U.S. Department of Transportation

National Highway Traffic Safety Administration

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The Need for Additional Heavy Truck Crashworthiness Standards

Required Under

The Moving Ahead for Progress in the 21st Century Act (MAP-21)

Report to the House Committee on Transportation and Infrastructure and the Senate Committee on Commerce, Science, and Transportation

Report to Congress

National Highway Traffic Safety Administration
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Executive Summary

The Moving Ahead for Progress in the 21st Century Act (MAP-21) directed the Secretary of Transportation to conduct a comprehensive analysis on the need for heavy truck crashworthiness standards. In the charge, Congress specifically noted roof strength, pillar strength, air bags, and other occupant protections standards, and frontal and back wall standards. As part of its evaluation, the National Highway Traffic Safety Administration (NHTSA) funded the University of Michigan's Transportation Research Center Institute (UMTRI) to summarize the most recently available data on heavy truck crashes.

From 2000 through 2007, an average of 757 truck occupant fatalities occurred annually. The number of fatalities dropped to 499 in 2009 but increased to 697 fatalities in 2012. The majority of fatalities are truck drivers and more than half were not wearing a seatbelt. Further, this study found that approximately three event occurrences make up 89 percent of crashes that resulted in a fatality or severe injury to truck drivers. The most harmful events are rollovers (41%), collisions with other vehicles (33%) or collision with a hard fixed object (15%). Vehicle rollover presents the greatest risk to heavy truck occupants with ejection of the occupants highly correlated to vehicle rollover.

Over many years, the Department of Transportation (DOT) and its partners have pursued a number of activities to help increase belt use. Observed seat belt use in heavy trucks has been steadily increasing with a 48 percent usage rate in 2002 increasing to 77 percent in 2010. However, despite this increase and effort by the DOT, this study finds that the lack of seat belt use was still present in many fatal crashes. NHTSA has routinely found that seatbelts are one of the most significant countermeasures available and can reduce an occupant's risk of crash injury and death when used.

To gain additional insight into fatal heavy truck crashes, a detailed investigation of fatal heavy truck crashes in 2011 was performed through the Truck Crashworthiness Data Special Study (this study is an Appendix to this report). The review found that a majority of these fatal crashes had severe deformation of the cab or intrusion significantly compromising the cab's occupant space. Specifically, fatal rollover events typically involved more than a single quarter turn, resulting in severe cab deformation. Impacts into fixed objects were all high energy events that allowed significant cab deformation owing to the mass of the tractor-trailer and high pre-impact speeds. Finally, vehicle to vehicle collisions involved high closing speeds and demonstrated extensive cab damage. The catastrophic aspects of these crashes hampered comparison between older cab designs and more recent cab designs that incorporated cab strength requirements.

Prior heavy truck crashworthiness research and practices have been developed through SAE International, which is a global association of engineers and technical experts within the aerospace, automotive and commercial-vehicle industries. To assess the viability of additional crashworthiness countermeasures such as those specifically noted in MAP-21, the agency assessed the current state of the art with respect to cab designs and occupant restraint systems, reviewed current best practices from vehicle manufacturers, and current SAE Recommended Practices. We found that manufacturers have incorporated SAE Recommended Practices into improving cab crashworthiness and some manufacturers offer advanced vehicle restraints such as air bags but the sales of such equipment is very low. Additionally, we observed that given the mass, high pre-crash-speeds, and the resulting transfer of energy through the cab,

significant research would be needed to determine the feasibility of new Federal safety standards above the current designs and best practices. Similarly, while we have recently implemented new standards for light vehicles in the area of roof crush and ejection mitigation, the feasibility of applying these standards to heavy vehicles is not readily apparent given the large differences in the vehicle types, masses, speeds involved, and the vehicle uses.

In light of the observations in this study, there are near-term activities that industry and government can pursue to improve the survivability of heavy truck crashes and reduce the injuries associated with them. Recognizing that requirements in the current SAE Recommended Practices have not been updated in over a decade, we believe there is merit in SAE International reevaluating the current practices to determine if additional improvements can be made. The agency has contacted SAE International and has asked them to reassess the Recommended Practices in light of our study and recent motorcoach crashworthiness research. NHTSA will closely follow and participate in this work.

In addition, the agency will leverage the UMTRI and Texas A&M Transportation Institute collaborative effort in examining truck crashworthiness and will continue to monitor additional injury risk reduction countermeasures such as enhanced seat belt reminders to determine whether those could reduce injury severity. As these activities will take time to complete, in the interim the agency is pursuing a Final Rule on Electronic Stability Control for truck-tractors and a proposal for Speed Limiters for heavy vehicles. We also plan to make a regulatory decision within the year regarding automatic braking technology for heavy vehicles and vehicle to vehicle communications technology. In addition, these current crash avoidance efforts including the finalization and implementation of improved stopping performance appear to offer significant benefit in preventing or mitigating these severe crash events from ever occurring in the first place.

1 Purpose

The Moving Ahead for Progress in the 21st Century Act (MAP-21) directed the Secretary of Transportation to conduct a comprehensive analysis on the need for heavy truck crashworthiness standards. Section 32201 directed the Department of Transportation (DOT) to do the following.

> *"The Secretary shall conduct a comprehensive analysis on the need for crashworthiness standards on property-carrying commercial motor vehicles with a gross vehicle weight rating or gross vehicle weight of at least 26,001 pounds involved in interstate commerce, including an evaluation of the need for roof strength, pillar strength, air bags, and other occupant protections standards, and frontal and back wall standards."*
>
> *"Not later than 90 days after completing the comprehensive analysis under subsection (a), the Secretary shall report the results of the analysis and any recommendations to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Transportation and Infrastructure of the House of Representatives."*

2 Introduction

The National Highway Traffic Safety Administration (NHTSA) has been monitoring heavy vehicle safety for many years and taken many actions to reduce or mitigate the occurrence of heavy vehicle crashes. Agency efforts are ongoing to promote Electronic Stability Control (ESC) in heavy vehicles, enabling a driver to retain vehicle control and reduce or mitigate rollover events. The agency has proposed to upgrade requirements for heavy truck tires to improve the safety in operating a heavy vehicle. Recent revisions to the Federal Motor Vehicle Safety Standard (FMVSS) 121, "Air Brake Systems" now require improved stopping performance for heavy vehicles. The agency's focus on heavy truck driver safety is continuing with research into forward collision avoidance and mitigation systems (F-CAM) to help reduce or mitigate heavy truck crashes.

While crash avoidance helps reduce crash events, vehicle crashworthiness can affect an occupant's injury in a crash. From 2000 through 2007, an average of 757 large truck occupant fatalities occurred annually. Large trucks are vehicles having a gross vehicle weight rating (GVWR) greater than 10,000 lb and are classified by a DOT weight class (3 to 8). From 2007 to 2009, there was a notable reduction in annual fatalities from 805 to 499. More recent data shows an increase in commercial motor vehicle occupant fatalities with 697 large truck occupants killed in 2012.[1] Additionally, nearly three thousand people suffer an incapacitating injury each year in heavy vehicles.[2]

In response to MAP-21, NHTSA contracted with the University of Michigan's Transportation Research Institute (UMTRI) to review heavy truck crashworthiness. Heavy trucks are classified as vehicles having a GVWR greater than 26,000 lb (Class 7, 8). UMTRI performed a review of government and industry standards covering truck crashworthiness, providing background of the regulatory development addressing truck safety and cab integrity. To review heavy truck crashes, UMTRI used its Trucks in Fatal Accidents (TIFA) database, which was developed from an in-depth review of the thousands of fatal accidents involving trucks. UMTRI also reviewed the 2000-2003 Large Truck Crash Causation Study (LTCCS) to provide an anecdotal analysis of heavy truck crash events. A report has been submitted to NHTSA, "Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant

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[1] *2012 Motor Vehicle Crashes: Overview. (2013),* NHTSA Research Note No. DOT HS 811 856, p. 2. Washington, DC, 2013.

[2] John Woodrooffe and Dan Blower. (2015). *Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 23. Washington, DC: National Highway Traffic Safety Administration.

Safety," documenting the research on heavy truck crashes. UMTRI's research and analysis is extensively cited in this report and is referred as the "UMTRI report."

In addition, NHTSA performed an in-house study of fatal heavy truck crashes that occurred in 2011. This research permitted evaluation of the crash performance of newer heavy trucks. Results are utilized within this report and the full study is provided in the Appendix. This report summarizes the UMTRI and NHTSA research.

3 Prior Society of Automotive Engineers Crashworthiness Research

Federal crashworthiness standards applicable to heavy trucks (Class 7, 8) have been in place since 1972 and cover basic restraint components – such as seat belt webbing and anchorages.[3] Commercial-vehicle engineering has been a focus of SAE International, which is a global association of engineers and technical experts within the aerospace, automotive and commercial-vehicle industries. In 1991, SAE International sponsored a Cooperative Research Program (CRP) to review the crash characteristics of heavy trucks and develop test procedures that could be used to evaluate heavy truck crashworthiness. At that time, there were approximately 700 occupants killed in crashes each year in large trucks. Interest over the safety of truck occupants promoted the multi-year commitment by SAE International to research truck cab crashworthiness and advance occupant protection. Research work supported the development of test procedures covering restraint performance, the maintenance of an occupant's survivable space, and the compliance of cab interior surfaces. The resulting SAE Recommended Practices provide a methodology for evaluating heavy truck crashworthiness.

3.1 SAE Recommended Practices

Recommended Practices were issued in 1998 and provide tools to improve heavy truck cab crashworthiness. The supporting work is documented within CRP -9 "Heavy Truck Crashworthiness (Statistics, Accident Reconstruction, Occupant Dynamics Simulation)" and CRP-13, "Heavy Truck Crashworthiness - Phase III; Restraint System Test Procedure Development, Cab Interior Component Test Development, and Cab Structural Test Procedure Development." These Recommended Practices are voluntary and intended to promote crashworthiness in new cab design. The Recommended Practices have been assigned document numbers within the SAE Standards library. A summary and brief description of the SAE Recommended Practices is provided in the following list:

- J2418 Occupant Restraint System Evaluation--Frontal Impact Component-Level
- J2419 Occupant Restraint System Evaluation--Frontal Impact System-Level
- J2420 COE Frontal Strength Evaluation - Dynamic Loading
- J2422 Cab Roof Strength Evaluation - Quasi-Static Loading
- J2424 Free Motion Headform Impact Tests of Heavy Truck Cab Interiors
- J2425 Steering Control Systems - Laboratory Test Procedure
- J2426 Occupant Restraint System Evaluation--Lateral Rollover System-Level

3.1.1 Recommended Practice J2418, J2419 - Occupant Restraint System Evaluation

Occupant restraint performance can be judged within a heavy truck cab environment subjected to defined crash pulses. Sled testing allows evaluation of individual restraint components as well as the entire system. Frontal impact restraint system testing focuses on the behavior of anthropomorphic test devices (ATDs) relative to their safety components and allows evaluation of occupant motion and contacts within a cab environment.

[3] FMVSS No. 209 – Seat Belt Assemblies; FMVSS No. 210 – Seat Belt Anchorages

3.1.2 Recommended Practice J2426 - Occupant Restraint System Evaluation--Lateral Rollover

Occupant response and restraint performance during rollover events is evaluated with a unique test fixture, the Lateral Rollover System. This fixture allowed a cab to be rotated to simulate a rollover event. The lateral/rotational deceleration pulse is imparted to the cab once 90° of rotation is completed.

3.1.3 Recommended Practice J2420 - COE Frontal Strength Evaluation

The Cab Over Engine (COE) Frontal Strength Evaluation Recommended Practice was developed to address the large number of such truck-tractor configurations at the time. COE cabs did not provide much deformable structure between their front bumper and the driver's seat. Current review of the 2006-2010 TIFA database shows that the COE configuration comprises merely 3.5 percent of the total vehicle population of Class 7 and 8 commercial vehicles. Currently, Cab Behind Engine (CBE) truck-tractors are the majority and this chassis structure offers a substantial crash zone between the bumper and driver's seat. The CBE configuration is referred to as a "conventional" truck-tractor. Consequently, the test procedure developed for evaluating frontal strength for COE vehicles is not applicable to the majority of CBE truck-tractors in operation today.

3.1.4 Recommended Practice J2424 - Free Motion Headform Impact Tests of Heavy Truck Cab Interiors

Recommended Practice J2424 utilizes laboratory test procedures to investigate the interaction of an occupant's head with the interior of a vehicle's cab elements. The free motion headform impact tests were based on FMVSS No. 201 (Occupant Protection in Interior Impact) testing methodology to address occupant protection in interior impacts. This Recommended Practice uses the same impact speed from the test procedure;[4] however, specific target locations and approach angles are not defined.

3.1.5 Recommended Practice J2425 - Steering Control Systems - Laboratory Test Procedure

The Recommended Practice for occupant interaction with the steering wheel was guided by FMVSS No. 203 (Impact Protection for the Driver from the Steering Control System) which addresses protecting an occupant in impacts with the steering wheel. Modifications were made to the orientation of the body form relative to the steering wheel during testing in order to better represent a heavy truck cab environment.

3.1.6 Recommended Practice J2422 - Cab Roof Strength Evaluation

The Recommended Practice to evaluate roof strength was initiated with the review of existing test procedures. Commonly referenced at that time was the UN Economic Commission for Europe (ECE R29: Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants of the Cab of a Commercial Vehicle). The ECE R29 procedure involves the application of up to 22,000 lb to a cab roof.

The SAE Recommended Practice J2422 involves a two-step procedure, an initial angled (20°) side impact (pre-load) to the cab (Figure 1) followed by loading to the roof (Figure 2). Load conditions for J2422 were defined in December 2003 with the dynamic pre-load as 1.6 times the reference energy level which is calculated from a vehicle's mass and dimensional properties. The quasi-static roof load is the maximum rated capacity of the vehicle's front axle, up to a maximum of 22,046 lb. This vertical loading was derived from the ECE R29 regulation, considered the most applicable resource. The cab is required to remain attached to the vehicle frame following the test in an orientation similar to the original and none of the doors shall open during the test. While the doors are not required to open following the test, space within the cab must be maintained for a 50th percentile male ATD positioned on his seat.

[4] TP-201, Laboratory Test Procedure for FMVSS No. 201, Occupant Protection in Interior Impact

Figure 1. SAE Recommended Practice J2422 Dynamic Pre-load Configuration

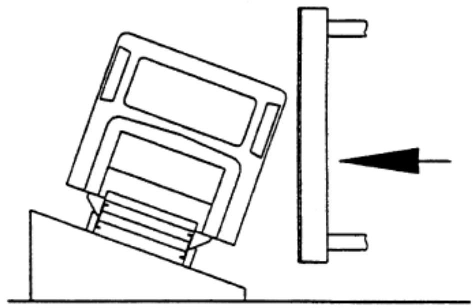
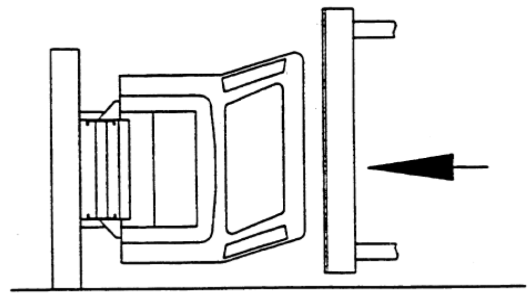


Figure 2. SAE Recommended Practice J2422 Quasi-static Roof Load Configuration



In January, 2011, ECE R29 was amended with changes to impact tests to truck cabs. A new front pillar impact test procedure was introduced and involves a pendulum impact of the vehicle's windscreen and "A" pillars midway between the upper and lower edges of the windscreen. In addition, the amended ECE R29 roof strength test has added the dynamic pre-loading step from SAE Recommended Practice J2422. The front pillar test and roof strength test can be performed on separate cabs with similar requirements regarding occupant survival space and cab to frame securement.

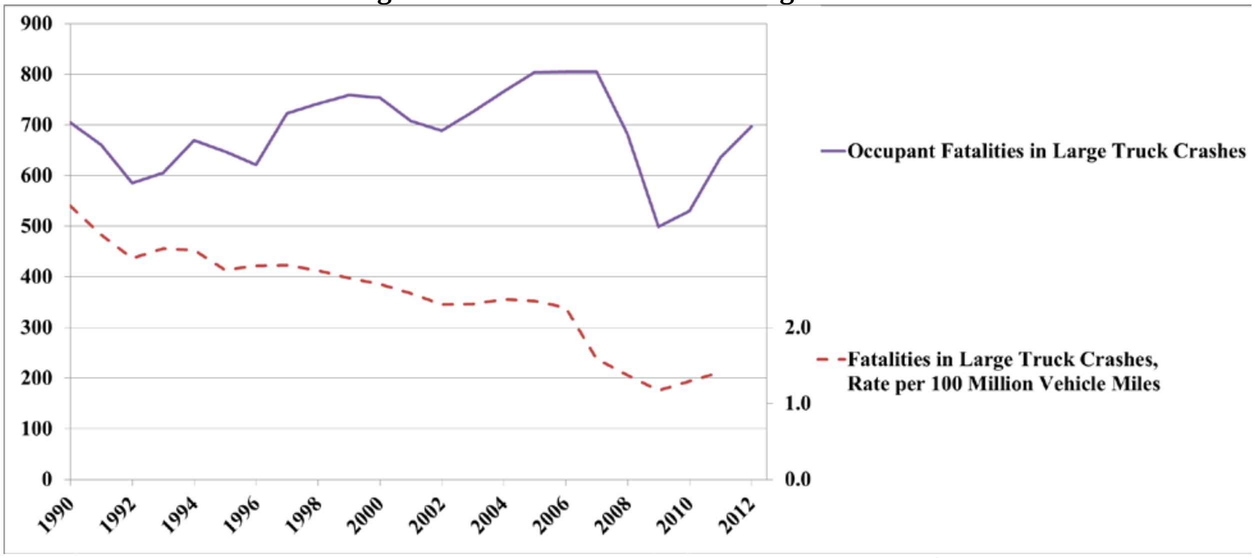
Discussion with members of the SAE International Truck Crashworthiness Committee indicates domestic heavy truck manufacturers use SAE Recommended Practices to evaluate cab performance, while computer aided design has provided for cab structural integrity improvements. Industry members report that SAE Recommended Practice J2422 roof strength requirements, demand for increased cab durability and advanced structural analysis methods contribute to cab structural integrity improvement over the past 15 years.

4 Trends in Heavy Truck Fatalities

A large truck is defined as a truck with a GVWR greater than 10,000 pounds. Truck configurations within this report are defined as single unit truck (SUT) or truck-tractors. Truck-tractors are the power unit within a combination unit, pulling a trailer. SUTs are single frame vehicles comprised of a power unit and a permanently mounted cargo/work body. The large truck population is also subdivided into medium and heavy trucks. Vehicles with a weight class of 3 – 6 are considered medium trucks. Heavy trucks are vehicles with a weight class of 7 and 8, indicating a GVWR greater than 26,000 lb.

Since 1990, the number of large truck fatalities relative to the number of miles travelled has been down. This is evidenced by the numbers reported by the Federal Motor Carrier Safety Administration (FMCSA) shown in Figure 3. The overall trend shown is a decline in commercial vehicle fatalities relative to the vehicle miles traveled. Figure 3 also includes the most recent NHTSA data showing 697 large truck occupant fatalities in 2012.

Figure 3. Trends: Fatalities in Large Trucks



Source: FMCSA. (2013). *Large Truck and Bus Crash Facts 2011*. p. 7. Washington, DC. U.S. Department of Transportation.

4.1 Seat Belt Use

Seat belt use is required for commercial vehicle drivers as specified in Title 49, Section 392.16 of the Code of Federal Regulations (49 CFR § 392.16), Use of seat belts. Section 392.16 states that "a commercial motor vehicle which has a seat belt assembly installed at the driver's seat shall not be driven unless the driver has properly restrained himself/herself with the seat belt assembly."

FMCSA reports that seat belt use in heavy trucks has been steadily increasing (Table 1) since the observed 48 percent usage in 2002, with a recent observed seat belt usage rate of 77 percent for occupants of Class 7 and 8 commercial vehicles.

Table 1. Large Truck Seat Belt Use Rates

	2002	2005	2006	2007	2008	2009	2010
Straight Truck	n/a	n/a	n/a	62%	66%	68%	71%
Articulated—Single Trailer	n/a	n/a	n/a	64%	73%	76%	80%
Class 7 and 8	48%	54%	59%	64%	71%	73%	77%

Source: FMCSA. (2011). *CMV Safety Belt Use Overview*. http://www.fmcsa.dot.gov/documents/safety - security/7768_FMC_SeatBeltReport_v5_042011-508.pdf
FMCSA. (2006) *Shoulder Belt Usage by Commercial Motor Vehicle Drivers, Executive Summary*. http://www.fmcsa.dot.gov/safety-security/safety-belt/exec-summary-2006.pdf
FMCSA. (2003). *Safety Belt Usage by Commercial Motor Vehicle Drivers, Executive Summary*. http://www.fmcsa.dot.gov/safety-security/safety-belt/fmcsafinal-safetybeltstudy-nov2003.htm

5 University of Michigan Transportation Research Institute's Report

The University of Michigan Transportation Research Institute's report, "Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety," compiled information about truck driver injury and injury mechanisms, provided a review of regulatory development and industry safety initiatives, and included suggestions for countermeasures. Highlights from this report are included to give a summary of findings.[5]

[5] Data in the tables may be subject to rounding errors.

5.1 Data

Data on injuries sustained by occupants of large trucks were gained from NHTSA's National Automotive Sampling System (NASS) General Estimates System (GES). GES is a nationally-representative sample of police-reported crashes. The GES includes vehicle information for trucks classified by power unit type (truck-tractor or SUT), along with injury data. Injury severity is indicated through the KABCO designation that is defined below (Table 2).

Data from TIFA and GES for 2006 to 2010 were combined to form a consistent and comprehensive description of large truck crashes of all severities. TIFA data was utilized to focus on fatalities within large trucks. TIFA is a census file, containing data for medium and heavy trucks involved in any traffic crash resulting in a fatality. Within TIFA, the majority of truck occupants are not fatal.

Table 2: KABCO Injury Definitions

Code	Description
K-injury	Fatal injury. A fatality that occurs within 30 days of a crash and is due to injuries received in the crash is counted as a fatal injury
A-injury	An incapacitating injury is one that prevents an injured person from walking, driving, or continuing with the normal activities of which the person was capable before the injury. Severe lacerations, broken limbs, skull fractures, or extended unconsciousness all count as incapacitating.
B-injury	A non-incapacitating but evident injury. Bruises, abrasions, and minor lacerations are counted as B-injuries.
C-injury	Possible injury, also known as complaint of pain. Examples include momentary unconsciousness, claim of injuries not evident, or limping.
O	No injury.

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety.* p. 18. National Highway Traffic Safety Administration.

A large truck's weight class can be identified directly in TIFA, but is not coded in GES data. Within TIFA, 99.9 percent of truck-tractors and 46.3 percent of SUTs are heavy trucks (Class 7, 8). Truck-tractors are coded by power unit type within GES, allowing identification of one group that fits the target heavy truck population. However, the weight class of SUTs within GES is not available. The grouping of SUTs in nonfatal crashes is a mixture of heavy- and medium trucks.

With the focus on heavy trucks, this lack of detail does not impair the crash and injury analysis. Data supports that the crash types and injury mechanisms identified for medium SUTs are also the primary concern for heavy SUTs. While the frequency of primary crash types may differ between medium and heavy SUTs, the crash type that produces the most fatal and incapacitating injuries are the same. TIFA review shows this same relation between heavy SUTs and truck-tractors. [6] Therefore, including all SUTs in the study's results does not compromise the identification of primary crash types and injury mechanisms for heavy vehicles.

5.2 Truck Driver Injury and Injury Mechanisms

Trends in fatal injuries for large trucks declined over the period included in the TIFA study, decreasing from 928 in 2006 to 569 in 2009 (Table 3). This decline may have been influenced by a reduction in all

[6]John Woodrooffe and Dan Blower. (2015). *Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 33-36. Washington, DC: National Highway Traffic Safety Administration.

motor vehicle travel and truck travel from 2008 to 2009.[7,8] Since 2009 there has been a steady climb in fatalities. Additional TIFA review shows that the majority of fatalities are drivers.

Table 3. Driver and Occupant Fatalities in Large Trucks (2006-2012)

Occupant type	TIFA[9]					NHTSA[10]	
	2006	2007	2008	2009	2010	2011	2012
Driver	784	796	639	487	540	n/a	n/a
Passenger	144	123	122	82	69	n/a	n/a
Total	928	919	761	569	609	640	697

Table 4 utilizes TIFA and GES to present the yearly average of injuries for large truck occupants from 2006 to 2010. The majority of fatalities and severe injuries occur in truck-tractors.

Table 4. Annual Truck Occupant Injuries by Truck Type and Severity
2006-2010 TIFA, 2006-2010 GES

Occupant injuries	All trucks	Truck-tractor	SUT	Unknown
Fatal	757	425	324	8
A-injury	2,959	1,627	1,294	39
B-injury	7,693	4,245	3,332	116
C-injury	9,082	3,823	5,089	170
Unknown severity	299	66	230	2
No injury	310,277	150,068	146,198	14,010
Other/unknown	21,615	11,093	7,878	2,644
Total	352,682	171,347	164,345	16,990

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 22. Washington, DC: National Highway Traffic Safety Administration.

Seat belts are the most significant countermeasure to reduce crash injury. The majority of heavy trucks have lap/shoulder belts installed at the left and right front seating positions, even though FMVSS 208 (Occupant Crash Protection) allows Type 1 (lap only) belts to be installed. A lap-only belt installation was only noted in 2 percent of cases.[11] Belt use rates are reported high for drivers within the TIFA and GES review (Table 5, Table 6).

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[7] John Woodrooffe and Dan Blower. (2015). *Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety*, pp. 19-20. Washington, DC: National Highway Traffic Safety Administration.
[8] FMCSA. *Large Truck and Bus Crash Facts 2011*. Washington, October, 2013.
[9] John Woodrooffe and Dan Blower. (2015). *Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 20. Washington, DC: National Highway Traffic Safety Administration.
[10] NHTSA. (2013). *2012 Motor Vehicle Crashes: Overview.* NHTSA Research Note No. DOT HS 811 856, p. 2. Washington, DC, 2013.
[11] John Woodrooffe and Dan Blower. (2015). *Heavy Truck Crashworthiness: Injury Mechanisms and Countermeasures to Improve Occupant Safety*, pp. 25. Washington, DC: National Highway Traffic Safety Administration.

Table 5. Annual Seat Belt Use for Drivers and Passengers, Truck-Tractor Crashes 2006-2010 TIFA, 2006-2010 GES

Occupant type	Belted	Not belted	Other/ unknown	Total
Driver	128,297	2,336	28,513	159,146
Passengers	7,276	3,644	1,282	12,201
All	135,572	5,980	29,795	171,347
Row percentages				
Driver	81%	2%	18%	100%
Passengers	60%	30%	11%	100%
All	79%	4%	17%	100%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 25. Washington, DC: National Highway Traffic Safety Administration.
* Percentages may not add to 100 due to rounding

Table 6. Annual Seat Belt Use for Drivers and Passengers, SUT Crashes 2006-2010 TIFA, 2006-2010 GES

Occupant type	Belted	Not belted	Other/ unknown	Total
Driver	104,753	4,339	26,312	135,404
Passengers	19,757	3,516	5,668	28,941
All	124,510	7,855	31,980	164,345
Row percentages				
Driver	77%	3%	19%	100%
Passengers	68%	12%	20%	100%
All	76%	5%	20%	100%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 26. Washington, DC: National Highway Traffic Safety Administration.

However, lack of driver seat belt use is observed for nearly half of all truck-tractor fatalities (Table 7). This table contains the average yearly number of truck-tractor occupants reported injured. This total number injured is less than the annualized number of track-tractor occupants involved in crashes (171,347) due to the fact that most crashes do not result in injury. When considering drivers within Table 7 where restraint use was known, 89 percent were belted.

Table 7. Annual Injuries by Severity and Belt Use, Truck-tractor Occupants Reporting an Injury 2006-2010 TIFA, 2006-2010 GES

Injury severity	Belted	No belts	Other / unknown	Total
Drivers				
Fatal	142	140	100	383
A-injury	1,170	190	141	1,501
B-injury	2,918	356	406	3,679
C-injury	2,885	222	329	3,436
Unknown severity	59	0	7	66
Total	7,174	908	984	9,066
	Belted	**No belts**	**Other / unknown**	**Total**
Passengers				
Fatal	2	31	9	43
A-injury	59	60	6	125
B-injury	84	430	52	566
C-injury	207	125	55	387
Unknown severity	-	0	-	0
Total	352	646	122	1,121

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 27. Washington, DC: National Highway Traffic Safety Administration.

Injured SUT drivers (Table 8) show an even higher percentage of non-belted fatalities (63%) and a lower seat belt use rate (87%).

Table 8. Annual Injuries by Severity and Seat Belt Use, SUT Occupants Reporting an Injury 2006-2010 TIFA, 2006-2010 GES

Injury severity	Belted	No belts	Other / unknown	Total
Drivers				
Fatal	83	142	35	260
A-injury	749	209	77	1,035
B-injury	2,139	292	199	2,629
C-injury	3,247	255	376	3,878
Unknown severity	43	27	128	199
Total	6,261	925	816	8,002
	Belted	**No belts**	**Other / unknown**	**Total**
Passengers				
Fatal	12	45	6	64
A-injury	134	115	10	259
B-injury	344	257	102	703
C-injury	559	329	322	1,211
Unknown severity	14	5	12	31
Total	1,063	752	452	2,267

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 28. Washington, DC: National Highway Traffic Safety Administration.

In truck crashes, some of the most harmful events are rollovers, collisions with other vehicles or collision with a hard fixed object. For all truck types, Table 9 shows these three events make up 89 percent of crashes that resulted in severe injury to truck drivers. Annualized from the collection of 2006-2010 TIFA and GES data, rollovers make up 41 percent, vehicle to vehicle impacts 33 percent and striking a hard fixed object comprise 15 percent of truck driver's fatal and incapacitating (K+A) injuries. Rollover is consistently noted as the Most Harmful Event for severe injuries and is a significant threat to truck occupants.

Table 9. Annual Truck Driver Injuries by Most Harmful Event, All Trucks, All Crash Severities 2006-2010 TIFA, 2006-2010 GES

Most Harmful Event		Truck driver injury					Total
		Fatal	Fatal or A-injury	Any injury	No injury	Unknown	
Rollover		233	1,320	5,614	5,380	118	11,112
Fire		74	90	213	1,079	0	1,292
Other non-collision		15	38	301	5,977	813	7,091
Collision with:	Truck/bus	88	395	1,938	20,232	1,985	24,155
Collision with:	Light vehicle	41	517	5,528	187,640	13,593	206,761
Collision with:	Unknown vehicle type	34	147	999	19,740	2,517	23,256
Collision with:	Train	17	39	90	194	49	333
Collision with:	Ped/bike/animal	3	27	94	5,815	229	6,138
Collision with:	Other non-fixed object	4	93	179	3,257	434	3,869
Collision with:	Hard fixed object	122	478	1,747	7,861	122	9,730
Collision with:	Soft/other fixed object	19	75	653	13,812	1,349	15,815
Unknown		1	1	3	41	0	44
Total		649	3,221	17,359	271,028	21,209	309,595
		Column percentages					
Rollover		36%	41%	32%	2%	1%	4%
Fire		11%	3%	1%	0%	0%	0%
Other non-collision		2%	1%	2%	2%	4%	2%
Collision with:	Truck/bus	14%	12%	11%	8%	9%	8%
Collision with:	Light vehicle	6%	16%	32%	69%	64%	67%
Collision with:	Unknown vehicle type	5%	5%	6%	7%	12%	8%
Collision with:	Train	3%	1%	1%	0%	0%	0%
Collision with:	Ped/bike/animal	1%	1%	1%	2%	1%	2%
Collision with:	Other non-fixed object	1%	3%	1%	1%	2%	1%
Collision with:	Hard fixed object	19%	15%	10%	3%	1%	3%
Collision with:	Soft/other fixed object	3%	2%	4%	5%	6%	5%
Unknown		0%	0%	0%	0%	0%	0%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 31. Washington, DC: National Highway Traffic Safety Administration.

Occupant ejection from a vehicle is highly associated with severe injuries and rollovers tend to account for the highest number of ejected drivers. For truck-tractor crashes within 2006-2010 TIFA, 65 percent of ejections occurred in a rollover (Table 10). The numbers within Table 10 are the total number of ejections from truck-tractors recorded within TIFA for that 5 year period.

Table 10. Ejection and Rollover, Truck-tractors in Fatal Crashes 2006-2010 TIFA

Rollover	Ejection: Not ejected	Ejected	Other/ unknown	Total
No roll	11,759	165	101	12,025
Rollover	1,428	295	16	1,739
Total	13,187	460	117	13,764
Column percent				
No roll	89%	36%	86%	87%
Rollover	11%	64%	14%	13%
Total	100%	100%	100%	100%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 40. Washington, DC: National Highway Traffic Safety Administration.

Data shows seat belt use virtually eliminates ejection for truck-tractor (Table 11) and SUT (Table 12) drivers. Each truck type shows a higher number of unbelted drivers ejected, as well as a higher risk of the unbelted being ejected.

Table 11. Seat Belt Use and Ejection, Truck-tractor Drivers 2006-2010 TIFA, 2006-2010 GES

Seat belt use	Ejection: Not ejected	Ejected	Other/ unknown	Total
Belted	127,317	148	831	128,297
Not belted	1,994	156	187	2,336
Other/unknown	27,606	36	871	28,513
Total	156,918	340	1,889	159,146

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 39. Washington, DC: National Highway Traffic Safety Administration.

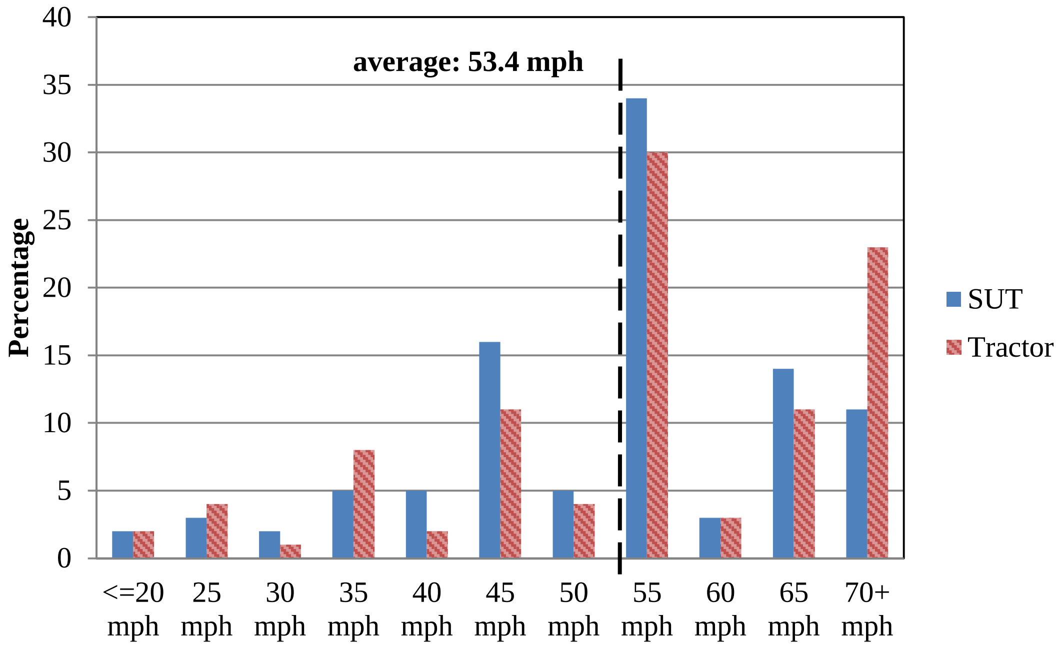
Table 12. Seat Belt Use and Ejection, SUT Drivers 2006-2010 TIFA, 2006-2010 GES

Seat belt use	Ejection: Not ejected	Ejected	Other/ unknown	Total
Belted	104,516	31	206	104,753
Not belted	4,135	179	26	4,339
Other/unknown	24,609	19	1,685	26,312
Total	133,259	228	1,917	135,404

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 38. Washington, DC: National Highway Traffic Safety Administration.

High speed crashes can produce fatal or severe injuries to truck drivers. Figure 4 below shows the distribution of fatal and A-injuries relative to the posted speed limit where the crashes occurred. The posted speed limit is used to provide an indication of truck operating speeds preceding the crash. The relatively small share of injuries on 50 mph and 60 mph roads likely reflects exposure, with relatively few roads posted at those speed limits. Nearly fifty percent of these crashes occur on roads with posted speed limits of 55 mph or higher.

Figure 4. Percentage of Truck Driver Fatalities and A-injuries and Posted Speed Limit 2006-2010 TIFA, 2006-2010 GES



Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 53. Washington, DC: National Highway Traffic Safety Administration.

5.3 LTCCS Case Review

Within their report, UMTRI performed an anecdotal analysis of truck cab crashworthiness with case review from the 2001-2003 LTCCS. Applicable LTCCS cases were identified with the following filter:

- Tractor-semitrailer or straight truck with no trailer.
- GVWR class 7 or 8.
- Truck driver fatal, A-, or B-injury.
- Truck model year 1995 or later.
- Truck rolled over **OR** primary crash impact was frontal, with no rollover.

The cases analyzed were not intended to be a representative sample of serious truck driver injuries. The LTCCS contains about 960 crashes and is not representative of a national population. The crash characteristics are presented in terms of the weighed population provided from the LTCCS study.

Rollovers are often “catastrophic impacts” and this characterization accounted for 7.8 percent of truck-tractor rollovers and 7.0 percent of SUT rollovers in terms of the weighed population. Trucks that rolled more than one quarter turn suffered substantial crush. In all frontal crashes, there was substantial damage to the cab. The cab was destroyed in 10 of the 21 frontal crashes reviewed. Seven of the 8 frontal crashes in which the driver was killed was considered a “catastrophic impact” and accounted for 7.4 percent of the weighted population.

An estimate of driver injury in rollover (Table 13) and frontal collisions (Table 14) was obtained through the LTCCS analysis, where there can be more than a single injury per driver. LTCCS injury data classifies injury severity using the Abbreviated Injury Score (AIS) scale with Table 13 and Table 14 only counting injuries with AIS equal to or greater than 2, eliminating minor injuries. Figure 5 and Figure 6 display the distribution of AIS2+ injury sources. Injury sources and body part injured in the rollover and frontal impact sample gave an indication of the injury mechanism in crashes.

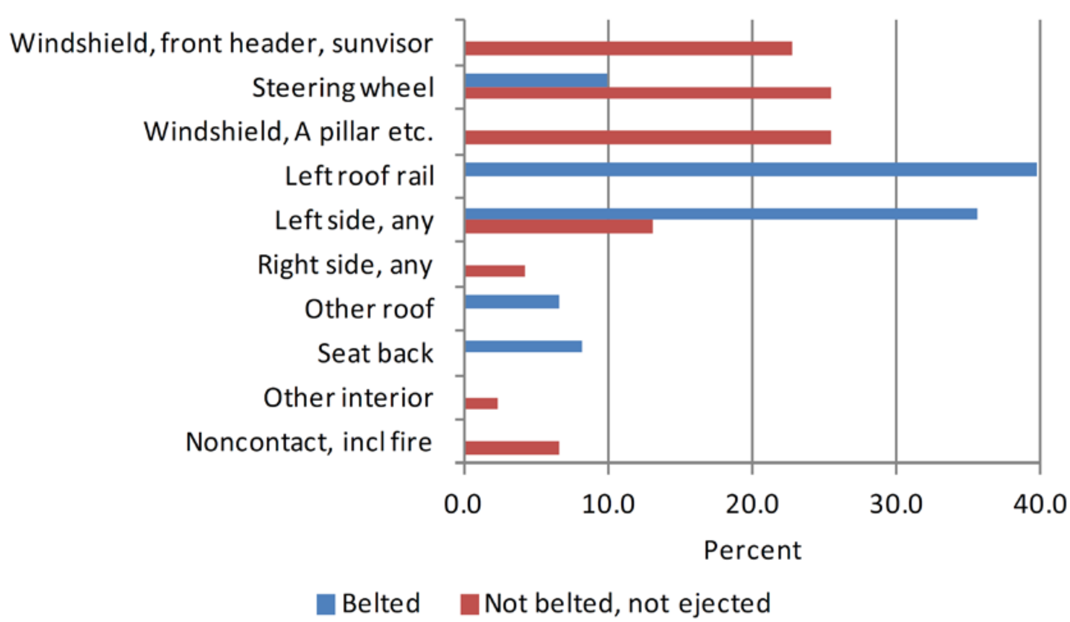
Table 13. Percentage Distribution of Driver Injuries (AIS2+) by Body Part Injured, Rollovers

Body part injured	Belted	Not belted, not ejection
Head	53%	34%
Face	10%	0%
Thorax	19%	16%
Abdomen	0%	0%
Spine	0%	12%
Upper extremities	19%	31%
Lower extremities	0%	1%
Unspecified	0%	6%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 82. Washington, DC: National Highway Traffic Safety Administration.
* Percentages may not add to 100 due to rounding

For belted drivers, the primary body parts injured were the head, upper extremities and thorax with the primary injury source being the left roof rail and left side of the cab. For unbelted drivers, the primary injury source was the steering wheel, windshield, A-pillar and front header. There was a greater percent of spine and upper extremities injury for unbelted drivers.

Figure 5. Driver Injuries (AIS 2+) from Cab Interior Contact, Rollover



Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 83. Washington, DC: National Highway Traffic Safety Administration.

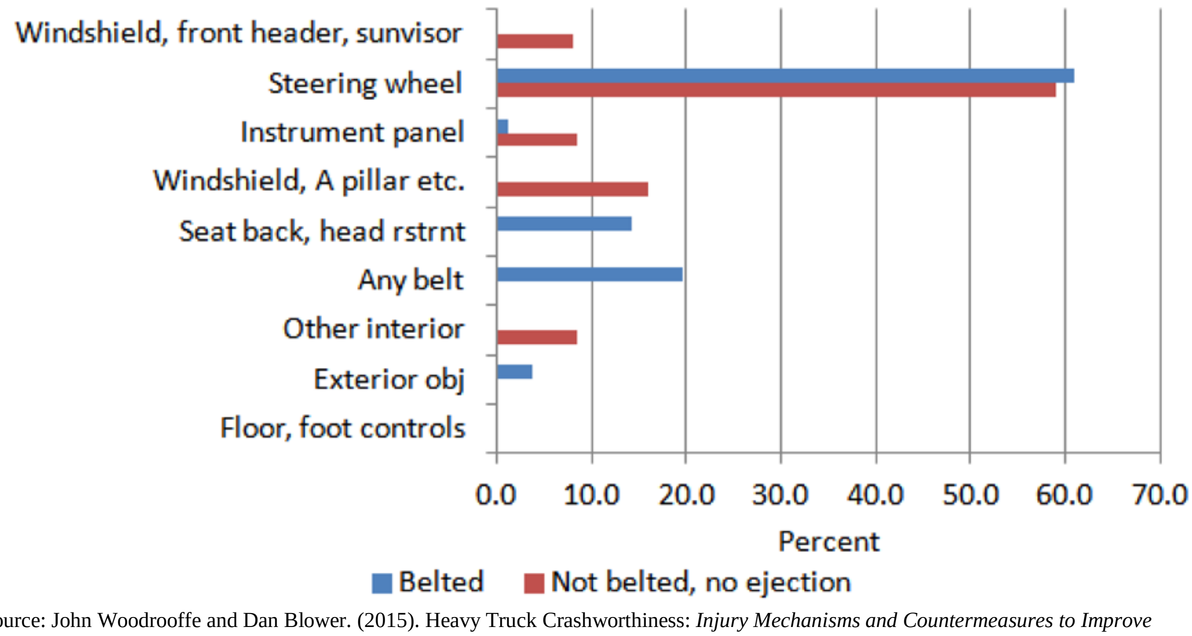
Seat belt use is shown by the distribution of injuries and the interior source of driver injury in frontal impacts (Table 14, Figure 6). For unbelted drivers, a higher percentage of head, spine and thorax injuries accompany a higher percentage of contact with the windshield, A-pillar, front header and instrument panel with the steering wheel being the predominant source for injury. For belted drivers restrained to their seats, the primary body parts injured were the face and lower extremities with the steering wheel being the predominant source for injury.

Table 14. Percentage Distribution of Driver Injuries (AIS 2+) by Body Part Injured, Frontal Collisions

Body part injured	Belted	Not belted, not ejected
Head	6%	40%
Face	55%	0%
Thorax	0%	21%
Abdomen	0%	3%
Spine	3%	31%
Upper extremities	11%	6%
Lower extremities	26%	0%
Unspecified	0%	0%

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 85. Washington, DC: National Highway Traffic Safety Administration.
* Percentages may not add to 100 due to rounding

Figure 6. Driver Injuries (AIS 2+) from Cab Interior Contact, Frontal Collisions



Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 86. Washington, DC: National Highway Traffic Safety Administration.

5.4 Industry Efforts

UMTRI formed a technical advisory group from the SAE International Truck Crashworthiness Committee that included representatives from domestic heavy truck manufacturers. Discussions with industry members covered their use of the SAE Recommended Practices to evaluate cab crashworthiness. These group members advised that there have been significant improvements in cab strength over the past 15 years.

UMTRI surveyed heavy truck manufactures and their model offerings for various safety features, including steering wheel air bags and supplemental restraints for rollover, such as a pull-down seat with side air bag. The typical driver's seat for a heavy truck is the air suspension seat. However, in a rollover event, the air suspension does not restrict travel upward toward the truck's roof. A pull-down seat is designed to compress the seat's suspension and reduce an occupant's vertical travel.

As shown in Table 15, various safety technologies have been developed within the industry and are available; however, according to UMTRI, there are unique characteristics within the freight transportation industry that creates barriers to broad acceptance of many of the safety developments. Order rates are very low for crashworthiness safety technologies that are available.

Table 15. Estimates of Technology Order Rate for Safety Technology by Vehicle Class

Technology	**Order Rates (2012)**	
	Class 8	**Class 5 - 7**
Daytime running lights (varies by manufacturer)	Standard *	50%
Hood mounted mirrors (varies by manufacturer)	Standard *	50%
Roll stability or electronic stability control	50%	< 5%
Lane departure systems	<10%	n/a
Traction control	60%	< 15%
F-CAM systems including adaptive cruise control – fully installed	<5%	n/a
F-CAM systems including adaptive cruise control – wired only	< 20%	n/a
Steering hub air bags**	< 5%	n/a
Pull down seats	< 1%	n/a

Note - * indicates that about 1 percent of purchasers refuse the standard item.
** order rate when not available as a standard feature
F-CAM systems are Forward Collision Avoidance and Mitigation Systems also referred to as collision mitigation braking systems.

Source: John Woodrooffe and Dan Blower. (2015). Heavy Truck Crashworthiness: *Injury Mechanisms and Countermeasures to Improve Occupant Safety*, p. 89. Washington, DC: National Highway Traffic Safety Administration.

5.5 Injury Mitigation

The analysis showed that vehicle rollover presents the greatest risk to vehicle occupants. However, it was not possible within the scope of UMTRI's study to analyze the forces experienced by truck cabs during crash events. The high kinetic energy in severe truck crashes could result in forces that exceed a cab's structural integrity. Cab survival space was typically compromised during rollovers of more than one quarter turn.

Existing safety equipment was again highlighted in the UMTRI report, as seat belts are available in all vehicles and keep occupants in their seats and also greatly reduce the likelihood of occupant ejection. Given the safety benefit associated with wearing seat belts in heavy trucks, UMTRI sees a potential in enhancing heavy truck driver safety by encouraging the installation of enhanced seat belt warning systems. Side curtain air bags are also noted given their ejection mitigation benefits to passenger car occupants.

The typical driver's seat for a heavy truck is an air suspension seat. To prevent a truck's rough suspension travel being directed into the driver, air suspension seats are used to cushion vibration and shock. A seat is supported by an air spring with linkage between the cab floor and seat frame controlling the seat's motion. The linkage directs vertical travel while the air spring supports the driver and provides a more comfortable interface, reducing any severe shocks delivered to the truck's suspension.

However, in a rollover event, this suspension allows upward travel toward a truck's roof. UMTRI notes an automatic seat pull-down system that is designed to reduce occupant movement in a rollover.[12] In the event of rollover, a roll sensor triggers the seat pull-down mechanism which lowers the seat thereby increasing the survival space for the vehicle occupant. This system also pre-tensions the seat belt once the roll sensor is triggered. A seat integrated side air bag would also deploy to reduce injury risk due to near-side contacts.

Frontal impact is one of the two collision types associated with severe driver injuries, but steering wheel air bags are rarely installed in heavy trucks. Air bags are standard on only one make of truck sold in the US-Volvo Truck. Within TIFA, there were only 168 deployments of air bags reported from 2006 to 2010. In the GES data used for nonfatal truck crashes, there were only 11 deployments from 2006 to 2010.

UMTRI cited one of its recent studies, "Estimation of Seatbelt and Frontal-Airbag Effectiveness in Trucks: U.S. And Chinese Perspectives"[13] which estimated that steering wheel air bags would provide an injury-reducing effect of 4 percent for belted drivers and 6 percent for unbelted drivers. This effectiveness was based on air bag research performed for passenger cars. The applicability of air bags in trucks was not studied with the review of 2006-2010 TIFA and GES data.

6 Truck Crashworthiness Data Special Study

The UMTRI report offers valuable insight into truck crashworthiness, but more research on fatal heavy truck crashes was conducted to allow a thorough study. NHTSA initiated the Truck Crashworthiness Data Special Study (TCDSS) to obtain recent field data of heavy truck crashes. The TCDSS data is comprised of fatal heavy truck crashes that were identified through the Fatal Analysis Reporting System (FARS). As an appendix to this Report to Congress, the "Truck Crashworthiness Data Special Study" documents the analysis and contains portions of the original case narratives.

6.1 Method

6.1.1 Case Selection

The FARS query was restricted to belted drivers in order to focus on fatal crashes with properly restrained heavy truck occupants. The 2011 FARS was the most recent data available at the beginning of the study to meet MAP-21 timing requirements. Applying the relevant search criteria as well as some case completeness criteria resulted in the identification of qualifying crashes.

6.1.2 Data Collection

A portion of the qualifying crashes were investigated by Special Crash Investigations (SCI) staff. If available, information was gathered from Police Crash Reports, on-scene and follow-on images of the crash site and the involved vehicles. Some cases benefited from supplementary detail, such as police reconstruction reports, crash scene diagrams, graphic images of the occupant's post-crash position, autopsy and medical records.

The SCI team conducted a clinical review of the available data for each case and generated a narrative summary that contained the following:

- Background
- Pre-Crash
- Crash

[12] UMTRI specifically discusses a device with this technology, the IMMI RollTek.
[13] Jingwen Hu and Dan Blower. (2013). *Estimation of Seatbelt and Frontal Airbag Effectiveness in Trucks: U.S. and Chinese Perspectives.* p. 35. The University of Michigan Transportation Research Institute.

- Post-Crash
- Occupant Injuries
- Occupant Kinematics

6.2 Case Analysis

An interdisciplinary team was formed at NHTSA to conduct the analysis of the TCDSS cases. This team consisted of crashworthiness engineers, biomechanical engineers, crash investigators and a statistician. The team reviewed each case, performing analysis of the crash stages and assessed vehicle dynamics and occupant kinematics. Four cases were noted where the driver of the heavy truck was not using a seat belt. Each of the four crashes was a catastrophic crash event with the cab structure suffering severe deformation; however, considering the lack of seat belt use, these cases were excluded from the crashworthiness analysis.

Nine cases were excluded from our analysis because of the uniqueness of the crash event made it difficult to effectively evaluate cab crashworthiness. Seven of the nine cases excluded had anomalous factors which compromised analysis of cab crashworthiness. In one case, a cab was displaced off the vehicle frame and fell from an elevated bridge. A number of cases involved a single quarter turn rollover event that oriented the cab into contact with a guardrail for a significant segment of the crash event. For such events, the safety systems were overwhelmed and the fatality was due to unique crash conditions. The two other cases did not provide enough information to determine the extent to which cab structure or restraint performance was a factor in the cause of death. Either the stated cause of death was not supported by the photographic record available or there was no reported cause of death.

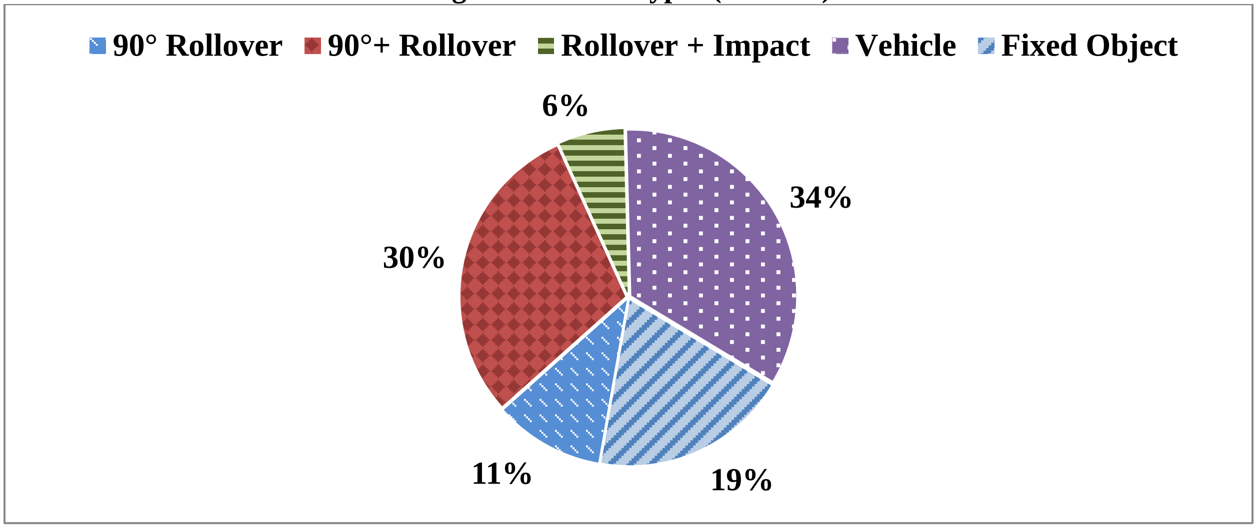
Several of the cases have fatalities that are unrelated to crashworthiness. There were two cases of drowning/immersion following the crash and four cases of heart attack. For heart attacks, the occurrence (pre- or post- crash) was determined through review of case detail. These six cases were removed from consideration in evaluating crashworthiness.

6.2.1 Crash Types

The 47 TCDSS cases that were reviewed for crashworthiness included 49 heavy truck fatalities. The 47 TCDSS cases were comprised of the following crash types:

1) 90 degree rollovers
2) Greater than 90 degree rollovers
3) Rollovers (any degree) with subsequent fixed object impact(s)
4) Collisions with other vehicles
5) Collisions with fixed objects

Figure 7. Crash Types (47 cases)



Rollover events occurred in 22 of the 47 crashes. Ejections were not expected given that all occupants were belted. Only three drivers were partially ejected and these ejections occurred in single quarter-turn rollovers. There were no total ejections of belted, fatally injured occupants.

6.3 Cab Crashworthiness

The 47 cases appropriate for analysis of cab crashworthiness were classified into the following Key Crash Event types: Rollover, Struck Fixed Object or Vehicle to Vehicle (Table 16). Classification was by the crash event responsible for compromising cab structure and/or causing the occupant's fatality.

Table 16. Key Crash Event

	Rollover	Struck Fixed Object	Vehicle to Vehicle
# of TCDSS cases	19	12	16

6.3.1 Fatality Factor

A fatality "factor" is an event or a condition that probably and logically increased the likelihood that the crash could be fatal to the occupant. A primary factor typically provides the necessary condition for a fatality. Secondary factors increase the risk or otherwise contribute to the fatality. With review of each case, a consensus was reached on the factors of the crash that led to the occupant fatality.

The following terms were used to describe a case's primary or secondary factors:

- Catastrophic crash
- Upper-component intrusion
- Vulnerable occupant
- Post-crash fire
- Partial ejection
- Tall, narrow object
- Offset impact

For the majority of the cases reviewed (42 of the 47), the primary factor contributing to fatalities was a "catastrophic crash." While it was not feasible to determine the impact loading into the cab structures within the TCDSS, it is clear that the crash energies involved are very high due to the large vehicle masses involved and high pre-crash speeds.

6.3.2 Rollover

Of the 19 cases where rollover was deemed the Key Crash Event, 14 events involved more than a single quarter turn. These events resulted in severe cab deformation and involved fatalities due to impact to the occupant's head, blunt force trauma or positional asphyxiation due to severe roof crush. Deformation was evaluated through examining case photographs for the vertical space remaining in the cab. Deformation of the cab was considered 'severe' if the deformation significantly compromised the occupant's survival space.

Table 17. Key Crash Event: Rollover

Case	rotation	primary factor	cab deformation	secondary factor
T002	630°	catastrophic crash	severe	upper-component intrusion
T003	180°	catastrophic crash	severe	upper-component intrusion
T010	180°	catastrophic crash	severe	upper-component intrusion
T013	360°	catastrophic crash	severe	post-crash fire
T019	360°	catastrophic crash	severe	upper-component intrusion
T024	180°	catastrophic crash	severe	upper-component intrusion
T027	180°	catastrophic crash	severe	upper-component intrusion
T042	540°	catastrophic crash	severe	upper-component intrusion
T046	180°	catastrophic crash	severe	upper-component intrusion
T049	180°	catastrophic crash	severe	upper-component intrusion
T055	630°	catastrophic crash	severe	none
T063	630°	catastrophic crash	severe	upper-component intrusion
T065	180°	catastrophic crash	severe	upper-component intrusion
T008	360°	catastrophic crash	severe	vulnerable occupant
T009	90°	partial ejection	minimal	none
T011	90°	partial ejection	minimal	none
T053	90°	partial ejection	minimal	none
T061	90°	vulnerable occupant	minimal	none
T021	90°	vulnerable occupant	minimal	none

For the five cases not classified as "catastrophic," the crashes were similar with only a single quarter-turn rollover event and minimal cab deformation. Three of these crashes were near-side rollovers with the fatality caused by partial ejection of the occupant through the side window. In the two remaining cases, the occupant's "vulnerable" status was considered the primary factor. The three previously mentioned rollover fatalities were caused by partial ejection; however neither "vulnerable" driver was ejected. While suffering injuries, it is plausible that health conditions may have compromised their survivability.

6.3.3 Fixed Object

In twelve cases, the Key Crash Event involved striking a fixed object. A rollover event preceded this harmful event in three of the cases, but they are included in this Key Crash Event category because the cab damage and injury to the driver was due to a fixed object impact.

Table 18. Key Crash Event: Struck Fixed Object

Case	trailer separation/ cargo shift	primary factor	cab deformation	secondary factor
T056	none	catastrophic crash	severe	upper-component intrusion
T028	none	catastrophic crash	moderate	none
T039	none	catastrophic crash	severe	upper-component intrusion
T015	none	catastrophic crash	severe	tall, narrow object
T017	none	catastrophic crash	severe	tall, narrow object
T045	none	catastrophic crash	severe	post-crash fire
T058	none	catastrophic crash	severe	vulnerable occupant
T032	X	catastrophic crash	severe	tall, narrow object
T006	none	catastrophic crash	severe	tall, narrow object
T035	X	catastrophic crash	severe	none
T040	X	catastrophic crash	severe	none
T050	X	catastrophic crash	severe	none

There were six cases involving tractor-semitrailer impacts into trees. These were all high energy events that resulted in significant cab deformation owing to the combined mass of the truck-tractor and trailer. Three cases involved the tractor-semitrailer departing the roadway and striking an embankment. Such events involve a very high vehicle deceleration linked to the rigidity of the crash partner. Subsequently, in each embankment strike, the trailer separated from the truck-tractor and its forward momentum was directed into the rear of the cab structure.

6.3.4 Vehicle to Vehicle

Six of the 16 vehicle to vehicle collisions were head-on impacts and are labeled as “12 o’clock / 12 o’clock” under impact orientation in Table 19. All of the head-on collisions involved speed differentials greater than 50 mph.

Table 19. Key Crash Event: Vehicle to Vehicle

Case	impact orientation	primary factor	cab deformation	secondary factor
T007	12 o'clock / 12 o'clock	catastrophic crash	severe	vulnerable occupant
T001	12 o'clock / 12 o'clock	catastrophic crash	severe	none
T038	12 o'clock / 12 o'clock	catastrophic crash	severe	none
T054	12 o'clock / 12 o'clock	catastrophic crash	severe	none
T059	12 o'clock / 12 o'clock	catastrophic crash	severe	none
T066	12 o'clock / 12 o'clock	catastrophic crash	severe	none
T012	12 o'clock	catastrophic crash	severe	none
T030	12 o'clock	catastrophic crash	severe	none
T047	12 o'clock	catastrophic crash	severe	none
T014	12 o'clock / 6 o'clock	catastrophic crash	severe	none
T022	12 o'clock / 6 o'clock	catastrophic crash	severe	none
T025	12 o'clock / 6 o'clock	catastrophic crash	severe	post-crash fire
T062	12 o'clock / 6 o'clock	catastrophic crash	severe	none
T026	12 o'clock / 6 o'clock	catastrophic crash	severe	none
T033	12 o'clock / 6 o'clock	catastrophic crash	severe	offset impact
T041	12 o'clock / 6 o'clock	catastrophic crash	moderate	vulnerable occupant

Three cases involved another heavy vehicle overturning in the roadway, leading to the crash. The combination of high closing speeds and the significant mass of the collision partner contributed to the catastrophic damage seen in these events.

Seven cases involved a tractor-semitrailer impacting the rear of another heavy truck, labeled as "12 o'clock / 6 o'clock" in Table 19. The majority of rear impacts into trailers involved significant underride. The range of travel speeds, where available in FARS, was 55 to 80 mph for four of the striking vehicles.

7 Conclusions

The analysis of crash databases has provided a statistical overview of heavy truck crashes. Even though seat belt use has increased in class 7 and 8 commercial vehicles, more than half of heavy truck fatalities were unbelted. Emphasis is warranted for all heavy truck occupants to utilize the primary safety device installed in their truck, the seat belt. Seat belt use could significantly reduce occupant ejection, preventing the event involved in nearly 20 percent of fatalities. Prior FMCSA study of preventable injuries through seat belt use estimates a reduction in injury severity of approximately 50 percent.[14] As the agency continues to monitor the effectiveness of light vehicle belt reminders, we may consider investigating belt use reminders within the truck fleet to promote increased belt use.

We may consider upgrading the seat belt requirements in heavy trucks. The majority of new heavy trucks are reported as having lap/shoulder belt assemblies at the front left and right seating positions. This could allow removing the Type 1 (lap belt) option at these positions from 49 CFR § 571.208 S4.3. The shoulder belt portion is more effective in reducing an occupant's upper body motion in light vehicle frontal impacts. Prior NHTSA light vehicle research estimates lap/shoulder belts to have a 40-50 percent fatality

[14] George Bahouth, Elizabeth Langston, A. James McKnight, Eduard Zaloshjna, Jerry Robin and Jerry Kumer. (2007). *Safety Belt Technology Countermeasures Study*. FMCSA Report No. FMCSA-RRR-07_029, p. 73-78, Washington: U.S. Department of Transportation.

and 45-55 percent injury reducing effectiveness compared to 30-40 percent fatality and 25-35 percent injury reduction effectiveness for lap belts within light vehicles. [15]

TCDSS cases involving impacts between large vehicles or fixed objects were examples of high energy events, unyielding impact partners or impact orientations compromising the cab structures. A steering wheel mounted air bag might be unlikely to enhance occupant protection in these cases. The lack of lower severity crashes within the TCDSS did not allow a complete analysis. Research in truck countermeasures is being initiated through the U.S. Department of Transportation's sponsorship of the Advancing Transportation Leadership and Safety Center (ATLAS).[16,17] This center's review of truck crash scenarios will enable computer simulations to investigate enhancing the safety of truck occupants, such as reducing ejection with the installation of side air curtains. NHTSA will stay informed of this center's research.

NHTSA's prior crashworthiness work for light vehicles would need a significant amount of research to determine their feasibility for heavy vehicles. The TCDSS showed restrained heavy truck occupants subjected to crash types that are overwhelmingly catastrophic. Heavy truck weights and high speeds contribute to energies an order of magnitude greater than the energy in light vehicle frontal barrier crash tests. These catastrophic crashes transfer extraordinary high levels of energy through the vehicle structure. Prior SAE International research generated Recommended Practices to promote increased cab strength, yet the magnitude of catastrophic events appears to be beyond their scope.

We found that manufacturers have incorporated SAE Recommended Practices into improving cab crashworthiness. However, the current SAE Recommended Practices have not been updated in over a decade. Accordingly, the agency believes there is merit in SAE International reevaluating the current practices to determine if additional improvements can be made. The agency has contacted SAE International and has asked them to reassess the SAE Recommended Practices in light of our study and recent motorcoach crashworthiness research. NHTSA will closely follow and participate in this work.

The agency will continue to monitor additional injury risk reduction countermeasures, while the current crash avoidance focus can yield the most benefit through the prevention of these catastrophic crashes. Agency investigation into heavy truck speed limiters indicate that by lowering speed, crash severity can be decreased.[18] Speed limiters could help to reduce the energy in heavy truck crashes and assist in reducing catastrophic crash events. NHTSA has announced its intention to pursue rulemaking and expects to issue a Notice of Proposed Rulemaking in 2015.

Additional technologies, such as F-CAM systems for heavy trucks show a benefit in reducing impacts into the rear of other vehicles.[19] Similarly, pending rulemaking on heavy truck-tractor Electronic Stability Control systems signal a reduction in loss of control events, rollovers and corresponding injuries. The agency's Preliminary Regulatory Impact Analysis on ESC estimates a reduction in targeted crashes that could save up to 60 lives.[20] NHTSA is committed to increasing heavy truck occupant safety through continued efforts to reduce events leading to a crash.

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[15] *Final Regulatory Impact Analysis, Amendment to Federal Motor Vehicle Safety Standard 208, Passenger Car Front Seat Occupant Protection,* NHTSA Publication No. DOT HS 806 572, pp. IV-1 - IV-16. (1984). Washington, DC: U.S. Department of Transportation.

[16] Atlas Center | UMTRI. www.atlas-center.org (August 19, 2014)

[17] "TTI's Safety Center Expands Research Opportunities Through New ATLAS Center ". Texas A&M Transportation Institute. June 10, 2014. Web. August 19, 2014

[18] Steven L. Johnson and Naveen Pawar. (2005). *Cost-Benefit Evaluation of Large Truck-Automobile Speed Limits Differentials on Rural Interstate Highways.* MBTC 2048. p.28 and 126. Washington, DC: U.S. Department of Transportation.

[19] *Ibid*.

[20] *Preliminary Regulatory Impact Analysis, FMVSS No. 136 Electronic Stability Control Systems On Heavy Vehicles,* Docket ID: NHTSA-2127-AK97 (2012)

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