, and for the right it was 47.5 mph. The median relative velocity was 50 mph for both. In contrast, the mean relative velocity when the middle of the rear of the truck was hit was 41.6 mph, with a median of 40 mph.

Table 32. Angle of Impact and Relative Velocity of Light Vehicles by Contact Point on Truck Rear TIFA 2008-2009

Measure	Contact point	Mean	Median	Minimum	Maximum	Std. Dev.
Angle (absolute value, degrees)	Left	9.6	0	0	80.0	16.2
	Middle	1.7	0	0	45.0	6.6
	Right	9.1	0	0	80.0	14.8
Relative velocity at impact (mph)	Left	46.0	50.0	16.4	77.4	15.3
	Middle	41.6	40.0	14.6	80.0	15.1
	Right	47.5	50.0	12.0	90.0	15.5

5.2.2. Light vehicles with air bags and belted occupants

To this point, the analysis of impact speeds on the rears of trucks has included all light-vehicle impacts regardless of restraint use or safety equipment (air bags) installed on the striking vehicles. The set of crashes investigated is limited to crashes with fatal injuries. This set is of great interest because it includes the most serious outcomes. However, whether the occupants of the striking vehicle were using available seat belts or the car was equipped with air bags also affects the probability of a fatal injury. In many of the crashes, striking-vehicle occupants did not use seat belts, or the vehicle was not equipped with air bags, or both. It is of interest to look at just the crashes in which the occupants were using the current common suite of restraints (i.e., seat belts and air bags). Restricting the crash population to these types gives a better idea of crash forces that an underride guard would need to handle when all the protective devices in light vehicles are present and used.

Restricting the set to light vehicles with belted front-seat occupants and an installed air bag reduces the number of records for analysis to 91. Table 33 presents basic descriptive statistics about the speeds of the respective vehicles at impact and their estimated relative velocities. The statistics here may be compared with the same statistics in Table 29, which includes all light vehicles striking the rear of a truck in fatal crashes. Despite the reduced sample size, the speeds are nearly identical. Mean truck speed at impact is 18.1 mph, with a median speed of 10 mph. Most of the trucks are stopped or nearly so. Mean and median light-vehicle (striking vehicle) speeds are slightly higher at 61.1 mph and 60 mph, respectively, compared to 59.8 mph and 58 mph for the full set. But the most telling comparison is for relative velocity at impact, where the two sets are virtually identical.

Table 33. Descriptive Statistics on Impact Speeds, Light Vehicle with Belted Front Seat Occupants, Air Bags

Measure	N	Mean	Min.	Max.	Median	Std. Dev.
Truck speed at impact (mph)	91	18.1	0	70	10	21.4
Light-vehicle speed at impact (mph)	91	61.1	20	110	60	17.2
Relative velocity at impact (mph)	91	43.6	12	80	45	15.8

The distribution of relative velocity at impact for light vehicles with belted front-seat occupants and installed air bags is shown in Figure 10. The range is slightly narrower than for the full set, but the overall shape is similar, without the peak at the 48 mph column. (Figure 10 was constructed using the same axes as Figure 7 to facilitate comparison.)

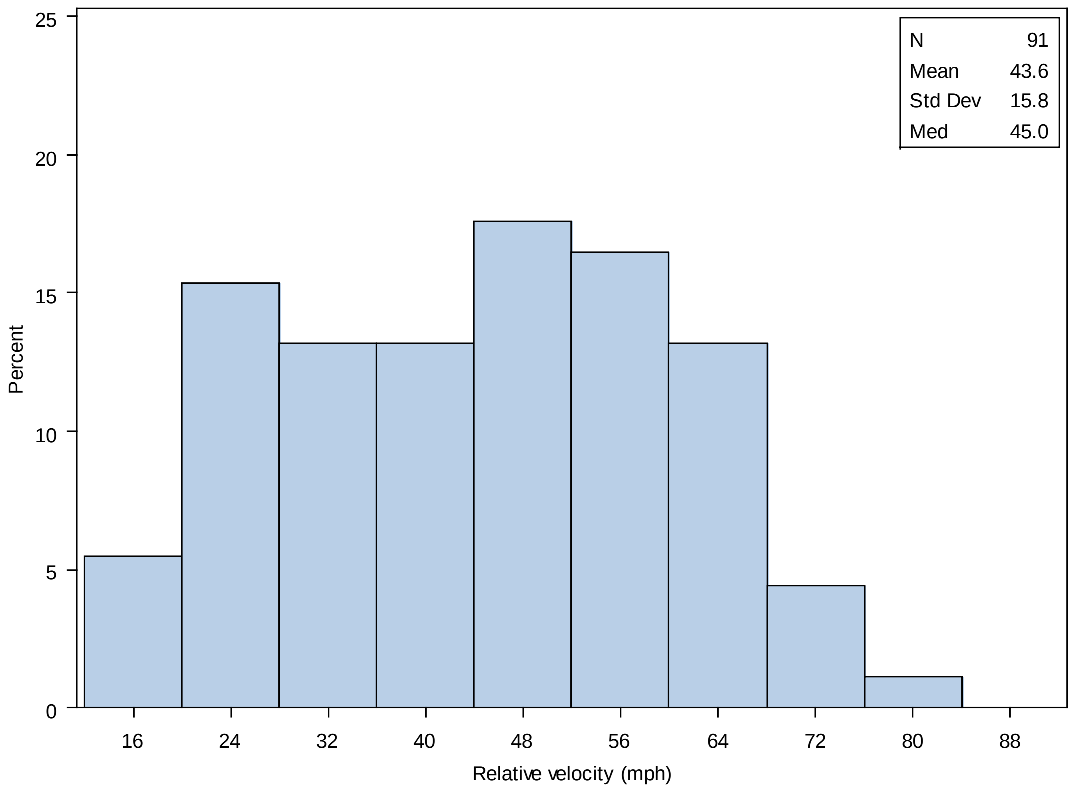


Figure 10. Estimated Relative Velocity, Light Vehicle With Belted Front Seat Occupants and Air Bag

Finally, the cumulative distribution of relative velocities is similar. The relative velocities of about 34 percent of the impacts were 35 mph or less. About 44 percent of the relative velocities were 40 mph or less. On the other hand, about one-third of the impacts were greater than 50 mph, and 10 percent were greater than 60 mph.

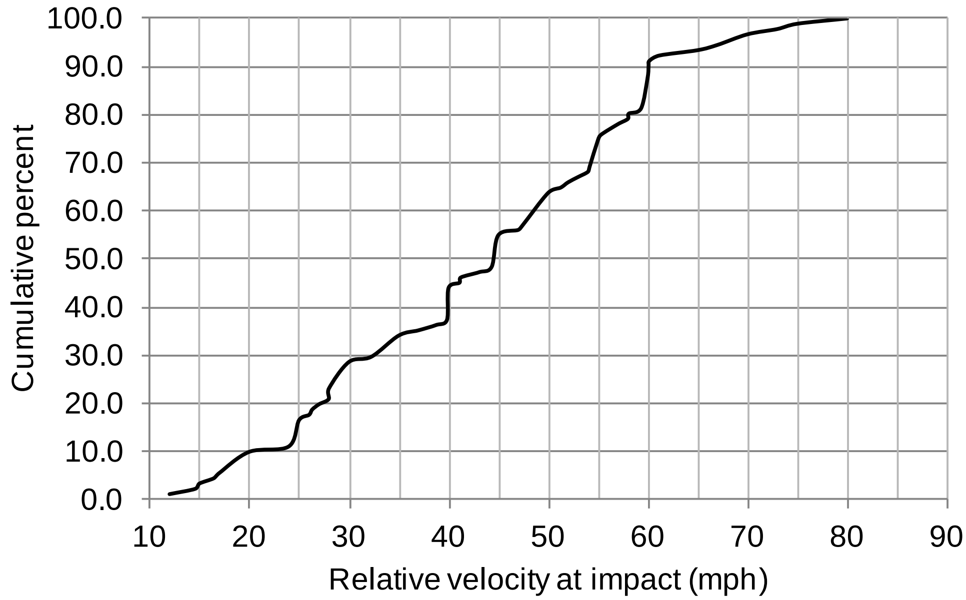


Figure 11. Cumulative Distribution of Relative Velocity, Light Vehicle With Belted Front Seat Occupants and Air Bag

The results in this section (5.2.2) were limited to light-vehicle impact where the front seat occupants were belted and air bags were installed. This set of striking vehicles is of interest because it is limited to cases where the primary required passenger restraint systems against frontal impact were present and engaged. The underride guard by itself cannot be expected to manage all the energy in the collision. Overall, this more-restricted set was statistically similar to the overall set of light vehicles striking the rear of trucks in fatal crashes. Of course, many of the rear-strikes were at speeds that are not realistically survivable.

5.2.3. Impact energy

Available data can also be used to calculate impact energies involved in these crashes. Impact energy may be considered more meaningful in evaluating underride guard standards because they account for differences in the masses of the striking vehicles. The impact of a 2,200 lb. vehicle is obviously much less than that of a 6,600 lb. vehicle. The amount of energy delivered by a striking vehicle is the critical variable in the performance of an underride guard, not just its relative velocity.

In this section, impact energy is calculated in terms of kilojoules (kJ). A joule is equal to the energy expended (or work done) in applying a force of one Newton through a distance of one meter (1 newton meter or N·m). A Newton is defined as the force required to accelerate one kilogram at the rate of one meter per second squared. A common illustration of the energy represented by one joule is the energy released when a small apple falls one meter. Given the much larger kinetic energy in motor vehicle collisions, kilojoules are used. A kilojoule is equal to 1,000 joules. Impact energy was calculated using Equation 3.

$$((M_{im}/2) * V_{rv}^{2})/1000 \qquad 3$$

Where:

E_{im} = Impact energy in kilojoules.
M_{im} = Mass of striking vehicle in kilograms.
V_{rv} = Relative velocity, in meters per second.

The curb weight of the striking vehicles ranged from about 2,200 lbs. to 6,600 lbs., with a mean of 3,606 lbs. and a median of 3,335 lbs.

Table 34 provides descriptive statistics about the impacts of light vehicles on the rears of trucks. The statistics are for light vehicles only. Curb weight could not be determined for one vehicle, therefore it was not included in the relative velocity analysis. The results are displayed for impacts distributed as primarily on the left, right, and middle of the rear of trucks, and then the sum of all rear-end impacts. Just as with the relative velocity analysis, mean kJ are greater for left and right impacts than those in the middle (i.e., with 100% overlap). The energies ranged from about 35 kJ to over 1,200 kJ.

Table 34. Impact Energy in Kilojoules, Light Vehicle Striking TIFA 2008-2009

Impact point	N	Mean	Median	Minimum	Maximum	Std. Dev.
Left	41	385.9	319.5	34.9	932.4	251.8
Middle	106	323.6	280.7	45.0	1206.3	244.4
Right	45	398.1	348.0	36.2	946.6	246.7
All	192	354.4	301.2	34.9	1206.3	247.7

Figure 12 displays the distribution of impact energy graphically. The *x*-axis labels are the midpoint of the range, so the bar labeled 120 shows that about 25 percent of the collisions were between 60 and 180 kJ. The distribution of kJ is skewed right, with some very energetic impacts, including one over 1,200 kJ.

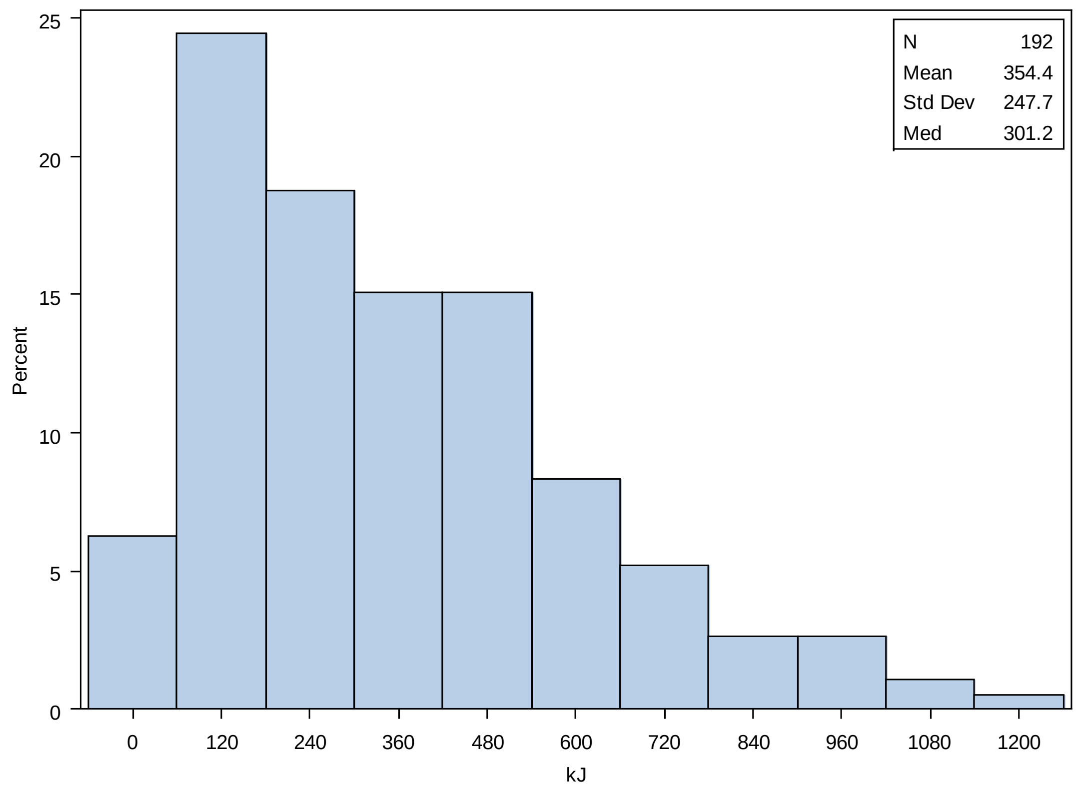


Figure 12. Distribution of Impact Energy in Kilojoules, Light Vehicles Striking, TIFA 2008-2009

Figure 13 shows the cumulative distribution of the rear-strikes in terms of kJ. About half are less than 300 kJ. Up to 100kJ accounts for only about 17 percent of the impacts, and up to 200kJ accounts for only about 34 percent. Almost a third of the impacts are more than 400kJ. This result is quite consistent with the findings for relative velocity–in fact, it is just a re-statement of those results accounting for the mass of the striking vehicles.

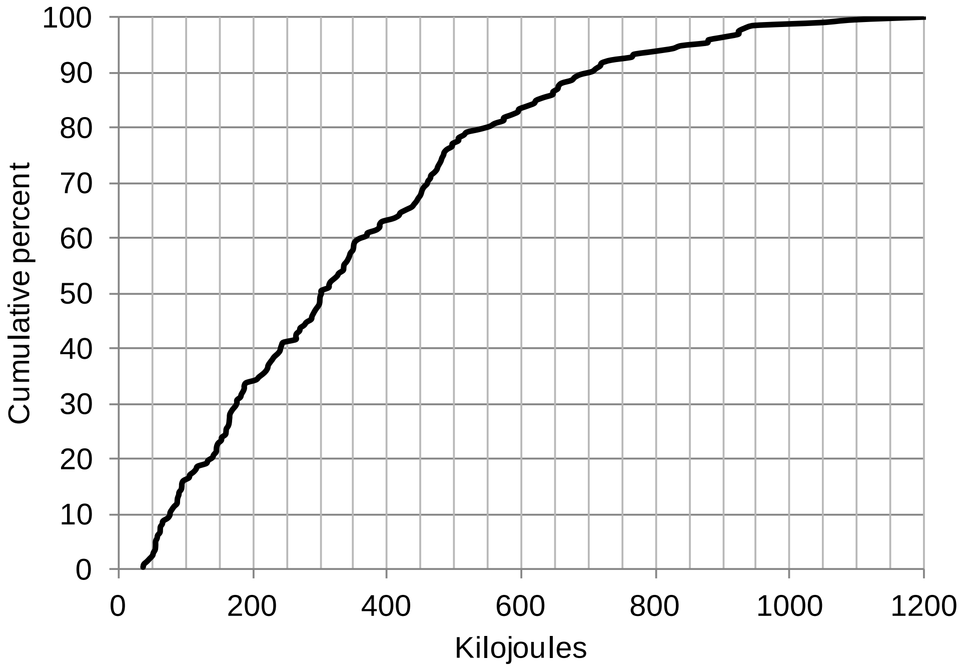


Figure 13. Cumulative Distribution of Rear Impact of Light Vehicles in Kilojoules TIFA 2008-2009

Figure 14 shows a scatter plot of kJ by relative velocity for the crashes. This chart is useful to gauge energies at different relative velocities. The increasing spread at the higher relative velocities is because energy increases as the square of the velocity, so differences in mass produce greater differences in impact energies at high speeds than they do at lower speeds. Most impacts at a relative velocity of 35 mph result in impact energies of 200 kJ or less. Some impacts at 30 mph are 200 kJ or slightly more, but most are 150 kJ or less. All 20 mph impacts are less than 65 kJ.

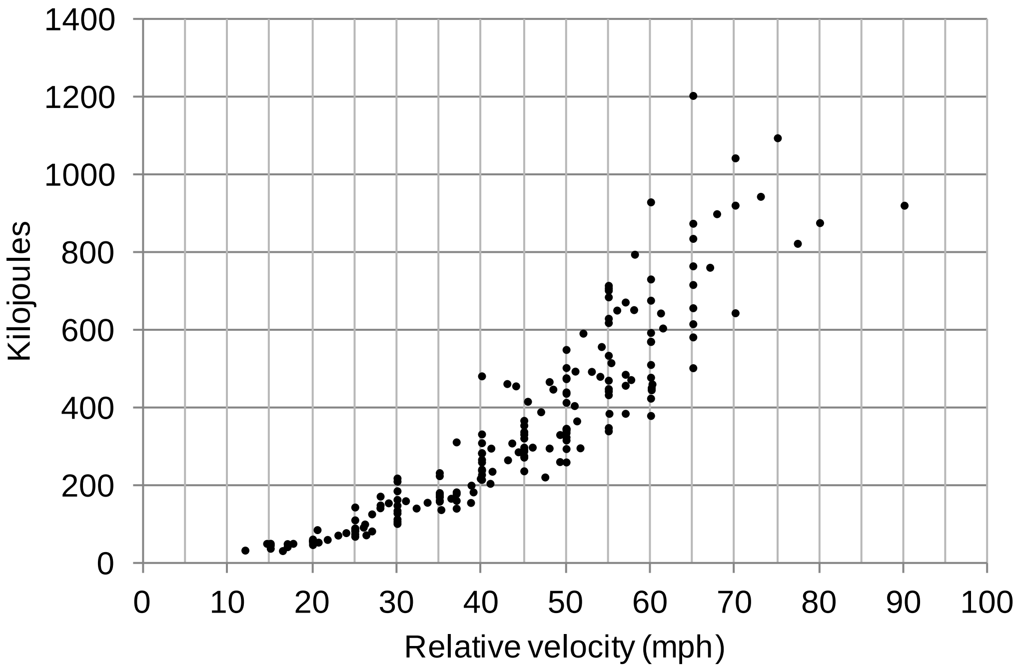


Figure 14. Light-Vehicle Rear-Impact Energy by Relative Velocity of Impact TIFA 2008-2009

5.3. Dimensions of striking vehicles and the rear dimensions of the trucks

Data was collected describing the front dimensions of the striking light vehicles, along with the weight, for the 438 light-vehicle rear-end crashes reviewed to estimate impact speed. (Impact speeds were not estimated for all because of data sufficiency problems, as described in section 5.1.) A proprietary database was used to collect dimension information: Expert Autostats® from 4N6XPRT Systems®. This database covers passenger cars, vans, utility vehicles and pickup trucks sold in the United States since the 1940s. The data include a wide variety of dimensional information, but front dimensions are relevant here (4N6XPRT_Systems 2012). Four dimensions were coded from these data, along with curb weight (used in calculating impact energy). These four dimensions are useful in capturing structures on the front of the striking vehicles that might engage rear underride guards and other rear structures on trucks, depending on the geometrical alignment. The data extracted from the database of light vehicle dimensions included:

- Vertical distance (inches) from ground to front bumper top;
- Vertical distance (inches) from ground to front top of hood;
- Vertical distance (inches) from ground to base of the windshield; and
- Horizontal distance (inches) from front bumper to the base of the windshield.

The front bumper is the initial energy-management structure in forward collisions. The vertical location of the top of the bumper with respect to underride guard height indicates whether the bumper will engage the guard, though of course the top of the bumper will be lower when the vehicle brakes and the nose of the car dives. The top of the front of the hood was taken as a surrogate for the top of the engine. The top of the engine would have been more useful, since the engine is a very substantial and heavy structure, but the top of the front of the hood is a reasonable substitute, since that distance generally should be only two or three inches above the engine in most vehicles. The height of the base of the windshield defines the vertical distance to the bottom of the greenhouse on vehicles. It is typically at the top of the firewall, and above it there is relatively little structure to resist intrusion on the horizontal plane. Finally, hood length provides an estimate of the distance a vehicle can underride a truck before the greenhouse is engaged by the cargo bed, absent any crush to the front structure of the vehicle.

Tables 35 through 38 provide descriptive statistics for each of the four dimensions, broken out by the type of striking light vehicle, and then aggregated over all light vehicles. These statistics only apply to the actual vehicles that struck the rear of trucks in the sample of crashes. They are not intended to be representative of the population of light vehicles actually operating on the roads, though it is expected that a true nationally representative sample would have similar results.

Table 35 gives statistics on the vertical distance to the top of the front bumper. The 1953 underride guard standard vertical height is 30 inches, which was reduced to 22 inches in the 1998 trailer standard. But for automobiles, mean bumper height is only 21.2 inches, with a median of 21 inches. For over half of these automobiles, the front bumper would go under a 1998 standard rear underride guard. Bumpers on the other light vehicle types are generally higher. Median bumper heights for minivans, large vans, and compact pickups range from 22.5 to 24 inches, which would engage the 1998 standard guard by 0.5 inches to 2.0 inches, assuming no braking and no nose dive on the part of the striking vehicle. Large pickups should fare better, which may contribute to their lower rates of underride and lesser extent of underride. The 30-inch guard height in the 1953 standard is higher than all but the maximum heights recorded for bumper tops.

Table 35. Height of Top of Front Bumper (Inches), Striking Light Vehicles

Vehicle type	N	Mean	Median	Min	Max
Auto	191	21.1	21.0	17	26
Utility	77	26.0	27.0	19	33
Minivan	39	22.7	23.0	17	27
Large van	12	23.3	22.5	18	26
Compact pickup	43	23.8	24.0	18	31
Large pickup	75	27.7	27.0	22	34
All	438	23.6	22.0	17	34

The top of the front of the hood is used as an approximation of engine height, though it is not ideal. However, the top of the engine is normally just a few inches below. For light vehicles, the average front hood top was 28.7 inches, with a median of 29 and maximum of 37 (Table 36). The other light vehicle types had higher hood fronts, and the overall average was 35.2 inches, with a median of 35 inches. Large vans and large pickups have the highest front hood tops, averaging 44.1 and 44.2 inches, respectively. The average for minivans is about 10 inches lower, at 34.3 inches, but that is still above the 1953 guard-height standard, and well above the 1998 guard-height standard. However, front hood height is used just as an approximation of engine height, and the main structure of the engine will be below those heights.

Table 36. Height of Top of Front Hood (inches), Striking Light Vehicles

Vehicle type	N	Mean	Median	Min	Max
Auto	191	28.7	29.0	19	37
Utility	77	40.0	40.0	35	45
Minivan	39	34.3	33.0	29	44
Large van	12	44.1	44.5	42	46
Compact pickup	43	38.3	38.0	33	44
Large pickup	75	44.2	44.0	37	53
All	438	35.2	35.0	19	53

The base of the windshield measures the lower bound of the greenhouse on vehicles. Descriptive statistics for this measure are provided in Table 37. For automobiles, utility vehicles, minivans, and compact pickups, mean and median heights are below typical cargo bed heights of trucks. For large vans and pickups, those distances are just above typical cargo bed heights.

Table 37. Height of Base of Windshield (Inches), Striking Light Vehicles

Vehicle type	N	Mean	Median	Min	Max
Auto	191	37.2	37.0	33	44
Utility	77	47.1	47.0	37	55
Minivan	39	44.8	44.0	33	53
Large van	12	53.0	53.0	51	56
Compact pickup	43	44.9	45.0	40	49
Large pickup	75	51.8	51.0	43	58
All	438	43.3	43.0	33	58

Finally, Table 38 addresses the horizontal dimension of the underride problem, with statistics on the front hood lengths of different striking vehicle types. Median hood lengths range from 33 inches for large vans to 52 inches on large pickups. The shortest observed was 8 inches on a minivan, and the largest was 65 inches on an automobile (a 2005 Ford Crown Victoria). The overall mean was 47.4 inches and the median was 49 inches.

Table 38. Hood Length (Inches), Striking Light Vehicles

Vehicle type	N	Mean	Median	Min	Max
Auto	191	49.1	49	33	65
Utility	77	48.8	49	29	61
Minivan	39	35.1	37	8	44
Large van	12	31.8	33	28	34
Compact pickup	43	47.8	47	44	54
Large pickup	75	50.7	52	15	57
All	438	47.4	49.0	8	65

Figure 15 compares the relevant distributions of the rear dimensions of trucks involved in fatal crashes and the front dimensions of the striking light vehicles. For trucks, boxplots of cargo bed heights are shown for straight trucks, straight trucks with trailers, and tractor/trailer combinations. All trucks, for which data could be obtained, involved in fatal crashes from 2008-2009 are included, not just those struck in the rear. Reference lines for the 1953 and 1998 guard-height standard are shown, at 30 inches and 22 inches, respectively. The striking light vehicles represented in the figure are limited to those just discussed: the 438 light vehicles for which an attempt was made to estimate impact speed. In the boxplots the cross identifies the mean, the horizontal line through the box represents the median, the box itself encompasses the middle two quartiles (the half of cases in the middle of the range), and the whiskers capture the full range.

The chart is a telling representation of the geometrical alignment in the vertical plane of the rear dimensions of trucks and the front dimensions of striking light vehicles. Most light-vehicle bumpers are entirely below the cargo beds of almost all straight trucks and tractor/trailer combinations. There is somewhat better alignment with trailers pulled by straight trucks, but straight trucks with trailers account for only a small part of the truck population. The situation is somewhat better for bumper alignment with 1998 standard guards, but even so, for almost 51 percent of light vehicles in this set, the top of front bumper was at the bottom of the 1998 standard, measured statically. Almost 95 percent are under the 1953 standard guard height. With respect to the front hood top height and base of the windshield height, almost all are under typical cargo bed heights for tractor/trailers. Over 98 percent of front hood heights are below the common cargo bed height of 48-50 inches, and almost 82 percent of base-of-windshield heights are below that level.

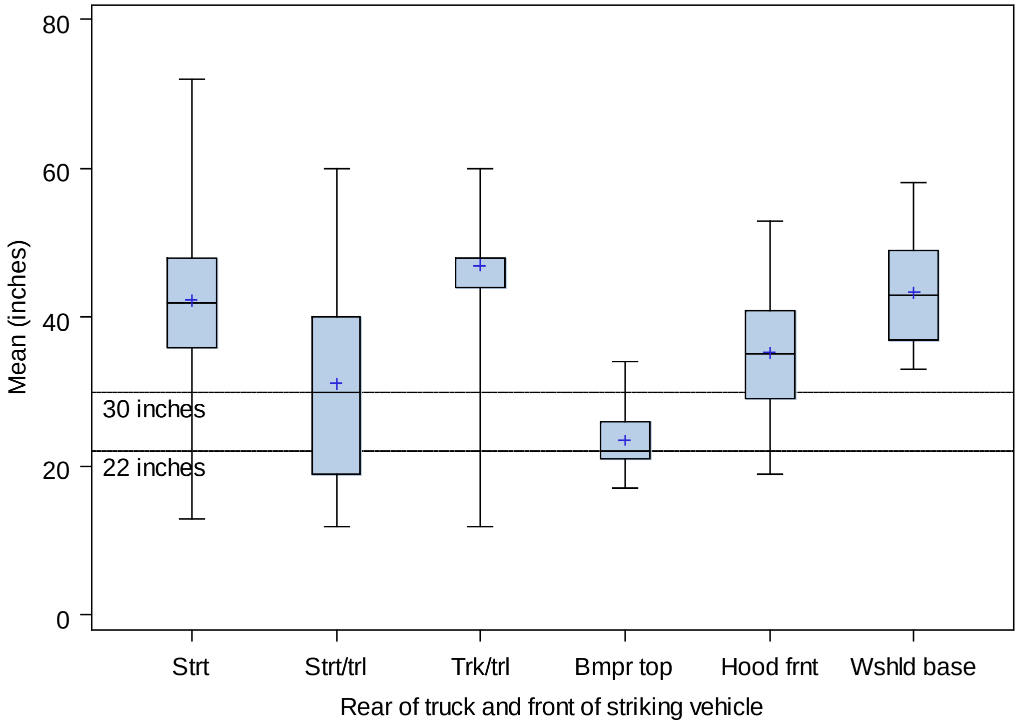


Figure 15. Striking Vehicle Front Dimensions and Truck Cargo Bed Heights

Figure 16 compares hood length on the striking vehicles with the observed rear overhang of truck cargo bodies collected on trucks in fatal crashes, 2008 and 2009. Mean and median hood lengths for the striking light vehicles are close to the mean and median rear cargo body overhangs on tractor/trailer combinations. This means that half of the light vehicles could underride half of the tractor/trailer combinations at least up to the base of the windshield before the front bumper of the light vehicle would encounter the rear face of trucks' rear tires. Typically, trucks with rear cargo body overhang of more than a few feet do not have low cargo bodies or rear-mounted equipment, so in these cases, the only protection for the striking vehicle is an underride guard.

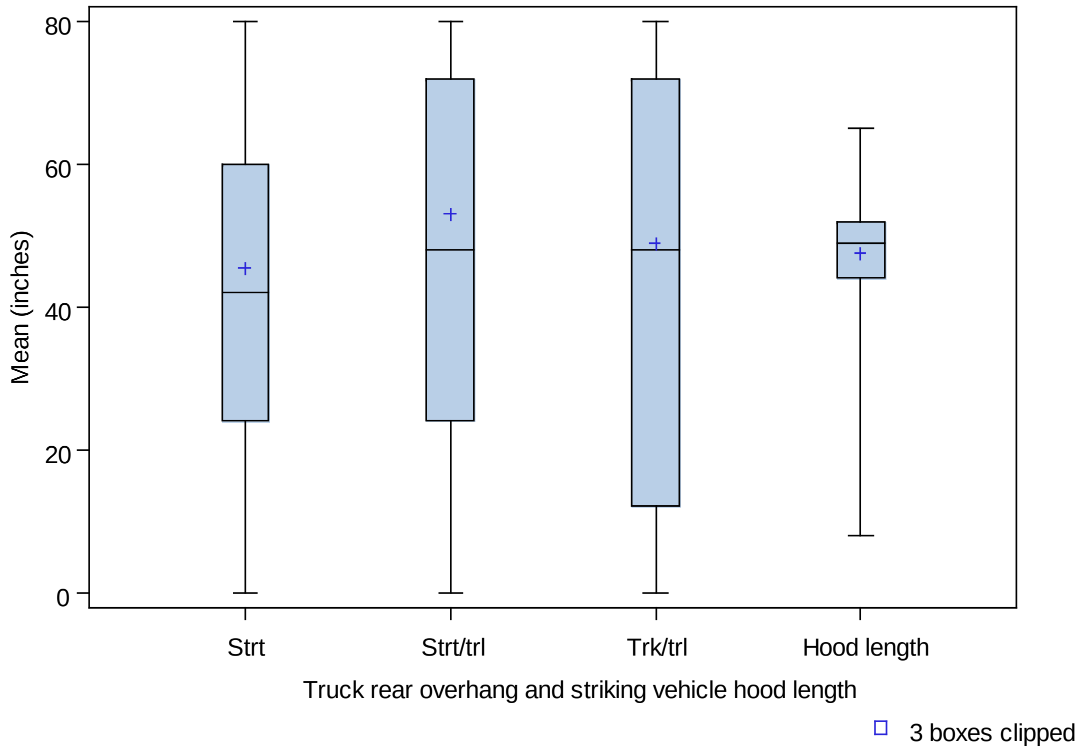


Figure 16. Striking Vehicle Hood Length and Truck Rear Overhang

5.4. Summary

Impact speeds and relative speed of trucks and light vehicles at impact were estimated for 193 light vehicles that struck the rear of a truck in fatal crashes. While this information does not directly illuminate the relationship between fatal injury and relative velocity, it does provide information about the range of impact forces seen in fatal rear-end crashes.

The mean velocity of trucks at impact was estimated at 16.3 mph, but almost 41 percent of the trucks were stopped at impact, and 52 percent were estimated to be going 5 mph or less (including stopped). For striking vehicles, the mean speed was 59.8 mph at impact, with a range of 15 mph to 110 mph. Relative velocity is more meaningful with respect to impact. Overall, the mean relative velocity at impact was estimated at 44.0 mph. About 32 percent of the impacts occurred at relative velocities below 35 mph, and in 43 percent, the relative velocity was 40 mph or less. However, many of the impacts were at very high relative velocities and probably not survivable. In over 25 percent of the cases, relative velocity was over 55 mph and in 13 percent it was more than 60 mph.

Interestingly, impacts on the left or right third of the truck's rear (offset collisions) were at higher relative velocities—46 mph to 47.5 mph—than to the middle at 41.6 mph. Also, the angle of impact was greater in offset impacts, though the average angle of impact on the left and right thirds was only about 9.1° to 9.6°, compared with 1.7° in the middle. Over 75 percent of the impacts are at 0° and from 0 to 10° contains about 84 percent of impacts.

Estimates were also made for light vehicles where the front seat occupants used seat belts and the vehicle was equipped with front air bags. This set represents striking vehicles using currently available and required frontal impact protection. Results for this group were similar to those for the whole population of light vehicles for which impact speed estimates could be made.

For trucks, the mean speed at impact was 18.1 mph, and for light vehicles it was 61.1 mph. Relative velocity was estimated at 43.6 mph. About 34 percent of the impacts in this group were at 35 mph or less; about 44 percent of the relative velocities were 40 mph or less. On the other hand, about one-third of the impacts were greater than 50 mph, and 10 percent were greater than 60 mph. All these results are very similar to the earlier results for all striking light vehicles.

Available data was also used to calculate impact energies involved in light-vehicle-striking crashes. Impact energy may be considered more meaningful in evaluating underride guard standards because energy accounts for differences in the masses of the striking vehicles. Estimates were made in kJ. Overall, the average impact energy was 354.4 kJ, with a range between 34.9kJ and 1,206.3kJ. Impacts up to 100kJ account for 17 percent of the cases, and impacts up to 200kJ account for 34 percent. Almost a third were over 400kJ. Just as with the relative velocity analysis, mean kJ are greater for left and right impacts than those in the middle, i.e., with 100-percent overlap. Mean kJ for impacts on the left and right of the rear were 385.9kJ and 398.1 kJ, respectively, while the mean was 323.6kJ for impacts on the middle. Most impacts at a relative velocity of 35 mph resulted in impact energies of 200 kJ or less. Some impacts at 30 mph were 200 kJ or slightly more, but most were 150 kJ or less.

Key front dimensions for the light vehicles in this analysis were extracted from a proprietary database. The dimension include the height of the front bumper top, height of the front hood top, height of the base of the windshield, and the length of the hood from the front bumper to the base of the windshield.

Most light-vehicle bumpers are entirely below the cargo beds of almost all straight trucks and tractor/trailer combinations. There is somewhat better alignment with trailers pulled by straight trucks, but straight trucks with trailers account for only a small part of the truck population. The situation is somewhat better for bumper alignment with 1998 standard guards, but even so, for almost 51 percent of light vehicles in this set, the top of the front bumper was at the bottom of the 1998 standard, measured statically. Almost 95 percent were under the 1953 standard guard height. With respect to the front hood top height and base of the windshield height, almost all are under typical cargo bed heights for tractor/trailers. Over 98 percent of front hood heights are below the common cargo bed height of 48-50 inches, and almost 82 percent of base-of-windshield heights are below that level.

Mean and median hood lengths for the striking light vehicles are close to the mean and median rear cargo body overhangs on tractor/trailer combinations. This indicates that half of the light vehicles could underride half of the tractor/trailer combinations at least up to the base of the windshield before the front bumper of the light vehicle would encounter the rear face of trucks' rear tires.

6. Override and underride in front and side impacts

6.1. Introduction

Side underride and front override in truck crashes have not been systematically studied because of the lack of data to identify and characterize the events. The Large Truck Crash Causation Study (LTCCS) data provide an opportunity to examine in a preliminary way the incidence of side underride and front override. The LTCCS case material include scene diagrams and photographs, photographs of all of the vehicles involved, and a relatively detailed narrative of the events of the crash, including the events pertinent to each vehicle involved. There is a standard set of photographs of each vehicle taken from prescribed positions around the vehicle, so that the entire perimeter of the vehicle is photographed. These photos are well-suited to determine if override/underride occurred to the truck and if the striking vehicle experienced passenger compartment intrusion. (NHTSA/FMCSA 2012).

The clinical review of the LTCCS is intended as an exploratory evaluation of front override and side underride in serious truck crashes. The LTCCS review is expected to provide a preliminary estimate of the incidence of front override and side underride (i.e., whether there is a significant safety problem) and an understanding of the critical elements needed to determine the most effective means to address the problem. The review of front and side impacts in the LTCCS data is a pilot survey that can support a decision as to whether a formal survey of front override and/or side underride is needed.

6.2. Data collection

LTCCS cases were selected for review based on the geometry of the crash. Cases were selected from crash types in which the front or side of a truck was struck. All configurations of vehicles identified as trucks were taken, so the cases reviewed included all types of trucks, including straight trucks, straight trucks pulling trailers, and tractors operating bobtail (no trailer) or pulling any number of trailers. Finally, the other vehicle was restricted to light vehicles, including passenger cars, minivans, light duty pickup trucks, and sport utility vehicles. Accordingly, the crashes selected for review involve a collision between a light vehicle and the front or side of a truck.

A total of 419 crashes were selected for review, of which 411 were determined to be valid collisions between a light vehicle and the front or side of a truck. Table 28 shows the cross-classification of the 411 valid LTCCS cases by crash configuration and truck combination type. Each crash geometry implies impact to a particular plane of a truck. For example, the rear-end striking geometry implies that the crash impact was to the front plane of a truck, while the same direction sideswipe implies that the side of a truck is involved. It should be kept in mind that the orientation of vehicles can change if they maneuver to avoid the crash or if the crash occurred because of loss of control. In such cases, the plane of contact may be different from what is implied by the overall geometry of the vehicle motions.

Table 39. Crash Configuration and Truck Combination Type, LTCCS Crashes Selected for Review

Crash geometry	Straight	Straight, trailer	Bobtail	Tractor-semitrailer	Tractor-double	Unknown	Total
Rear-end striking	29	1	0	67	1	0	98
Same direction sideswipe	10	2	5	73	4	3	97
Head-on	12	3	2	12	3	0	32
Opposite direction sideswipe	10	3	1	27	3	1	45
Truck turns across light vehicle path	10	2	0	21	2	0	35
Light vehicle turns across truck path	23	3	1	22	1	0	50
Straight paths, truck into light vehicle	15	2	1	11	3	0	32
Straight paths, light vehicle into truck	6	1	1	12	2	0	22
Total	115	17	11	245	19	4	411

The distribution of truck configurations is reasonable, and similar to the general population of trucks in crashes involving serious injuries. The two dominant types are straight trucks and tractor-semitrailers, which account for 28 percent and 59.6 percent of the cases, respectively. Bobtails (tractors without a trailer) account for fewer than 3 percent of the trucks, while straight trucks pulling a trailer are about 4.1 percent, and tractors with 2 trailers (tractor-double) are about 4.6 percent of the review cases. Almost 70 percent of the trucks were pulling a trailer, while the remaining trucks (straight trucks and bobtails) were single-unit vehicles with no trailer. Truck configuration was not coded for four trucks because they were involved in hit-and-run crashes.

The LTCCS cases are based on a sample of fatal and serious injury (incapacitating and non-incapacitating but evident) truck crashes. The LTCCS file includes both records for crashes that were sampled for the study as well as records from the pilot phase of the project. The records sampled for the main phase of the study have sample weights, which can be used to calculate estimates of the whole population of crashes from which the LTCCS crashes were sampled. The pilot phase cases do not have sample weights, or rather the sample weights are zero. The selected cases include both types in order to maximize the number of crashes available for review. The distributions shown therefore do not account for the population weights, but are based on the unweighted counts of cases reviewed.

Two coders separately reviewed all 411 crashes, using all appropriate case materials in LTCCS. After the review, any differences were identified and reconciled. The two coders were each very experienced with trucks, truck crashes, and crash reports. One of the coders is an editor on the TIFA project, former truck driver, and holder of a commercial driver's license. The other is one of the authors of this report. A third reviewer, a mechanical engineer and experienced crash investigator, spot-checked a sample of 50 crashes. This reviewer is the other author of this report.

The coders recorded the following data elements:

- Whether the crash met the selection criteria (front or side impact).
- The vehicle number of the light vehicle.
- Whether there was override or underride, coded as yes/no.
- Whether the light vehicle experienced passenger compartment intrusion, coded as yes/no.
- The impact point on the truck, using the standard diagram from FARS.
- The impact point on the light vehicle, using the standard diagram from FARS.
- If the impact was to the front of the truck, whether the impact was to the left, right, or middle of the front.
- If the impact was to the front of the light vehicle, whether the impact was to the left, right, or middle of the front.
- Whether the light vehicle struck the truck's axles, coded as yes/no.
- Truck front axle set back on the truck, coded yes/no.
- Truck front bumper height, coded above the front axle, at the front axle, or below the front axle.
- Truck cargo bed height, coded as standard (dock height), high, or low.
- Equipment mounted on the side of the truck, coded as yes/no.
- Description of the equipment.
- Whether the cargo bed prevented underride, coded yes/no/not struck.
- Whether the axles prevented underride, coded yes/no/not struck.
- Whether the side equipment prevented underride, coded yes/no/not struck.
- A comment field, describing the crash and any details pertinent to override/underride or passenger compartment intrusion.

Some of the crashes involved multiple impacts between the subject truck and other light vehicles involved in the crash. When there were multiple impacts between a truck and the selected light vehicle, the first impact that resulted in override or underride was coded. If there was no override or underride, then the first impact was coded.

Some definitions for the more important fields are included here:

Override/underride was identified if there was evidence that any portion of the light vehicle went under the truck. Photos of both the truck and the light vehicle were examined for this evidence, as well as remarks in the researcher's narrative, and even the scene diagrams. Some scene diagrams clearly depict light vehicles under trucks at points in the crash sequence. The definition of override/underride in NHTSA's Crashworthiness Data System (CDS) file includes any uneven crush on the light vehicle in the vertical plane, with greater crush above than below. On trucks, the coders looked for evidence of damage to the undercarriage or bottom of cargo bodies. Some LTCCS cases included photos taken on scene, clearly showing a light vehicle under a truck.

PCI (passenger compartment intrusion) was recorded if there was any deformation of the passenger compartment, including distortion of the passenger compartment such as the A-pillar being pushed back. Coders also included cases where the knee bolster or below was crushed back into the compartment. The standard set of photos taken of virtually every vehicle includes interior shots of the front and rear seating area, so this type of intrusion could be identified. PCI was coded almost exclusively from post-crash photos of the light vehicle.

The FARS "clock-face" diagrams were used to code the **area struck** on trucks and light vehicles. The diagrams used are reproduced from the FARS Coding and Validation Manual (NHTSA, 2011). Though the diagrams apparently use a "clock-face" metaphor, in fact the points correspond to specific locations on trucks and light vehicles. Figure 17 shows the diagrams used for tractor-semitrailers and light vehicles. The point for 11 corresponds to the left side of a truck-tractor's cab, 6 corresponds to the entire rear of both a truck and a car. The point for 10 identifies the portion of the tractor under the front of a semitrailer (the kingpin position), and on a car it is the point at the windshield. Scene diagrams and photos of the vehicles were used to code these fields.

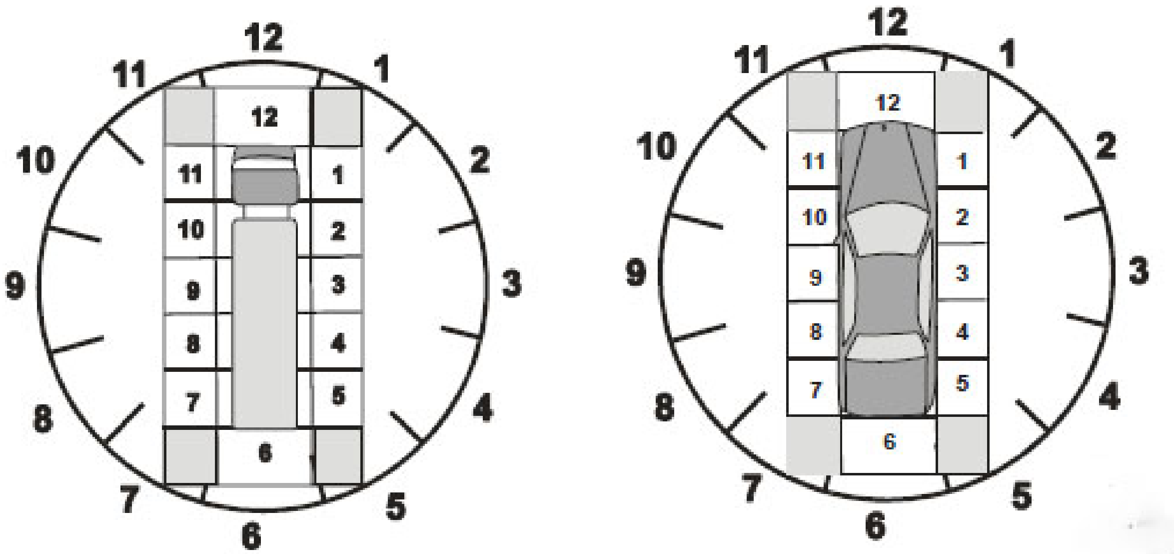


Figure 17. Truck and Car Diagrams Used to Code Impact Point

The illustration to the right shows **setback** and set forward front axle configurations for one truck model. In this example, the setback position is 22.1 inches back from the forward position. Setback was coded "yes" if the face of the steer axle tires appeared to be 12 inches or more behind the front bumper. This distance was established by analogy with the rear axle setback distance standard for trailers. (Rogers, 2007).

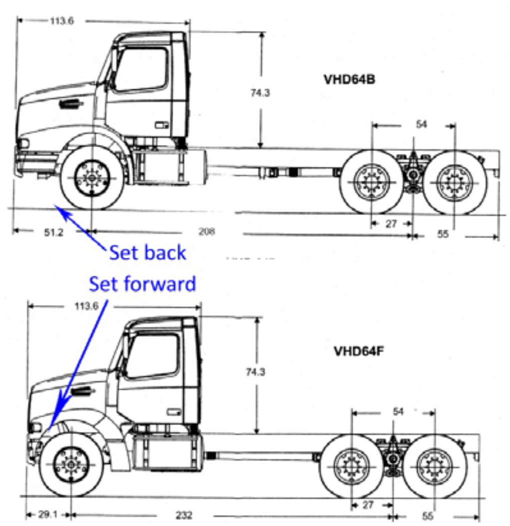


Figure 18. Front Axle Location in Truck

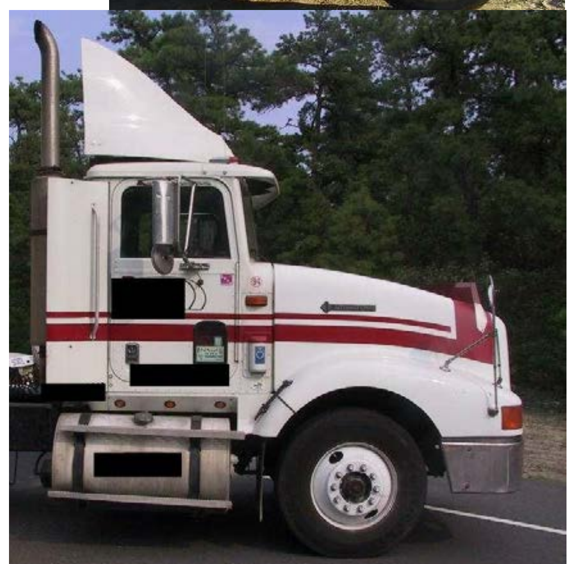
This trailer illustrates the typical **cargo body height** that is classified as "high." Many liquid and dry-bulk tankers were also classified as high cargo beds because the shape of the tank.

This two-axle van trailer defines standard cargo bed height. Standard height is established by dock height, which is typically about 50 inches. Depending on the application, trailer cargo beds are designed to this height to facilitate loading and unloading at standard docks.

Low boys–flatbed trailers often used to haul heavy equipment–are possibly more typical, but this livestock trailer illustrates some features of trailers classified as low bed. Many beverage trucks and trailers also have low cargo beds.

The bumper on this tractor was classified as “above axle” in the **bumper height** field. The bottom of the bumper is higher than the center of the axle, in this case, several inches higher. Bumpers that were discernibly higher than the center of the axle were classified as “above axle.”

On this tractor, the bottom of the bumper appears to be right at the level of the center of the axle. The axle is also classified as “set back.”



The bumper on this tractor is classified as “below axle,” because the bottom of the bumper is below the center of the front axle. This bumper is a factory-original, but many after-market bumpers are similar. Many tractors are fitted with broad and low chrome bumpers to dress up the appearance of the tractor.

Side-mounted equipment was recorded if the truck or trailer had some sort of equipment mounted on the side of the vehicle that appeared to be substantial enough to obstruct underride. Evidence for side-mounted equipment came almost entirely from photographs of the sides of the trucks. In some cases, the nature of the equipment was described in the researcher's narrative, but for the most part, the photographic evidence was all that was available. Tool boxes, substantial tanks, and sturdy spare tire racks were accepted, but items such as aerodynamic skirts were excluded. Tag axles were accepted as mounted equipment because they can be either in the lift position, in which they would not function as an axle, or down, when they serve as an axle. In either position, however, they can be a substantial obstruction to override/underride if struck.

Hit axles was coded "yes" if there was any evidence that the light vehicle contacted any axle on a truck. Evidence includes a mention in the researcher's narrative and photographic evidence, for example, scuff marks on a tire or deformation of a wheel. In many cases, damage from a light vehicle striking an axle is labeled specifically in photos documenting the damage.

Cargo bed prevent, **axles prevent**, and **equipment prevent** were coded "yes" if there was evidence that the light vehicle struck the cargo bed, axles, or side-mounted equipment, respectively, and there was no override/underride. In the case of the cargo bed and side-mounted equipment, the evidence came primarily from photographs documenting damage or contact marks.

6.3. Results

In the first part of this section, statistics are presented that describe the trucks in terms of the features that could impede override/underride. These features include front axle setback, front bumper height, cargo bed height, and equipment mounted on the side of a truck or trailer that appears sturdy enough to prevent underride.

6.3.1. Physical description

Axle setback means that the leading surface of the tire was setback from the front bumper by more than 12 inches. The criterion for setback used here is by analogy to the 1998 rear underride guard standard, which requires an underride guard if the surface of the tires is more than 12 inches from the rear of the cargo body. Within the industry there appears to be no fixed standard for the use of the term, though it is often used for axles setback 16 inches or more. It is important to be aware that the definition used here is somewhat less than typical usage in the industry. In relation to override/underride, axle setback allows the possibility for more penetration in frontal collisions, because the tires are moved rearward from the front bumper. On the other hand, a setback axle provides space that could be used to manage energy in frontal collisions (Klingenberg, 1987). In the sample of cases used for this analysis, newer trucks were more likely to have the front axle set back than older model trucks. The average model year for axle setback trucks in these data was four years newer than trucks with the axle set forward.

Overall about 56.2 percent of the trucks had front axles that appeared to be set back (Table 40). The proportion of setback front axles is somewhat less for straight trucks than tractors, 50.8 percent to 59.6 percent. This difference is probably related to the application of the trucks, because there was no significant difference in the mean or median models years by truck configuration.

Table 40. Front Axle Setback by Power Unit Type
Selected LTCCS Crash Types

Power unit type	Front axle setback			Total
	Yes	No	Unknown	
Straight	67	62	3	132
Tractor	164	104	7	275
Unknown	0	1	3	4
Total	231	167	13	411
Row percentages				
Straight	50.8	47.0	2.3	100.0
Tractor	59.6	37.8	2.5	100.0
Unknown	0.0	25.0	75.0	100.0
Total	56.2	40.6	3.2	100.0

Figure 19 shows the distribution of bumper height by truck configuration. Lower bumpers engage more of the mass of light vehicles in collisions, while higher bumpers permit more override. Bumper height clearly varies by the type of power unit. On straight trucks, whether straight truck alone or pulling a trailer, about half of the bumpers are at axle height, but a large proportion are higher than the center of the axle. For straight trucks with trailers, it is about 29.4 percent, but for straight trucks with no trailers, 44 percent were judged to have bumpers higher than axle height. Many of these vehicles are construction vehicles, such as dump trucks and concrete mixers. For tractor combinations, a significantly larger proportion have bumpers that extend below axle height. About 42.7 percent of tractor-semitrailers had low bumpers, 47.1 percent at the axle, and only 10.1 percent over axle height. The distribution of bumper height on tractor-double combinations was more similar to tractor-semitrailers than straight trucks, with bumpers extending below axle height on 35.3 percent, at the axle on 41.2 percent, and above the axle at 23.5 percent. There were only 19 doubles and 17 straight trucks with trailers, so the distributions are less stable for those combinations. Still, it is clear that many tractors have front bumpers that extend fairly low. Over-the-road tractors often have after-market bumpers that are low, and many newer tractors are designed with a more aerodynamic front, which includes lower front bumpers.

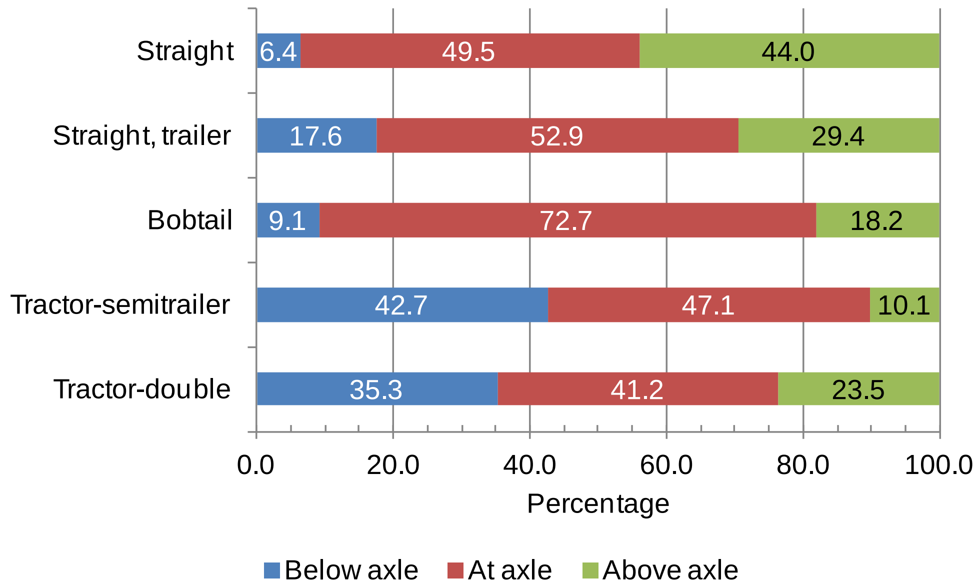


Figure 19. Front Bumper Height by Truck Configuration
Selected LTCCS Crash Types

Cargo bed height can clearly affect the probability of underride in side collisions with light vehicles. Cargo bed height is recorded for either the cargo body of a straight truck or the trailer cargo body of a combination vehicle. For straight trucks pulling trailers, cargo bed height is recorded for the unit that was struck. The “standard” bed height is for the usual dock height of about 50 inches. Virtually all van trailers that are not for special applications like home movers are standard height. Examples of high cargo beds include some tankers, rock dump bodies or trailers, and construction vehicles like concrete mixers. Low cargo beds include lowboy trailers for heavy equipment hauling, moving vans, livestock vans, and some specialized work trucks like utility bodies.

In the crash population examined here, most cargo bed heights were judged “standard,” as would be expected, but cargo bed height clearly varies by truck configuration. Over 70 percent of tractor-semitrailers had standard height cargo beds, which makes sense because they are van trailers used for general freight and need to access standard docks. Most straight trucks also had standard height cargo beds, but only a slight majority (Table 41). High cargo beds were recorded for 27 percent of straight trucks, and 17.4 percent were judged to have low cargo beds. The high beds included some concrete mixers, and some very heavy-duty rock dumps. The low cargo beds were more often utility and trucks with working bodies. The percentage of high cargo beds among tractor-double combinations was not expected, but there were only 19 doubles in the data, and those combinations included several heavy dump trailers.

Table 41. Cargo Bed Height by Truck Configuration
Selected LTCCS Crash Types

Cargo bed height	Straight	Straight, trailer	Tractor-semitrailer	Tractor-double	Unknown	Total
Standard	61	7	175	8	1	252
Low	20	3	20	4	0	47
High	31	7	46	6	0	90
Unknown	3	0	4	1	3	11
Total	115	17	245	19	4	400
Column percentages						
Standard	53.0	41.2	71.4	42.1	25.0	63.0
Low	17.4	17.6	8.2	21.1	0.0	11.8
High	27.0	41.2	18.8	31.6	0.0	22.5
Unknown	2.6	0.0	1.6	5.3	75.0	2.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

Some trucks had equipment, tool boxes and other gear mounted on the sides of the truck or trailer. In some cases, the equipment appears relatively substantial, so that it might prevent or reduce underride in certain side-impact collisions. Overall, about 16.1 percent of the trucks had side-mounted equipment below the level of the cargo bed that appeared to be sturdy enough to impede underride in at least some collisions. Straight trucks and straight trucks pulling trailers were more likely to have such equipment than tractor-trailers. About 36.5 percent of straight trucks and 41.2 percent of straight trucks with a trailer had some sort of side-mounted equipment. The percentages were much lower for tractor combinations. Only about 5.3 percent and 10.5 percent of tractor-semitrailers and tractor-doubles, respectively, had such equipment.

Table 42. Side-Mounted Equipment by Truck Configuration
Selected LTCCS Crash Types

	Mounted equipment			
Truck configuration	Yes	No	Unknown	Total
Straight	42	70	3	115
Straight, trailer	7	10	0	17
Bobtail	1	10	0	11
Tractor-semitrailer	13	228	4	245
Tractor-double	2	16	1	19
Unknown	1	0	3	4
Total	66	334	11	411

Truck configuration	Mounted equipment			Total
	Yes	No	Unknown	
	Row percentages			
Straight	36.5	60.9	2.6	100.0
Straight, trailer	41.2	58.8	0.0	100.0
Bobtail	9.1	90.9	0.0	100.0
Tractor-semitrailer	5.3	93.1	1.6	100.0
Tractor-double	10.5	84.2	5.3	100.0
Unknown	25.0	0.0	75.0	100.0
Total	16.1	81.3	2.7	100.0

Tag and lift axles were accepted as mounted equipment, because they may be up or down. In either position, they are virtually as substantial as fixed axles. Tag and lift axles account for 28.8 percent of the instances of side-mounted equipment. Of course, these extra axles are present on both sides of the vehicle. Most of the other substantial equipment is present only on one side. Table 43 shows the distribution of the most common classes of items that were found on the sides of trucks. The most common type of side-mounted equipment was various types of boxes for tools and other items. Tanks and the hydraulic equipment used for dumping mechanisms, concrete pumps, and cranes was the third most common type.

Table 43. Types of Equipment on the Sides of Trucks or Trailers Selected LTCCS Crash Types

Equipment type	N	%
Tag axle	19	28.8
Tool boxes, etc.	26	39.4
Tanks, hydraulics, etc.	10	15.2
Spare tire & metal rack	5	7.6
Other	6	9.1
Total	66	100.0

6.3.2. Override/underride in crashes

In this section, we present results on override/underride and PCI in the crashes reviewed. The results include the frequency of override/underride and PCI in the crashes and how certain characteristics of the trucks – bumper height, front axle setback, cargo bed height, and side mounted equipment – affect the probability of override/underride and PCI in the crashes.

Overall, override or underride was observed in almost two-thirds of the crashes reviewed. Table 44 displays these results. Of the 411 crashes reviewed, which were all collisions between the front or side of a truck and a light vehicle, some portion of the light vehicle went under the truck in 266 (64.7%), there was no override/underride in 121 (29.4%), and override/underride could not be determined in 24 (5.8%). The cases where override/underride could not be determined typically did not include relevant photographs of the light vehicle or where the damage appeared to be largely from another collision, such as a subsequent rollover.

Table 44. Incidence of Override/Underride in Front or Side Crashes,

Override/ underride	N	%
Yes	266	64.7
No	121	29.4
Unknown	24	5.8
Total	411	100.0

PCI for the light vehicle was observed in most of the collisions, with PCI recorded for 56.9 percent of the light vehicles (Table 45). PCI could not be determined for 5.1 percent of the cases, primarily where there were no photographs or if there were secondary events and it could not be determined if any PCI occurred in the collision with the truck or in the secondary event.

Table 45. Incidence of Light Vehicle PCI in Collisions With the Front or Side of Trucks

PCI	N	%
Yes	234	56.9
No	156	38.0
Unknown	21	5.1
Total	411	100.0

Clearly, PCI can occur without override/underride and override/underride can occur without PCI. But PCI is strongly associated with override/underride. In about 76.7 percent of override/underride cases there was at least some PCI, while there was no PCI in 76 percent of crashes where there was no override/underride. In almost half of these crashes (204 of 411), where a light vehicle collided with the front or the side of a truck, there was both some override/underride as well as some PCI. On the other hand, in almost a quarter of the cases (92 of 411), there was neither override/underride nor PCI.

Table 46. PCI by Override/Underride

Override or underride	PCI			Total
	Yes	No	Unknown	
Yes	204	59	3	266
No	28	92	1	121
Unknown	2	5	17	24
Total	234	156	21	411
Row percentages				
Yes	76.7	22.2	1.1	100.0
No	23.1	76.0	0.8	100.0
Unknown	8.3	20.8	70.8	100.0
Total	56.9	38.0	5.1	100.0

Table 47 classifies the part of the truck struck as either the front, side of the truck cab, the cargo body, or the trailer. The side of the truck cab for tractors includes any portion of the tractor sides, including the drive axles; for straight trucks, it is the portion of the truck not under the cargo body. The cargo body category is limited to straight truck cargo bodies, whether of a straight truck alone or of a straight truck pulling a trailer. The trailer category includes impacts to the sides of any trailer, whether pulled by a tractor (as a tractor-semitrailer or tractor-double) or a straight truck pulling a trailer.

Table 47. Override/Underride by Truck Side and Component Struck

Truck component involved	Override/Underride			Total
	Yes	No	Unknown	
Front	177	58	11	246
Cab side	37	38	10	85
Cargo body	10	8	1	19
Trailer	42	17	2	61
Total	266	121	24	411
Row percentages				
Front	72.0	23.6	4.5	100.0
Cab side	43.5	44.7	11.8	100.0
Cargo body	52.6	42.1	5.3	100.0
Trailer	68.9	27.9	3.3	100.0
Total	64.7	29.4	5.8	100.0

Override/underride was most common in frontal impacts or side impacts on trailers. In frontal impacts (including both straight trucks and tractors), override occurred in 72 percent of the cases. Similarly, when the collision was with the side of a trailer, the light vehicle underrode the trailer in 68.9 percent of the impacts. Underride was less common in collisions with truck cabs or with the cargo body area of straight trucks. In the cases where a light vehicle struck the side of a cab (tractor or straight truck), there was some underride in 43.5 percent; and where the cargo body area of a straight truck was struck, there was some underride in 52.6 percent. A statistical test of the difference was not significant, partly due to the fact that there are only 19 cargo body impacts.

Table 48 shows the combinations of truck and light vehicle sides involved in the crashes. The percentages are calculated to show the distribution of the sides of the light vehicles contacted by each component of the trucks in the crashes. When the front of the truck was involved, in 17.5 percent of the cases the truck front hit the front of the light vehicle; the light vehicle side was involved in 44.3 percent of impacts with truck fronts and the back of the light vehicle was involved in 38.2 percent. Truck front into light-vehicle side accounted for 109 of the 411 LTCCS crashes reviewed, by far the greatest number. And overall, the front of the truck was involved in 246 of the crashes, while the side of the truck was contacted in 165. For the light vehicles, the front was involved in 28 percent of the crashes, the side in 47.4 percent, and the back in 24.6 percent.

Table 48. Truck Component Involved by Plane of Light Vehicle Engaged Selected LTCCS Crashes

Truck component involved	Plane of light vehicle engaged			Total
	Front	Side	Rear	
Front	43	109	94	246
Cab side	28	54	3	85
Cargo body	12	6	1	19
Trailer	32	26	3	61
Total	115	195	101	411
Row percentages				
Front	17.5	44.3	38.2	100.0
Cab side	32.9	63.5	3.5	100.0
Cargo body	63.2	31.6	5.3	100.0
Trailer	52.5	42.6	4.9	100.0
Total	28.0	47.4	24.6	100.0

6.3.2.1. Front impacts

Truck bumper height is associated with override when impacts are with the front of trucks. For trucks with front bumpers classified as “above axle,” 87.3 percent of front impacts resulted in override, compared with 72.4 percent of those where the bumper was “at axle” and 57.7 percent of those with low bumpers. The relationship is linear, with each step down in the category having a lower incidence of override in frontal impacts. Even with relatively few cases, the override rate from the “below” is statistically different from the “above axle” group, at the 0.06 level. Front bumper height is a factor in the incidence of override/underride.

Table 49. Front Override by Bumper Height, Front Impacts Only

Bumper height	Override/Underride			Total
	Yes	No	Unknown	
Above axle	48	6	1	55
At axle	84	26	6	116
Below axle	30	21	1	52
Unknown	15	5	3	23
Total	177	58	11	246
Row percentages				
Above axle	87.3	10.9	1.8	100.0
At axle	72.4	22.4	5.2	100.0
Below axle	57.7	40.4	1.9	100.0
Unknown	65.2	21.7	13.0	100.0
Total	72.0	23.6	4.5	100.0

For PCI in frontal impacts (no table), there also appears to be a relationship with bumper height, but it is not as strong and linear as for override/underride. Overall, some PCI was observed in 64.5 percent of frontal impacts. The proportions of PCI in at-axle and below-axle cases are slightly lower and similar to each other, at 62.1 percent and 62.5 percent, respectively. The proportion of “above axle” cases with PCI is higher at 72.7 percent, but the differences are not statistically significant. The differences are not statistically significant even when at-axle and below-axle are combined to compare above-axle with all other bumper placement. It does seem reasonable that a higher bumper would contribute to PCI, but the evidence is not clear from these data.

There was no difference in override by front axle setback (Table 50). There is override/underride in about 72 percent of front impacts for each axle location. This lack of a difference is probably related to two factors. First, the front face of the tires presents a relatively narrow obstacle to override. Truck tires are typically about 11 inches wide; for a 96-inch-wide truck, that leaves a gap of about 6 feet between the wheels. Moreover, in practical terms a light vehicle would have to go some distance under the truck in order to contact the front wheels. So it would not be expected that axle setback would have much effect and the data show none.

Table 50. Front Override by Front Axle Setback, Front Impacts Only

Front axle setback	Override/Underride			Total
	Yes	No	Unknown	
Yes	98	33	5	136
No	73	24	4	101
Unknown	6	1	2	9
Total	177	58	11	246
Row percentages				
Yes	72.1	24.3	3.7	100.0
No	72.3	23.8	4.0	100.0
Unknown	66.7	11.1	22.2	100.0
Total	72.0	23.6	4.5	100.0

In terms of PCI, there is weak evidence that axle setback is associated with higher rates of PCI, but the difference is small. PCI in the struck light vehicles was recorded in 67.6 percent of frontal impacts by trucks with setback front axles, compared to only 61.4 percent when the striking truck had a set-forward front axle. This may indicate that the setback front axles allowed override of greater extent than set-forward front axles. But the difference in the incidence of PCI by steer axle setting is small.

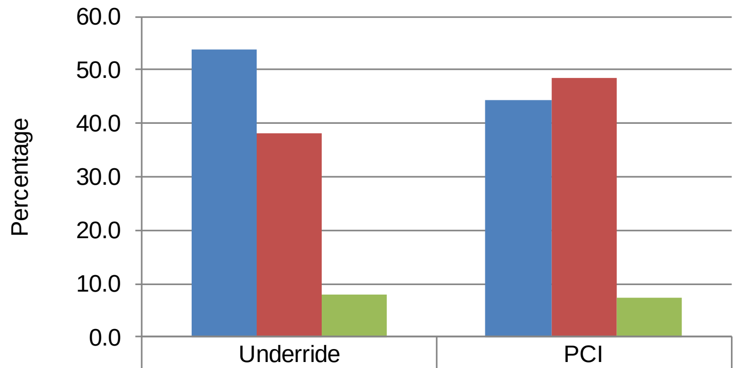
Interestingly, there was also a suggestive but not statistically significant difference in the incidence of override by the contact point on the front of the truck. When the primary contact point was with either the left or right third of the truck front, override/underride occurred in about 68.1 percent to 68.7 percentof the impacts. When contact was with the middle third–basically all impacts with complete overlap–there was override/underride in 77.1 percent. Based on Table 50, the difference is probably not due to contact with the tires, but the explanation may be that the struck vehicle is knocked out of the truck's path when the impact is to one side of the truck's front, rather than absorbing all the energy of the collision. The degree of symmetry is also of note. The number of collisions on the left and right sides of truck front bumpers in these data is very similar, at about 30 percent of the impacts on each side.

Table 51. Front Override by Frontal Contact Point

Front contact point	Override/underride			Total
	Yes	No	Unknown	
Left	49	18	5	72
Middle	81	22	2	105
Right	46	18	3	67
Unknown	1	0	1	2
Total	177	58	11	246
Row percentage				
Left	68.1	25.0	6.9	100.0
Middle	77.1	21.0	1.9	100.0
Right	68.7	26.9	4.5	100.0
Unknown	50.0	0.0	50.0	100.0
Total	72.0	23.6	4.5	100.0

6.3.2.2. Side impacts

There was a total of 165 collisions between a light vehicle and the side of a truck or truck combination in the set of 411 LTCCS cases reviewed. Figure 20 shows the proportional distribution of underride and PCI in these side impacts. (The term "underride" is used here because in these crashes, the light vehicle is almost always the striking vehicle.) Some underride was coded in 53.9 percent of the crashes, and PCI was coded in 44.2 percent. The rate of override/underride in side impacts is lower than the rate when the front of the truck is involved. Overall, there was some override/underride in 72 percent of front impacts, compared with 53.9 percent when the truck side is struck. Rates of light-vehicle PCI are also lower, with PCI observed in 65.4 percent of front impacts (previous section) and 48.5 percent of side impacts. Underride and PCI could not be determined in 7.9 percent and 7.3 percent of side impacts, respectively.



	Underride	PCI
Yes	53.9	44.2
No	38.2	48.5
Unknown	7.9	7.3

Figure 20. Incidence of Underride and PCI in Side Impacts

Obstacles to underride in the event of a side collision include a low cargo bed on the truck or trailer, significant equipment mounted on the side of the truck that could serve as an underride guard, or hitting the axles (wheels and tires) on the side of the truck. The review process collected information on each of these factors to see how they affect underride.

Cargo bed height was categorized as “standard,” “low,” or “high.” Standard was defined as standard loading dock height, which is about 50 inches. Cargo beds that extended below the top of the tires were classified as low, and beds located more than a few inches over the tires were classified as high. Many of the low cargo beds, such as lowboy trailers, are no more than 12-18 inches off the ground. In terms of underride, only the low category was associated with significantly lower rates of underride. Table 52 shows the cross-classification of cargo bed height and override/underride. Only impacts on the side of a trailer or the cargo area on a straight truck are included in the table. There were only 10 strikes on low cargo bodies, and only 3 of those resulted in underride. In contrast, of the 57 impacts on standard height cargo bodies, 42 resulted in underride. The difference in proportions (30% to 73.7%) is statistically significant. Impacts on high cargo bodies resulted in underride at about the same rate as for standard height cargo bodies. The difference is small and statistically indistinguishable. The ones that did not go under all were prevented by hitting axles.

Table 52. Override/underride by Cargo Bed Height Impacts on Cargo Area or Trailer

Cargo bed height	Override/Underride			Total
	Yes	No	Unknown	
Standard	42	14	1	57
Low	3	6	1	10
High	7	4	0	11
Unknown	0	1	1	2
Total	52	25	3	80
Row percentages				
Standard	73.7	24.6	1.8	100.0
Low	30.0	60.0	10.0	100.0
High	63.6	36.4	0.0	100.0
Unknown	0.0	50.0	50.0	100.0
Total	65.0	31.3	3.8	100.0

The results for PCI were similar to those for underride. A high proportion of the striking light vehicles experienced PCI when colliding with standard or high cargo beds. The proportion was significantly lower when striking low cargo bodies. PCI was recorded for 70.2 percent and 72.7 percent of side impacts on standard and high cargo bodies, respectively, but only 30 percent of impacts on low cargo bodies. High and standard cargo bodies can present increased risk of PCI because they are positioned on the same level as the greenhouse on a light vehicle.

Side-mounted equipment was not found to have any appreciable effect on the rate of underride or PCI. Only 16.1 percent of trucks were coded with some substantial piece of equipment mounted on the side of the truck or trailer. There was no indication of any difference in underride or PCI for trucks with side-mounted equipment that were struck in the side. Underride was coded for 60.9 percent of trucks with side-mounted equipment and 54 percent for trucks without side-mounted equipment. This difference is both small and not statistically significant. Nor was there any statistically significant difference in the proportion of PCI between trucks with side-mounted equipment and those without.

Table 53. Override/Underride by Side-Mounted Equipment
Side Impacts Only

Side-mounted equipment	Override/Underride			Total
	Yes	No	Unknown	
Yes	14	8	1	23
No	75	54	10	139
Unknown	0	1	2	3
Total	89	63	13	165
	Row percentages			
Yes	60.9	34.8	4.3	100.0
No	54.0	38.8	7.2	100.0
Unknown	0.0	33.3	66.7	100.0
Total	53.9	38.2	7.9	100.0

The failure to observe any effect from side-mounted equipment may be due to a number of factors. Typically, the equipment was mounted on only one side of the truck, and the other side may have been hit. Sometimes the equipment was fairly compact, and did not occupy much of the length of the truck. It was attempted to code only substantial equipment, but that judgment had to be made from photographs only. And finally, the sample size of cases is small. Only 23 trucks with side-mounted equipment were struck in the side and the equipment itself was struck in only 8 of the crashes. In none of those crashes did the equipment prevent underride.

Axles, however, are a different matter. Most light vehicles hit some portion of the axles in impacts to the side of trucks. In 73.9 percent of side impacts, light vehicles hit some portion of the axles. This includes any part of a tire or wheel. Whether a light vehicle struck an axle could not be determined for 9.1 percent of side impact crashes; considering only crashes where it could be determined whether an axle was struck, for 81.3 percent the answer was yes. This makes some sense since many trucks have more than two axles; for many trucks a large part of the side is occupied by axles. However, hitting an axle does not mean that underride was prevented. In many instances, the axles do prevent underride, but in other, there is underride because the angle of impact is shallow or the light vehicle only hit a portion of the tire. In fact, as Table 54 illustrates, light vehicles that hit truck axles actually were more likely to underride than those that did not. The difference is not statistically significant, but interesting nonetheless.

Table 54. Override/Underride by Whether Striking Vehicle Hit Axles
Side Impacts Only

Hit axles	Override/Underride			Total
	Yes	No	Unknown	
Yes	72	45	5	122
No	12	16	0	28
Unknown	5	2	8	15
Total	89	63	13	165
		Row percentages		
Yes	59.0	36.9	4.1	100.0
No	42.9	57.1	0.0	100.0
Unknown	33.3	13.3	53.3	100.0
Total	53.9	38.2	7.9	100.0

Overall, when truck axles were struck in side-impact crashes, the axles prevented underride in 32 percent of the crashes. However, the prevention rate varied by crash type. In same-direction sideswipe or a crossing-paths types of crashes, hitting axles prevented underride in 32.7 percent and 37.5 percent of crashes, respectively. When the crash was on opposite-direction sideswipe type, hitting axles prevented underride in only 20.7 percent of crashes. Moreover, opposite-direction sideswipe crashes was the crash configuration most likely to include striking the axles. In 93.5 percent of opposite-direction sideswipe crashes, light vehicles struck at least some portion of the axles. This makes some geometrical sense, considering the angle of impact in such crashes. But in same-direction sideswipes and crossing-paths crashes, there is more of a chance of hitting a gap between the axles, if there is such a gap.

6.4. Summary and implications

The clinical review of the LTCCS was undertaken as an exploratory evaluation of front override and side underride in serious truck crashes. The goals were to determine the incidence of front override and side underride (i.e., whether there is a significant safety problem) and to develop an understanding of the data elements needed to determine the most effective means to address the problem.

LTCCS cases were selected from crash types in which the front or side of a truck was struck. Coders recorded data on side and front impact crashes, including whether there was underride or override, passenger compartment intrusion, the impact points for both the truck and the light vehicle, whether the truck's axles were struck, and whether that prevented override/underride. In addition, the coders captured information about certain key features of the geometry of the trucks, including front bumper height, front axle setback, cargo bed height, and whether there was substantial equipment mounted on the side of the truck that might prevent underride.

Overall, in front and side impact crashes, some underride was identified in 53.9 percent of the crashes, and PCI was coded in 44.2 percent. The rate of override/underride in side impacts is lower than the rate when the front of the truck is involved. There was some override/underride in 72 percent of front impacts, compared with 53.9 percent when the truck side is struck. Rates of light vehicle PCI are also lower in side impact crashes, with PCI identified in 65.4 percent of front impacts but only 48.5 percent of side impacts. Underride and PCI could not be determined in 7.9 percent and 7.3 percent of front and side impacts, respectively.

Impacts to truck fronts and to the sides of trailers tended to result in override/underride at higher rates than impacts to the sides of truck cabs or straight truck cargo bodies. When the truck front was involved, there was identifiable override in 72 percent of the impacts. Similarly, impacts on trailer sides resulted in underride in 68.9 percent of the crashes. Side impacts to truck or tractor cabs resulted in underride in 43.5 percent of cases, and side impacts to the cargo body area of straight trucks resulted in underride in about 52.6 percent of such crashes.

In frontal impacts, truck bumper height appears have a linear relationship with the probability of override. Override occurred in 87.3 percent of frontal impacts where the bottom of the front bumper was above the axle, 72.4 percent when the bumper was at the axle, and only 57.7 percent when the bottom of the bumper was below the axle.

Front axle setback did not appear to affect the incidence of override, but there did appear to be some effect on PCI, such that there was somewhat more PCI identified for setback front axles than for axles set forward. In side impacts, the important elements were cargo bed height and whether the striking vehicle hit the axles. Only low cargo beds were associated with lower probabilities of underride (about 30%). Standard height (about dock height or 48-50 inches) and high cargo beds had statistically indistinguishable rates of underride.

Light vehicles hit the truck’s axles in 73.9 percent of side impacts, and overall light vehicles that hit the truck’s axles actually underrode the truck at higher rates than light vehicles that did not. However, it was found that the geometry of the crash had a significant effect on whether striking the truck’s axles would prevent underride. In crashes in which the light vehicle was going in the same direction as the truck and sideswiped it, and in crashes where the light vehicle struck the truck at about a 90° angle, hitting the truck’s axles prevented underride in about 35 percent of cases. But when the light vehicle was going in the opposite direction as the truck and moved into in at a shallow angle, hitting the axles prevented underride in only about 20.7 percent of crashes.

The review of LTCCS cases produced evidence that front override and side underride are significant problems in serious crashes between heavy trucks and light vehicles. Front override and side underride were found in most of the crashes examined. Preliminary estimates from this review are that override occurs in almost three-quarters of crashes involving the front of the truck, and in over half of the crashes when the sides of the trucks were struck. The results here are based on only a limited sample of serious crashes for which detailed investigations were available, but they clearly indicate a potential safety problem due to the geometrical mismatch between light vehicles and trucks as currently configured. In impacts with the front of a truck, bumpers on many trucks are higher than bumpers on light vehicles. On the sides of many trucks, gaps between axles leave space for underride and standard height and high cargo beds on trucks are higher than the bumpers and other structural components on light vehicles.

The LTCCS investigation materials provided information that in some ways was well-suited to the task. Crash diagrams gave clear guidance on contact points and, in some cases, where underride occurred. The narratives were also very helpful in describing complex sequences of events. In many cases, there were multiple impacts between a truck and the other vehicle, and the narrative helped sort out, in conjunction with photographs of the vehicles, which impact was associated with different damage areas. In other cases, there were secondary impacts, including rollovers, of the light vehicles, and researcher's narrative helped to determine if observed PCI resulted from the rollover or from hitting the truck.

Override/underride in front and side impact crashes is a significantly more complex problem than rear underride. In a large majority of rear underride crashes, both vehicles are going in the same direction, so the dynamics of the crashes are relatively simple, and simply depend on the relative speeds of the vehicles. But crashes involving front and side impacts on trucks are more complicated. Many frontal impacts are simple rear-ends, geometrically the same as in rear-underride, although of course the front structure of trucks differs substantially from the rear. But many of the crashes are crossing-path type, where the struck vehicle is moving perpendicularly across the front of the truck. Estimating relative velocities in these cases is much different, particularly when the other vehicle turns across the front of the truck. Similarly, side impact cases can either be a perpendicular impact on the side of the truck at an intersection, or a shallow approach angle from the opposite direction with a high closing speed, or a shallow approach angle when a same-direction vehicle drifts into the truck or the truck changes lanes into the other vehicle. These all present radically different problems.

In terms of data collection, the use of materials such as available in the LTCCS is almost ideal. The photographs of the trucks and the other vehicles were invaluable in determining override/underride and PCI. Not all of the cases had the same set of photographs, but the fact that, generally speaking, each vehicle was fully documented with a set of panoramic photos allowed reviewers to establish whether there was override/underride or PCI with relatively high confidence. The photos were also very helpful in determining if axles were struck. Collecting this kind of information by means other than photographs would be less reliable.

Many of the data elements collected as part of the review proved to be very useful and relevant to the problem, though not all. The role of side equipment seems negligible, and data on its presence does not appear to be of high value. Data elements to be collected should include:

- Override or underride and PCI;
- Impact point on the truck, broken down by component. The value of the clockface metaphor is limited. A better approach would be a more detailed set of codes based on truck components and arrangement of axles;
- Whether the axles were struck;
- Whether the cargo body was struck;
- Angle of impact;
- Front bumper height;
- Front axle set back;
- Cargo body height;
- Number of axles and spacing. Some trucks presented a wall of axles on the side, allowing no opportunity for significant underride and no place to locate side underride guards. Other trucks had broad open spaces between axles.

In addition, estimates of the degree of override/underride for front impacts and side impacts would be useful, though complex to develop. As the review of LTCCS cases showed, all four sides of light vehicles were struck and overridden, and one would want different measures of degree for impacts on the side of a light vehicle from on the rear.

Estimates of closing speeds would also be extremely valuable for different crash configurations, but the review of the LTCCS cases showed how difficult they would be to obtain reliably in the different crash types. Many of the crashes were very dynamic, with several impact events. Side impact crashes were either straight-on into a truck’s side, a same-direction sideswipe where the light vehicle drifted over or in some cases changed lanes into a truck, or high-speed opposite direction collisions. Relatively few of the LTCCS crashes had speed data that could be used to estimate impact speeds.

Though preliminary, the results here may point to opportunities to address the problem of front and side impact crashes in some ways. Low front bumpers were associated with lower rates of override. The front axle set back may provide space for structures to help manage the energy in collisions where the front of the truck is involved. With respect to side impacts, some crash geometries such as same direction sideswipes may be mitigated by side underride guards if closing speeds are low enough to be managed by practical structures. Further research on these crashes can point to methods to reduce the severity of these crash types.

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Appendix A: Data Collection Forms, 2008 and 2009.

TIFA Underride Data Collection Form

1. Case number __ __ __ __ __ __ __ __ (1 2 3 4 5 6 7 8)

2. Rear overhang, back of tires to end of cargo body (inches) __ __ __ (9 10 11)

3. Cargo overhang, end of cargo body to end of cargo (inches) __ __ __ (12 13 14)

4. Height of top of cargo bed (inches) __ __ __ (15 16 17)

5. Was there an underride guard on truck or trailer?
   - Yes [ ] 1
   - No [ ] 2
   - Unknown [ ] 9

   (18)

6. Height of bottom of underride guard from ground (inches) __ __ __ (19 20 21)

7. Width of underride guard (inches) __ __ __ (22 23 24)
   (less than full width?)
   (full width?)

8. Was there anything else that extended below the level of the cargo body? (steps, lift gate, booms, etc.)
   - Yes [ ] 1
   - No [ ] 2
   - Unknown [ ] 9

   (25)

9. What was it? (editor only)
   __ __ __ __ __ __ __ __ __ __
   __ __ __ __ __ __ __ __ __ __
   (26-45)

10. Was the rear of the truck or trailer struck?
    - Yes [ ] 1 (continue)
    - No [ ] 2 (stop)
    - Unknown [ ] 9 (continue)

    (46)

11. How much damage to the underride guard?
    - None [ ] 1
    - Minor [ ] 2
    - Moderate [ ] 3
    - Major [ ] 4
    - Unknown [ ] 9

    (47)

12. Did the striking vehicle hit the rear tires?
    - Yes [ ] 1
    - No [ ] 2
    - Unknown [ ] 9

    (48)

13. Extent of underride?
    - None [ ] 1
    - Less than halfway up the hood [ ] 2
    - Halfway or more but not to the windshield [ ] 3
    - To the windshield or more [ ] 4
    - Unknown amount [ ] 7
    - Unknown [ ] 9

    (49)

14. Extent of underride (inches) __ __ __ (50 51 52)

(editor only 15, 16, 17, 18)

15. Comments:
    __ __ __ __ __ __ __ __ __ __
    __ __ __ __ __ __ __ __ __ __
    __ __ __ __ __ __ __ __ __ __
    __ __ __ __ __ __ __ __ __ __
    (53-92)

16. FARS vehicle number of striking vehicle: __ __ (93 94)

17. What state/country was truck or trailer registered in? __ __ (95 96)

18. Case type: __ (97)

S:\Data2\TIFA\underride_v3.pub, 10/9/09 version

TIFA Underride Data Collection Form 2009

1. Case number: ___ ___ - ___ ___ ___ ___ - ___ ___ (1 2 3 4 5 6 7 8)

2. Describe the vehicle configuration AND cargo bed (pickup truck, pickup pulling a flatbed utility trailer, straight truck with box van cargo body, tractor-trailer with single drop deck flatbed trailer, tractor with lowboy trailer, tractor with moving van trailer, tractor with hopper/bottom dump trailer, etc.):

____

Editor only ___ (9-48)

Trailer Information — if straight truck-trailer or tractor-trailer combination (if no trailer, **go to 8**).

3. Trailer length (feet): ___ ___ (49 50)

4. Trailer axles:

Together	[ ] 1
Spread	[ ] 2
Single Axle	[ ] 3
Unknown	[ ] 9

(51)

5. Trailer year: ___ ___ ___ ___ (52 53 54 55)

6. Trailer Make: ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ (56 57 58 59 60 61 62 63 64 65 66 67 68 69 70)

7. Trailer VIN: ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ (71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87)

Information about the rear of **ALL vehicles**.

8. Rear overhang, back of tires to end of vehicle (inches): ___ ___ ___ (88 89 90)

9. Cargo overhang, end of vehicle to end of cargo (inches): ___ ___ ___ (91 92 93)

10. Height of top of cargo bed, at very rear of vehicle (inches): ___ ___ ___ (94 95 96)

11. Rear ground clearance, excluding underride guard and any mounted equipment (inches): ___ ___ ___ (97 98 99)

12. Was there an underride guard on truck or trailer?

Yes	[ ] 1
No (**go to 15**)	[ ] 2
Unk (**go to 15**)	[ ] 9

(100)

13. Height of bottom of underride guard from ground (inches): ___ ___ ___ (101 102 103)

14. Width of underride guard (inches): (less than full width?) (full width?) ___ ___ ___ (104 105 106)

15. Was there anything else that extended below the level of the cargo body at the very rear? (steps, liftgate, booms, etc.)

Yes	[ ] 1
No	[ ] 2
Unknown	[ ] 9

(107)

16. What was it?

____

____

Editor only

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

(108-137)

Page 1

S:\cnts\tifa\Forms\Underride Survey, 2009 Underride Survey Form.pub, 10/27/2010

17. Was the rear of the truck or trailer struck (includes the rear corners)?

Yes	[ ] 1 (**continue**)
No	[ ] 2 (**stop**)
Unknown	[ ] 9 (**continue**)

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18. How much damage to the underride guard?

None	[ ] 1
Minor (some contact but little damage)	[ ] 2
Moderate (some bending from original position, < 45 degrees)	[ ] 3
Major (significant bending from original position, > 45 degrees; includes torn off)	[ ] 4
No guard	[ ] 8
Unknown	[ ] 9

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19. Did the striking vehicle hit the rear tires?

Yes	[ ] 1
No	[ ] 2
Unknown	[ ] 9

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20. Extent of underride on striking vehicle?

None	[ ] 1
Less than halfway up the hood	[ ] 2
Halfway or more but not to the windshield	[ ] 3
To the windshield or more	[ ] 4
Unknown amount	[ ] 7
Unknown	[ ] 9

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21. Extent of underride on struck unit (inches): ___ ___ ___ (142 143 144)

Editor only

22. Comments:

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

145-184

23. FARS vehicle number of other contacting vehicle: ___ ___ (185 186)

24. In what state/country was truck or trailer registered? ___ ___ (187 188)

25. Derived question # : ___ (189)

26. Offset rear-end collision?

Yes	[ ] 1
No	[ ] 2
Unknown	[ ] 9

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Appendix B: Description of mounted equipment

Description	N	Description	N
Air tank	1	Pipe	3
Airbrake connectors	1	Pipe + bumper	1
Attenuator	8	Pipes	1
Auger	4	Plate	2
Automobile lift platform	1	Plate + hitch	1
Axle guard + hitch	1	Plates	1
Bars	1	Platform + hoses	1
Booster axle	2	Platform + valves	1
Broom guard	1	Pull-out ramp	4
Bumper	130	Pull-out ramps	2
Bumper & step	1	Pump	9
Bumper + chutes	1	Pump box	2
Bumper + hand truck	1	Pump box + bumper	1
Bumper + hitch	35	Pump housing	2
Bumper + levelers	1	Push bar	2
Bumper + lights	2	Push bumper	1
Bumper + outriggers	4	Push plate	1
Bumper + pintle hook	1	Rails	1
Bumper + ramp	1	Ramp	20
Bumper + step	1	Ramp + steps	1
Bumper + steps	1	Ramp attachment	1
Bumper + tire	1	Ramps	4
Bumper + valve	1	Receptacle lifts	1
Bumper,lights+ hitch	1	Rollers	1
Bumper+pull-out ramp	1	Salt spreader	5
Cargo area+ liftgate	1	Sander	1
Chute	4	Skid plate	7
Conveyor belt	1	Slide-out ramp	3
Conveyor belt, chute + ladders	1	Sliding ramp	1
Crane	1	Sliding ramps	1
Discharge hose	1	Spare tire hanger	1
Discharge line	1	Sprayer	4
Discharge tube	1	Sprayer+ folding step	1
Dock bumpers	1	Spreader	12
Drop-down lift	1	Spreader bar	1
Equipment boxes	1	Spreader chute	3
Equipment operator seat	1	Sprinkler bar	1
Extended bumper	1	Stabilizer	1
Folding ramp	2	Stabilizers	3

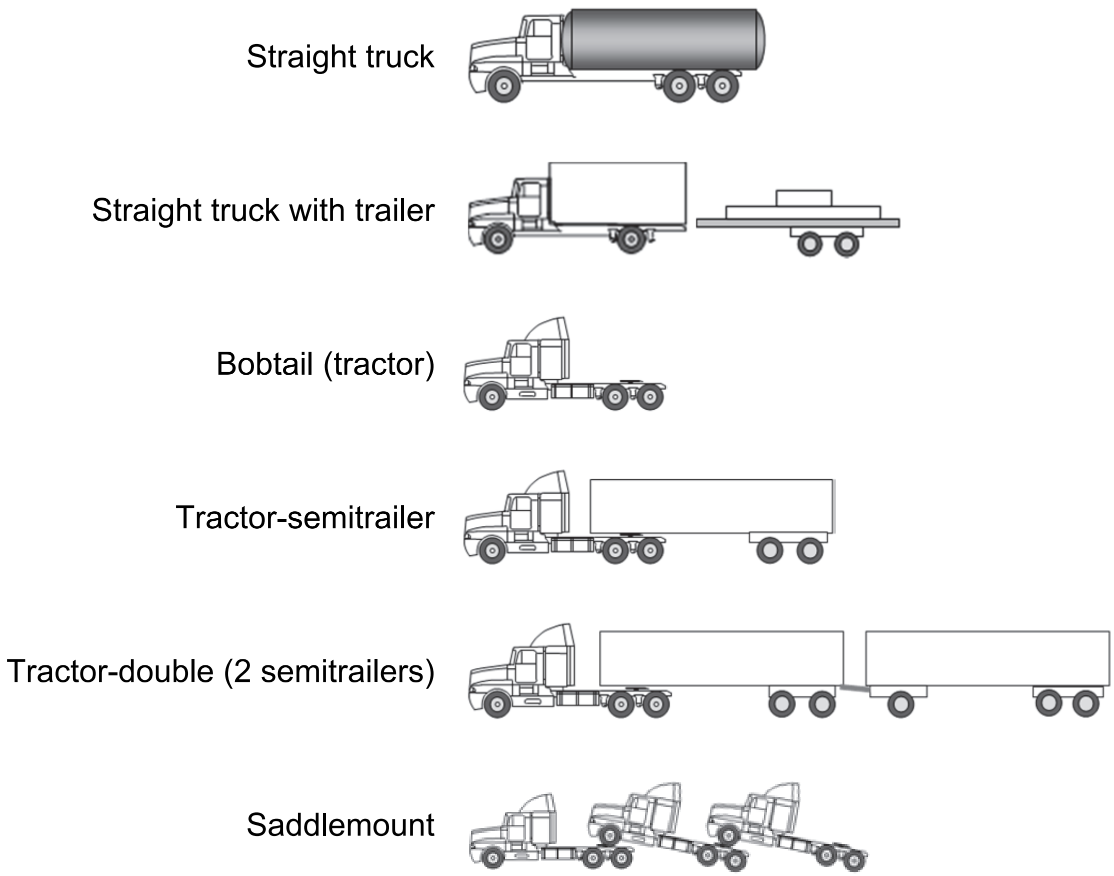
Description	N	Description	N
Folding step	1	Stairs	1
Folding steps + pull-out ramp	1	Steel plate	5
Fold-out steps	1	Steel plate + outriggers	1
Forklift	13	Step	63
Forklift attachment	10	Step & hitch	1
Gearbox	1	Step & winch	1
Hitch	116	Step + hitch	3
Hitch + spreader	2	Step + liftgate	1
Hitch + taillights	1	Step bumper	130
Hitch + vise	1	Step bumper + fender	1
Hitch plate	3	Step bumper + hand cart	1
Hoist component	1	Step bumper + hand truck	1
Hooks	1	Step bumper + hitch	5
Hose	1	Step bumper + liftgate	1
Hose cabinet	1	Step bumper + lights	1
Hose connection	1	Step bumper + outriggers	2
Hoses	4	Step bumper + pull-out ramp	6
Hoses + valves	1	Step bumper + ramp	3
Hydraulic jacks	1	Step plate	1
Hydraulic motor + ladder	1	Step plates	1
Hydraulic tow bar	1	Step platform	3
Hydraulics	1	Steps	56
I-beam	1	Steps + bumper	1
Iron bar	2	Steps + loading device	1
Ladder	5	Stinger bar	26
Ladder + steps	1	Suspension	1
Ladder step	1	Sweeper brush	1
Lift axle	1	Tag axle	3
Liftgate	198	Tailgate	1
Liftgate + corner guards	1	Taillight mount	1
Liftgate + steps	1	Taillights	3
Liftgate mechanism	4	Tank drain	1
Light bar	1	Tow hook	1
Live bed mechanism	1	Towing mechanism	1
Loading compartment	1	Traffic cone holder	1
Loading device	1	Tube	1
Loading mechanism	1	Tubing	3
Loading ramp	1	Valve	3
Loading ramps	1	Valve cage	1
Metal bar	1	Valve plate	2

Description	N	Description	N
Metal plate	2	Valves	5
Meter + bumper	1	Valves in metal cage	1
Nozzle	1	Vehicle loading ramp	1
Outriggers	6	Wheel lift	91
Outriggers + hitch	1	Wheel lift + bumper	1
Pintle hitch	37	Wheel lift + stabilizer	2

Appendix C: Definitions of striking vehicle type

Label	Vehicle type
Auto:	Automobiles and automobile derivatives; typical light passenger vehicles, including convertibles, sedans, station wagons, hatchbacks, coupes, auto-based pickups and panels, limousines
Utility:	Compact and large sport utility vehicles, utility station wagons like Chevrolet Suburban, and unknown type of utility vehicle
Minivan:	Minivans such as Chrysler Town and Country, Plymouth Voyager, Toyota Sienna, GMC Astro, Mercury Villager
Large van:	Vans used often for light commercial purposes, such as Econoliner, E150-E350, Vandura, Tradesman
Compact pickup:	Small pickup trucks such as the S-10, Ranger, Scamp, and Sonoma
Large pickup:	Standard-size pickup trucks, such as F100-350, Ram, Silverado, and Sierra.
Bus:	School buses, other buses including transit, intercity, and bus based motor homes
Truck:	Medium and heavy trucks and truck-tractors
Motorcycle:	Motorcycles, mopeds, ATV, and snowmobiles
Large equipment:	Farm equipment or construction equipment other than trucks
Other/unknown:	Other vehicle type or unknown motorized vehicle type

Appendix D: Line drawings of some truck configurations



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