Cargo Tank Incident Study (CTIS)

Rollover Data and Risk Framework

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13. ABSTRACT (Maximum 200 words)

It is critical to our nation's safety to minimize the risk of accidents involving the transportation of hazardous materials on our nation's roadways via commercial cargo tank trucks. This research included a detailed human factors analysis of cargo tank rollovers (2011-2014); driver performance errors were the most frequently identified contributing factor. The largest percentage of errors were attributed to poor directional control, followed by overcompensation. We also provide a comparison of crash statistics from about 10 years ago to data from tanker rollovers (not hazmat specific) that occurred between 2011 and 2014 using the GES database to determine any notable changes in tanker rollover trends in the last decade. We analyzed the relationship between training regulations, training curricula, training technology, and advanced safety technology, noting gaps that may be compromising safety, which led to three main recommendations. First, we recommend that FMCSA and PHMSCA collaborate to develop a Tank Vehicle Endorsement Curriculum. Second, we recommend that *Section 8 Tank Vehicle* in the model commercial driver's license (CDL) manual be redesigned for easier access to information relevant to tank vehicles. Finally, we recommend that the tanker industry explore the benefits of tank-vehicle-specific rollover prevention signage.

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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")
oz	ounces	28.35	grams	g
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
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
mL	milliliters	0.034	fluid ounces	fl oz
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
g	grams	0.035	ounces	oz

SI* (MODERN METRIC) CONVERSION FACTORS

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)**

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- Federal Motor Carrier Safety Administration (FMCSA)
- Tank Trailer Manufacturers Association
- National Tank Truck Carriers (NTTC)
- National Association of Publically Funded Truck Drivers (NAPFTD)
- Professional Truck Driver Institute
- Commercial Vehicle Training Association (CVTA)
- Bendix®
- Meritor WABCO
- Lytx®
- Doron
- FAAC
- L-3.
- Virage
- AplusB Software

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List of Abbreviations

Abbreviation	Term
AAMVA	American Association of Motor Vehicle Administrators
ABS	Automatic Braking System
ACC	Adaptive Cruise Control
BASICs	Behavior Analysis and Safety Improvement Category
BSM	Brake Stroke Monitoring
CAS	Collision Avoidance Systems
CBT	Computer Based Training
CDL	Commercial Driver's License
CDLIS	Commercial Driver's License Information System
CFR	Code of Federal Regulations
CIB	Crash Imminent Braking
CLP	Commercial Learner's Permit
CMV	Commercial Motor Vehicle
CSA	Compliance, Safety & Accountability
CTIS	Cargo Tanker Incidents Study
CV	Commercial Vehicle
DC	District of Columbia
DOF	degrees of freedom
DOT	Department of Transportation
ELDTAC	Entry-Level Driver Training Advisory Committee
ESC	Electronic Stability Control
FCWS	Forward Collision Warning/mitigation Systems
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	Field Operational Test
FMCSR	Federal Motor Carrier Safety Regulation
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
H	Hazmat Endorsement
HFCAS	Human Factors Analysis and Classification System
HM	Hazardous Materials
HMCRP	Hazmat Cooperative Research Program
HMR	Hazardous Material Regulation
HOS	Hours of Service
ID	Identification
IIHS	Insurance Institute for Highway Safety

Abbreviation	Term
Kbps	Kilobits per second
LDWS	Lane Departure Warning System
LTCCS	Large Truck Crash Causation Study
MCMIS	Motor Carrier Management Information System
N	Tanker Endorsement
N/A	Not Applicable
NASS	National Automotive Sampling System
NHTSA	National Highway Transportation Safety Administration
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
OHMS	Office of Hazardous Materials Safety
PAR	Police Accident Report
PHH-20	PHMSA's Engineering and Research Division
PHH-40	PHMSA Field Services Support Division
PHH-60	PHMSA Program Development Division
PHMSA	Pipeline and Hazardous Materials Safety Administration
PII	Personally Identifiable Information
RSC	Rollover Stability Control
RSS	Roll Stability System
SME	Subject Matter Expert
SMS	Safety Measurement System
STAMP	Systems-Theoretic Accident Modeling and Processes
TIFA	Trucks in Fatal Accidents
TPMS	Tire Pressure Monitoring Systems
VNTSC	Volpe National Transportation Systems Center
X	Hazmat and Tanker Endorsement

Preface

This report will describe results from an in depth crash analysis of 93 case studies of cargo tank rollovers that occurred during a defined period covering 2011 through 2014. We analyzed each rollover focusing on potential human factors causes associated with each crash. This report also provides an analysis of the relationship between training regulations, training curricula, training technology, and rollover prevention technology. We note any operational gaps that may be compromising safety. Literature reviews, crash analyses, subject matter experts (SME), and stakeholder consultation were used to inform this research.

This report was prepared for The Department of Transportation (DOT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Hazardous Materials Safety (OHMS). Findings from this report may also inform PHMSA's Engineering and Research Division, Program Development Division, and Field Operations Division, who were previously involved in a review of rollover incidents. The Federal Motor Carrier Safety Administration (FMSCA), the National Highway Transportation Safety Administration (NHTSA), and the Federal Highway Administration (FHWA) are also the target audience for this research.

1. Executive Summary

The mission of the Pipeline and Hazardous Materials Safety Administration (PHMSA) is to protect people and the environment from the risks of hazardous materials in transportation with the vision that no harm results from hazardous materials transportation (Pipeline and Hazardous Materials Safety Administration, 2012). Because hazardous materials are a large, vital part of our daily lives, it is critical to our nation's safety to minimize the risk of accidents involving the transportation of these materials on our nation's roadways via commercial cargo tank trucks, the leading cause of injury and death from hazardous material transportation incidents.

The report is divided into 7 main sections in addition to this one. The next section of the report introduces the purpose of the research and the research goal in more detail, including an explanation of how this work aligns with the 2012-2016 PHSMA Strategic Initiative. Next, we describe the various data sources that informed this work. Chapter 4 describes the statistical analyses of 93 hazmat tanker rollovers and the comparison of rollover data in the cargo tank truck industry from about ten years ago to more recent data. Details are provided regarding methodology, theory, and the development of the risk framework used to analyze the crashes. We provide charts, tables, and/or graphs to summarize results. Chapter 5 provides a summary of advancements in rollover prevention technology since 2007 followed by a discussion of advancements in training technology in Chapter 6. Chapter 7 discusses commercial motor vehicle (CMV) driver training as it relates to PHMSA, FMCSA, and various state governments. A detailed discussion about regulatory gaps and recommendations is provided. Chapter 8 provides a summary of findings, discussion, and recommendations for next steps and future research. A brief summary of the research is provided below.

This research included a detailed analysis of 93 cargo tank rollovers that occurred between 2011 and 2014. We analyzed various elements associated with each rollover focusing on potential human factors contributors. Information from police accident reports (PARs), photographs, witness statements, media articles, and 5800.1 forms, were the primary data sources for this analysis. Driver factors were the most frequently identified contributing factor in cargo tank rollovers. Specifically, driver performance errors comprised about half of the rollovers; the largest percentage of those types of errors can be attributed to poor directional control, followed by overcompensation. The second most frequent type of driver error was driver decision error, which in nearly all cases involved the driver going too fast for conditions. Interestingly, though, in two thirds of these cases, the drivers were traveling under the posted speed limit. When comparing these data to the safety records of each driver we found no significant differences in the distribution of driver errors across drivers with no, one, or multiple previous violations. These results suggest that training and safety technology should, at least in part, address unintentional lane departures and appropriate speeds for tank truck operators. These results also indicate that there does not appear to be a pattern of unsafe driving among tank truck operators in our sample; drivers had the same likelihood of rolling over despite whether or not they were involved in a previous crash.

We also provide a comparison of crash statistics from about 10 years ago to data from tanker rollovers (not hazmat specific) that occurred between 2011 and 2014 using the GES database to determine any notable changes in tanker rollover trends in the last decade. We found that although the average number of cargo tank rollovers has decreased since the 2007 Battelle report, there has not been a clear overall downward trend over the last decade. The number of cargo tanker rollovers, according to the GES data, seems to vary year by year. The largest proportion of cargo tank rollovers occurred on roadways that were not divided. Further, the majority of cargo tank rollovers occur on straight roads (away from intersections or junctions); since the 2007 Battelle report, more rollovers occur on straight roads versus curved roads. Significantly more rollovers involved traveling straight as a last pre-crash movement in our data compared to previous data. Just under half of the cargo tank rollovers involved excessive speed. The majority of critical events resulting in a rollover crash were driver related in our dataset, similar to the data reported in 2007. Finally, the average age of cargo tank truck drivers seems to be greater than it was in 2007, indicating that younger drivers are not entering the industry as much as they used to.

Both advanced safety technology and training technology have become move available and sophisticated over the past decade. Prior to 2007, stability control systems and lane departure warning systems were the advanced safety technologies largely available and in use; driver monitoring technologies were in their early stages. Since then, not only have stability control, lane departure warning, and driver monitoring technologies become more sophisticated, but the range of safety technologies has greatly expanded to include collision mitigation and blind-spot protection systems. Fleet monitoring systems now provide fleets with extensive real-time data to enhance the efficiency of operations and inform training programs. Market penetration for these technologies is mostly saturated by larger carriers. The most effective technology for mitigating tank truck rollovers seems to be are lane departure systems, as many rollovers in our dataset could be attributed to poor directional control (weaving and drifting), perhaps the result of distraction or fatigue.

Availability and usage of Computer Based Training (CBT) for CMVs has increased over the last decade as well, in part due to the growing availability and of Internet access via home computers and portable electronic devices (smartphones, etc.). Faster Internet connections facilitate the use of CBT features such as games, video files and real-time visual communication during training. Likewise, the availability and use of simulators as instructional tools has also become increasingly more popular over time. A few companies develop tank truck simulators that are on the market today, but it is unclear whether they are capable of simulating liquid weight shift using probabilistic data to truly emulate the behavior of liquid in a cylindrical container during a given scenario.

We analyzed the relationship between training regulations, training curricula, training technology, and advanced safety technology, noting gaps that may be compromising safety. Literature reviews, subject matter experts (SME), and stakeholder consultation were used to inform this research. We developed three main recommendations based on regulatory gaps. First, we recommend that FMCSA and PHMSCA collaborate to develop a Tank Vehicle Endorsement Curriculum (model or mandatory TBD) that includes guidelines for the use of the PHMSA/FMCSA Rollover Prevention Training Video. Second, we recommend that *Section 8 Tank Vehicle* in the model commercial driver's license (CDL) manual should be redesigned. Trainees should be able to unambiguously access information relevant to tank vehicles in that one section rather than having to reference other sections; language that is making a relevant point but only in the context of a box trailer should be deleted from this section. Recommended behaviors should be specific and, where appropriate, quantified. Finally, we recommend that the tanker industry explore the benefits of tank-vehicle-specific rollover prevention signage with recommended speed limits for posting on curves and ramps to determine safe tanker (vs. tractor-trailer) speeds under varying tank load conditions and curve/ramp geometries.

2. Introduction

2.1 Purpose

This report will describe results from an in depth crash analysis of 93 case studies resulting in cargo tank rollovers that occurred during a defined period covering 2011 through 2014. We analyze various elements associated with each rollover, focusing on potential human factors causes associated with each crash. This report will also provide a comparison between rollovers from about 10 years ago and the more recent rollovers (2011 through 2014) as reported in the GES database. We also analyze the relationship among training regulations, training curricula, training technology, and advanced safety technology. We note any gaps that may be compromising safety. Literature reviews, crash analyses, subject matter experts (SME), and stakeholder consultation were used to inform this research.

2.2 Background

Hazardous materials are a vital part of our economy. They are essential to our daily life. For example, we use gasoline to travel from place to place. We use oil or gas to heat our homes in the cold weather. We use hazardous materials to create medicine, fertilizer, and purified drinking water, among other things. Although there is a low risk of accidents involving the transport of hazardous materials, when an accident does occur, the consequences of accidents involving these substances pose a danger to society regardless of the mode in which they are traveling (i.e., air, sea, rail, roadway). It is paramount to our nation’s safety to minimize the risk of accidents involving the transport of hazardous material. This document will focus on the transport of hazardous materials on our nation’s roadways via commercial motor vehicles (CMV), specifically cargo tank trucks.

The mission of the Pipeline and Hazardous Materials Safety Administration (PHMSA) is to protect people and the environment from the risks of hazardous materials transportation with the vision that no harm results from hazardous materials transportation (Pipeline and Hazardous Materials Safety Administration, 2012). In support of this mission, PHMSA’s aim has been to reduce the number of hazardous materials incidents involving death or major injury to between 21 and 32 per year, and reduce the number of hazardous materials incidents with environmental damage to between 44 and 64 per year. To achieve these goals, the agency focused on a variety of factors that influence the safe transport of hazardous materials in their 2012-2016 Strategic Plan. Among these factors, and of critical importance to this research, are **tank truck crashes and rollovers**; **human error and poor safety culture**; **understanding and targeting risk**; **mitigation and response**; and **advances in technology**. Each of these factors is described briefly below as it relates to the current research.

2.2.1 Tank Truck Crashes and Rollovers

2.2.1.1 Large Truck Rollovers

Heavy trucks (those greater than 10,000 lbs.) are particularly susceptible to rollover crashes due to various vehicle factors including their size, weight distribution, and varying types of freight. Moonesinghe et al. (2003) suggest that the heavier the truck and cargo, the more prone the truck is to rollover. They also found that at speeds over 55 mph, inclement weather and road curvature increase the chances of large truck rollovers. The Federal Motor Carrier Safety Administration (2007) found that among vehicle types, large trucks accounted for the highest percentage of injury crashes resulting from rollovers.

2.2.1.2 Tank Truck Rollovers

In a tank vehicle, there is very little room for error in handling. Where rollovers are concerned, the primary issue is that the liquid nature of the cargo causes a tanker to behave differently from a tractor-trailer transporting solid non-bulk cargo. This rollover risk while carrying liquid cargo is true regardless of whether the tank vehicle is carrying hazardous or non-hazardous materials. Tank vehicles also have a high center of gravity, but the additional factor that makes them even more vulnerable is that the liquid cargo responds to g-forces, surging forwards and backwards, and also sloshing from side to side. The liquid has room within the tanker to do this when tanks are not loaded to capacity. Tank vehicle in particular are partially filled because of weight restrictions, or in the case of volatiles to allow for expansion (outage).

Some tanks have configurations involving baffles, to limit front-back surge, but others are smoothbore; regulations specify which type of tank to use for which liquid cargo. In all cases, tank structure does not control side-to-slide sloshing. Consequently, a tank vehicle driver needs to know that the tank will behave differently from a box trailer in commonplace situations such as stopping, turning, on curves, in reaction to skid, and especially when executing avoidance maneuvers. Furthermore, the extent to which a particular liquid cargo will slosh and surge will depend on its viscosity as well as on the extent to which the tank is filled. The driver needs to know the specific behavior of the particular liquid cargo being transported.

2.2.1.3 Hazmat Rollovers

Tank truck rollover crashes carrying gasoline and other flammable liquids are the leading cause of injuries and death from hazardous materials transportation incidents. These rollover crashes account for approximately 75% of gasoline-related fatalities (Pipeline and Hazardous Materials Safety Administration, 2012).

The agency has posed several major strategies to address tank truck rollovers: develop new standards for electronic stability control and work with other DOT operating administrations to improve driver training and reduce driver fatigue. Furthermore, PHMSA had proposed new rules for reducing hazard associated with tank truck wet lines, although as of the writing of this report, this rulemaking was withdrawn. In support of these strategies, this work presents the current training requirements and training techniques (including technology) for commercial truck drivers with hazmat endorsements from the perspective of PHMSA and FMCSA. Further, we have researched the regulations associated with this training and identified gaps that, if filled, could contribute to training safer drivers. This work also investigated the impact of driver fatigue on a selection of rollover case studies that occurred between 2011 and 2014 by analyzing Police Accident Report (PAR) narratives, witness statements, follow-up surveys, and other related incident documentation.

2.2.2 Human Error and Poor Safety Culture

Human error is often identified as the major contributing cause in accidents involving motor vehicles. In their 2007 report, Battelle found that driver error was associated with 75% of cargo tank rollovers (Pape, et al.). In a separate Fire Engineering Report, the author suggested that although vehicle mechanical failure sometimes occurs, a large majority of accidents involve operator error (Peters, 2007). Findings such as these were most likely arrived at using traditional accident analyses, which describe the accident as a temporal string of human errors and failures that lead up to the incident or accident (Levenson, 2003). However, traditional models may fail to take into account other contributing factors in the accident besides human error. A more comprehensive systems model views accidents as the result of interactions among system elements extending beyond the immediate lead up to the incident.

Transporting hazardous materials is a complex system comprising many interrelated parts. For example, the driving performance of a single driver can be influenced by the training he or she received, the company for which he or she was hired, the agencies which regulate his or her responsibilities, the behavior of other vehicles on the road, and societal attitude towards truck driving. Although this research did not utilize traditional Systems-Theoretic Accident Modeling and Processes (STAMP) methodology to analyze the incidents, we did capture and consider some systemically induced factors that may have contributed to the accident (e.g., safety culture of the carrier). We also used traditional methodology to evaluate the type of human error involved in the accident when applicable. Using this approach to analyze rollover incidents supports PHMSA’s strategy to address both human error and safety culture.

2.2.3 Understanding and Targeting Risk

PHMSA aims to develop a risk management framework and improve data collection to better manage serious risk and understand future trends. While analyzing data to better understand potential contributing factors for tank truck rollovers, we developed a framework to identify and categorize contributing risks. This framework can be used to help the agency better determine the types of data they need to collect to more adequately understand the types of existing risk and potential emerging trends. In developing this framework and analyzing data, we also identified areas in which current data collection could be improved to allow for more efficient and effective analysis of incident data. We hope that it will be quite straightforward to apply our risk framework to future rollover incidents once data collection content and processes both improved.

2.2.4 Advances in Technology

Finally, the current research supports the agency's aim to address advances in technology to improve or manage hazardous material transportation risks. FMCSA sponsored a Battelle report to study cargo tank rollovers, including driver and other contributing factors, and their design and operation to improve their roll stability (Pape, et al., 2007). Part of their methodology included an analysis of data from four crash databases (Motor Carrier Management Information System (MCMIS), Large Truck Crash Causation Study, Trucks Involved in Fatal Accidents (TIFA), and General Estimates System (GES)) to identify common conditions associated with cargo tank rollovers. Since this report's publication in 2007, new technological advances have been made and implemented on some commercial vehicle fleets, including tank trucks. The current work investigated if, and the extent to which, the presence or absence of safety technology may have influenced the tanker roll stability and the driver operating technique. This work also researched the use of training technology and its potential to better prepare drivers to prevent rollovers in the presence of risk factors such as slosh and surge.

2.3 Research Goals

Using data from two crash databases (MCMIS and GES) and from PARs, the goal of this research was to better understand the common factors across cargo tank truck rollovers occurring in the last several years. Separately, this research provides an analysis of current cargo tank truck training trends, including technology, and regulatory gaps related to training and safety. We also provide an overview of safety assist technology in terms of new products, implementation, effectiveness, and adoption attitudes.

2.4 Approach

The approach for the research was broad in some areas and more focused in others. One objective was to understand the requirements and practices for training cargo tanker drivers. We identify regulatory gaps regarding cargo tanker driver training and provide recommendations to fill those gaps. We performed an in depth review of training literature including academic articles, government reports, appropriate chapters of the Code of Federal Regulations (CFR), training school curricula and methodology, listening session transcripts regarding entry-level driver training, discussions with training experts and schools, and training technology manuals. A second objective was to better understand changes in rollover prevention technology since 2007 in terms of advancements, availability, and adoptability. We used a similar approach to our training analysis to analyze rollover prevention technology. We reviewed technology manuals, academic reports, government reports, and other relevant literature.

We updated crash statistics data since the 2007 report, focusing on tables ES-1, ES-2, and ES-3 using data from MCMIS and GES. Our focus was on determining the type of vehicle configurations involved in rollovers and the important circumstances surrounding the rollover.

We performed a very detailed analysis of hazmat tanker rollovers that occurred between 2011 and 2014 for which we had surveys, PARs, and other incident data (we call this set of rollovers "case studies"). For this analysis, we focused primarily on the contents of PARs, including narrative reports and diagrams from law enforcement, witness narrative statements, and photographs of the scene. We also used descriptive data from PARs, incident reports, and surveys to understand crash circumstances such as location, weather, commodity, etc.

We created our own risk framework as a first step in categorizing the risks associated with hazmat tank truck rollovers. This framework was informed by preceding sources and established terminology, but we expanded the range of factors considered. We then used this framework to develop a formal protocol for coding the data. Two trained coders coded each incident. Discrepancies in coding were resolved by a third party, an impartial senior researcher; discrepancies that were not easily resolved were escalated to a group discussion among transportation human factors specialists.

2.5 Document Overview

The remainder of this report will address the research objectives of this project. In Chapter 3, we discuss the various sources of data and databases used for the analysis of hazmat tank truck rollover incidents. Chapter 4 describes the analyses, including the development of the risk framework. Details are provided regarding methodology and theory. We provide charts, tables, and/or graphs to summarize results. Chapter 5 provides a summary of advancements in rollover prevention technology since 2007. Chapter 6 presents a discussion of advancements in training technology. Chapter 7 discusses CMV driver training as it relates to PHMSA and FMCSA regulations, and state government and private-sector implementation of those regulations. We then identify regulatory gaps in the training of tank truck drivers, including those transporting hazmat, and offer recommendations to improve driver and public safety. Chapter 8 provides a summary of findings, discussion, and recommendations for next steps and future research.

3. Data Sources

In the following sections, we describe the various sources of data and databases used for the analysis of hazmat tank truck rollover incidents including a summary of the stakeholder outreach effort. When applicable, we first provide an overview of the data source followed by a summary of the specific types of data we used from that source.

3.1 PHMSA Incident Reports

3.1.1 Overview

To improve hazardous material transportation safety, PHMSA uses Incident Reports (Form DOT 5800.1, Appendix A) to identify safety trends and initiate new safety programs. All industries regulated by PHMSA are required to report incidents that meet established reporting criteria, which are detailed in 49 CFR Parts 171-180. Section 171.16 (Detailed Hazardous Materials Incidents Reports, 2013) requires that all hazmat incidents be reported in writing within 30 days of the incident, followed by a second report within one year of the incident.

The 5800.1 is intended to capture critical information about each incident, including location, cause, and consequences. Information reported is used for future safety analysis by PHMSA and other research entities including other government agencies, academia, and industry. PHMSA provides guidance for companies (CMV carriers in this case) to properly prepare a 5800.1 written incident report.

3.1.2 Data

We only used a subset of information fields from the 5800.1 for this research; this form is not human factors focused, so only some fields applied to our research goals. Some fields were crosschecked with the PAR for each incident. When information between the two sources did not match, we used the information from the PAR rather than the 5800.1. We prioritized the PAR because it comes from a source with the most direct opportunity to observe the circumstances of the accident; is it completed by a law enforcement officer who was present at the scene of the accident immediately after it occurred. In contrast, the 5800.1 is completed after the accident (sometimes weeks afterwards), and not necessarily by someone who was at the scene of the accident. Among other sources of data, we used the following information fields from the 5800.1 form to analyze rollover incidents:

- Incident Date (question 3)
- Time of Accident (question 4)
- Carrier Information (question 10)

- Cargo Type (question 14)
- Cargo Amount & Capacity (question 27)
- Fatalities (question 33a)
- Injuries (question 34)
- Estimated Speed (question 37)
- Existence of Multiple Compartments
- Narrative Description of Events (Part VI)

Information about the carrier was used to look up carrier safety records in MCMIS. That information is discussed in more detail below in 3.5 and 4.5.3.4.

3.2 Police Accident Reports (PARs)

3.2.1 Overview

PARs are written reports prepared by law enforcement officers who investigate motor vehicle crashes. While the overall content is fairly standard, each state has its own PAR format and coding schemes, so the detailed information reported varies slightly across the US. The information reported consists of a description of the driver(s) involved in the accident, the location of the accident, the conditions that lead up to and/or may have caused the accident, witness reports, diagrams, and any other information the officer finds to be relevant and worth reporting[1].

3.2.2 Data

The PARs were the primary source of information for the human factors causal analysis due to the level of detail recorded and the types of information obtained by law enforcement. The PARs that we received varied in quality. While many were legible and complete, some were poorly scanned and others were only partially completed. As noted above, when information between databases did not match, we used information from PAR since it was collected at the time of the incident. For our analysis, we used the following data fields along with information from other sources (discussed in this section):

- Incident Date
- Time of Incident
- Lighting Conditions
- Type of Road
- Road Surface Conditions (Weather)
- Tank Driver's Age

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[1] Traffic crash reports and the corresponding code sheets available for each state can be found here: http://www.actar.org/reports.html.

- Tank Driver's Gender
- Licensing State
- Speed Limit and Recorded Speed
- Injuries
- Fatalities
- Diagram of the Incident
- Attached photos

Along with the above data fields, we also used the narrative description of events provided by law enforcement and witnesses to extract much of the data we used to analyze the incidents. When reading the narrative descriptions we pulled out information such as:

- Number of vehicles in the accident
- Location of vehicle(s) on/off the roadway (i.e., exit ramp, right lane, shoulder, etc.)
- Tripped versus un-tripped rollovers
- Existence of guardrail
- Vehicle related failures (e.g., flat tire)
- Presence of animals, objects, or pedestrians
- Description of human factors (i.e., startle, inattention, under the influence of substances, fatigue, illness, etc.)
- Driver experience level
- Environment details (e.g., signage, potholes, etc.)
- Presence and behavior of other drivers on the roadway

3.2.3 Obtaining PARs for Hazmat Rollovers

Information contained in the PAR is critical to performing a thorough human factors analysis of hazmat tank rollovers. All hazmat incidents are required to be reported in writing within 30 days of the incident via the 5800.1 form (Detailed Hazardous Materials Incidents Reports, 2013). However, PHMSA does not require a PAR from the state, unless the accident resulted in serious injury, death, or a tow-away as a *consequence of release of the hazardous material.* Thus, not all hazmat rollover incidents for which carriers submitted a 5800.1 to PHMSA had a PAR available. In our original set of reports from 2012-2013 (those provided by PHMSA), only 44 PARs were provided.

For those cases lacking a PAR, we reached out to local and state jurisdictions to obtain them. First, we compiled a list of incidents in for which we needed PARs by state. We then performed Internet searches to understand the process of requesting PARs for each state in our list. The process varies vastly between states. We ultimately were able to obtain 43 more reports. By broadening the period from 2011-2014, PHMSA was also able to provide an additional 19 PARS.

Some of these reports had to be removed from the analytic dataset due to data quality issues. We had to discard 13 of them because the PARs we received from the three sources were not the correct report for the incident under study or were incomplete or illegible. After these were removed, our final dataset comprised 93 cases with complete and usable PARs.

3.3 PHMSA Surveys

3.3.1 Overview

PHMSA's Office of Hazardous Material Safety Engineering and Research (PHH-20), Program Development (PHH-60) and Field Services Support (PHH-40) Divisions performed a review of 142 cargo tank rollovers that occurred between October 2012 and September 2013. After reviewing the completed 5800.1 forms, they administered a survey to collect additional information from the carriers to supplement the 5800.1 incident data (Appendix B). Eighty-eight of these surveys were completed and returned. The survey contained four sections, which were comprised of 13 questions in total. Respondents were asked to provide pictures when possible. When the surveys were returned partially completed, further clarification was requested from the carrier. That clarification was sometimes received but sometimes it was not.

3.3.2 Data

The survey is summarized in more detail below in Table 1. For this human factors research, we did not use all data collected by the survey (questions in bold print were used). Specifically, we used questions I.1, II.1, and IV.1 when available.

Table 1. Summary of PHMSA Cargo Tanker Survey.

Section	Questions
I. Tank Data	**1. Configuration?** 2. Gross Vehicle Weight? 3. Material of Construction?
II. Tank Rollover Protection	**1. Description of rollover protection devices.**
III. Accident Data	1. Rollover Direction? 2. Degree of Rollover? 3. Leak Location? 4. Damage? 5. Damage Extent? 6. Longitude Skid? 7. Ground Condition? 8. Road Material?
IV. General Information	**1. Description of the probable incident cause in detail?**

3.4 Google Maps

Google Maps was used when more detail was needed regarding the location of the incident than was provided in the textual documents. For example, sometimes information regarding the type of roadway was inconsistent between the 5800.1, the PAR, and MCMIS; the roadway may have been listed as a two-way trafficway divided with a positive barrier in one database and two-way trafficway not divided elsewhere. In these situations, we would look up the location of the incident on Google Maps Earth View to determine the layout of the roadway. Google Maps Earth View was also used to determine the presence or absence of a guardrail when insufficient information was provided. We also utilized Google Maps to determine whether or not the accident occurred on an entrance or exit ramp when the reports were unclear. To determine the exact location of the incident we used latitude and longitude coordinates when provided. Without this information, we used the street address as provided on the PAR, or if not available, as provided on the 5800.1.

Using Google Maps has limitations, however. The images available in Google Maps are from a variety of different periods across the US. We were unable to determine whether the road looked the same during the time of the incident. Although it is unlikely that this would affect many of our cases, it is a possibility. In some cases, the precise location of the incident on the road was difficult to determine which made locating guardrails, shoulders, and/or medians more difficult. For example, sometimes the road had a guardrail on some segments of the road, but the guardrail was absent on other segments. When we had a mile-marker to reference, it was easier to find the exact location of the incident, but mile-marker was not always provided. Other times, the officer did provide the mile-marker, but we were unable to zoom in on it using Google Maps.

3.5 Motor Carrier Management Information System (MCMIS)

3.5.1 Overview

MCMIS is a federally managed database of CMV drivers' safety performance information. It contains the information of approximately 1.5 million unique CDL drivers along with inspection records and safety metrics for each driver. Safety metrics are generated from inspections, violations, and Driver Out-of-Service orders. It also contains the crash history for drivers of CMV freight and passenger vehicles, including hazardous material transporters required to comply with both the Federal Motor Carrier Safety Regulations (FMCSRs) and the Hazardous Materials Regulations (HMRs). A driver with a CDL does not necessarily drive a commercial motor vehicle for a living, or may never operate in locations where inspections occur. If there is no inspection or crash, there is no data in MCMIS. Thus, many drivers in MCMIS do not have safety performance data of any type.

For this effort, MCMIS data was queried to provide information on crashes, descriptive data for the carriers for which they were driving and safety performance data from roadside inspections. We also used data from FMCSA's Safety Measurement System (SMS) to better understand carrier safety culture. SMS uses safety data to assess carrier safety using metrics called BASICS (Behavior Analysis and Safety Improvement Categories) (Federal Motor Carrer Safety Administration, 2012) . The BASICs incorporate violations of the Federal Motor Carrier Safety Regulations (FMCSRs) and Hazardous Materials Regulations (HMRs) and focus on behaviors that may increase the severity of crashes (Federal Motor Carrier Safety Administration, 2010).

There are seven BASICs: Unsafe Driving, Crash Indicator, Hours of Service (HOS) Compliance, Vehicle Maintenance, Controlled Substances/Alcohol, Hazardous Materials Compliance, and Driver Fitness. For each BASIC there is threshold point beyond which a carrier is prioritized for potential intervention. Each carrier has a percentile score based on their safety data. High percentiles indicate worse safety performance[2].

3.5.2 Data

MCMIS data for carriers and drivers was retrieved based on carrier DOT number, date, and in some cases by matching other identifying properties about the crash with the rollover event identified in the PAR. For this study, we recorded whether carriers were above the threshold on all seven BASICS. These data allowed us to better understand the safety culture of the carriers for which the drivers were employed during the time of the rollover. To get some understanding of each driver's safety history, we looked at percentile scores for the following BASICS: Unsafe Driving, Controlled Substances/Alcohol, Crash Indicator, Hours of Service, and Driver Fitness, because these are the most relevant to driver behavior. Although the BASICs are not traditionally applied to drivers, we used this metric as a proxy to understand if drivers showed a pattern of unsafe driving or not.

3.6 National Automotive Sampling System (NASS) General Estimates System (GES)

3.6.1 Overview

Started in 1988, the NASS GES database contains data from a nationally representative sample of police reported motor vehicle crashes, regardless of their severity[3]. The database concentrates on only police reported crashes, because they are thought to be the most important to the highway safety community and the general public. Crashes that are not reported to police are thought to be less likely to cause injury, most likely only causing property damage. In order to ensure a nationally representative sample, PARs are chosen weekly by GES data collectors from 60 target areas (400 police jurisdictions) that represent an accurate cross section of US geography, roadway mileage, population, and traffic density.

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[2] For more details regarding SMS and the BASICs see https://csa.fmcsa.dot.gov/Documents/SMSMethodology.pdf.

[3] More detail on the NASS GES database can be found at http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+(NASS)/NASS+General+Estimates+System.

To be eligible for this GES sample, the crash must have resulted in a PAR, must involve at least on vehicle traveling on a traffic way (a roadway open to traffic), and must have resulted in property damage, injury, or death.

Approximately 50,000 PARs are randomly selected each year. After data collection, a trained contractor interprets, codes, and enters data from the PAR into an electronic database. Although some format changes are made to the database every other year, in general about 90 data elements are coded from various different PARs (with varied formats) into a common format. Personally Identifiable Information (PII) is not provided in the database. Quality assurance testing is performed more than once throughout the process.

Information contained in the database is used to estimate the number of crashes that occur across several different types of crashes and the outcome of those crashes. This information may be used to identify larger traffic safety patterns or for regulatory and consumer initiatives. These data may also be used to form the basis of cost and benefit analyses for traffic safety initiatives. The audience for GES data is large, encompassing government, academics, and industry.

3.6.2 Data

The NASS GES database structure has changed repeatedly since the database was first started, with changes made over time to which variables were included, how variables were named, and how response options were coded for each variable. Between years, the same variable may gain or lose response options and the same response option may be shifted from one numerical code to another. The most recent set of changes to the data structure occurred in 2010. To minimize confusion resulting from these changes, we avoided using data that spanned across 2010, instead choosing to limit our analysis to data from 2011 to 2014.

Some variables in the GES database are missing data when the relevant information was not available in the sampled PARs. In most instances, missing data was imputed using sequential regression. Many GES variables are provided in two formats: one with the data as originally collected, including some missing data; and one with missing data imputed. When the option was available, we used variables with imputed data over variables with missing data.

The GES database uses a nested structure for the data. Variables are separated into several data files based on the unit of analysis at which they are collected, including among others the Accident, Vehicle, and Persons files. When moving between different data files, cases from one file frequently have a many-to-one relationship with cases from another file; a single row in the Accident file may involve several Vehicles, and a single Vehicle may contain multiple Persons.

We retrieved the following data files:

- Accident

- Vehicle
- Persons
- Distract
- Drimpair
- Maneuver
- Mfactor
- Violatn
- Vision

For the sake of brevity, we only list the analytic variables below, and not the case numbers and other identification variables used to link data corresponding to the same accident across these multiple data files.

We retrieved the following variables from the Accident data file:

- Number of Vehicles in Crash
- Number of Persons in Motor Vehicles In-Transit
- Manner of Collision
- First Harmful Event
- Number Known Injured in Crash
- Maximum Injury Severity in Crash
- Alcohol Involved in Crash
- Relationship to Junction
- Type of Intersection
- Relationship to Trafficway
- Land Use
- Lighting Condition
- Atmospheric Conditions

We retrieved the following variables from the Vehicle data file:

- Body Type
- Number of Occupants
- Vehicle Trailing
- Vehicle Configuration
- Cargo Body Type
- Travel Speed
- Speed Limit
- Speed Related
- Rollover
- Location of Rollover
- Most Harmful Event

- Pre-Event Movement
- Critical Event – Precrash
- Trafficway Description
- Total Lanes in Roadway
- Roadway Alignment
- Roadway Grade
- Roadway Surface Condition
- Related Factors – Vehicle Level
- Related Factors – Driver Level

We retrieved the following variables from the Persons data file:

- Age
- Sex
- Person Type
- Police Reported Alcohol Involvement
- Police Reported Drug Involvement

The following variables were retrieved from their corresponding data files. Each of these data files consists of a single variable, accompanied by the case numbers necessary to link it back to the correct row from the Vehicle or Persons files.

- Violations Charged
- Driver's Vision Obscured By
- Driver Maneuvered to Avoid
- Driver Distracted By
- Condition (Impairment) at Time of Crash- Driver
- Contributing Circumstances, Motor Vehicle

3.7 Stakeholder Outreach

3.7.1 Overview

As a final data source, Volpe conducted informal telephone conversations with a variety of organizations, including tank truck carrier company officers and associations, training schools, training associations, training technology manufacturers, advanced safety technology manufacturers, PHMSA, and FMCSA. Two members of the Volpe team were often present during these discussions; one team member took notes while the other led the conversation. The purpose of these interviews was to collect anecdotal information from industry and government. While these anecdotes do not represent the thoughts and practices of the industry as a whole, they do offer insight into the state of the practice. Results from these interviews will be dispersed throughout this report when relevant.

3.7.2 Training

3.7.2.1 Training Schools and Associations

Conversations with training associations served largely to facilitate outreach to training schools. Training associations were able to leverage existing membership data to identify schools that could offer insight about tank training practices. We spoke with two separate training schools that were identified by the training associations: a community college and a private school.

3.7.2.2 Carrier Safety Managers and Industry Associations

Through a literature search of corporate tank truck carrier training practices, we identified a sample of carriers with noteworthy training practices. Conversations with these carriers included topics such as their training practices; preferences for hiring drivers to operate hazmat and non-hazmat tank vehicles; and initial and recurrent training and evaluation practices. A leading industry association provided us with points of contact from these carrier companies. We followed up with these individuals via e-mail for further clarifications and details when needed.

The industry association also invited the Volpe team to connect (via teleconference) with approximately 70 carrier safety managers who were participating in a safety conference. All managers indicated that they worked for carriers with approximately 100 or more power units that carry hazmat; a smaller portion reported working for carriers that carry non-hazmat. Only four of the safety managers reported that their carrier has access to a simulator for training purposes. We also spoke with this group about training and hiring practices and other safety related topics.

3.7.2.3 Technology Manufacturers

To better understand the current advanced safety technology market, we reached out to a handful of leading industry technology manufacturers. We identified the companies of interest by conducting a market research analysis of all companies and products with relevant technology and chose the ones we perceived to be the largest players in the market. Technology of interest included stability control systems, driver monitoring systems, collision mitigation technologies, blind spot protection systems, and fleet tracking systems.

During these calls, company representatives first described the technology of interest including how it works and any improvements made to the technology over that past 10 years or so. We also discussed topics such as availability and effectiveness of the technology within the tank truck industry, industry adoption trends, and the cost of the technology. These conversations, along with literature reviews of Internet marking material and specifications, informed the information presented in Chapter 6.

4. Hazmat Tank Truck Rollover Data Analyses

4.1 Overview

Our analysis had two goals. The first goal was to determine the potential human and other factors contributing to each of the rollovers to the extent possible, using the data provided by PHMSA and local enforcement entities, plus any other data that could be obtained (i.e., via Google maps, newspaper articles, etc.). The second goal was to outline an approach to assess which of the identified human factors appeared to be the greatest contributors to rollovers, and create a logical risk framework to help identify and categorize other risk factors that contribute to the rollovers. This section will describe the development of the risk framework and its contents, data analysis including data coding, and the results of our analysis.

4.2 Data Sources Used

For the analysis of the 2011-2014 case studies, we recorded descriptive data to better understand each individual case and to more accurately categorize trends between rollover incidents. Although there was a broad range of descriptive data available for each incident, particularly pertaining to the characteristics of the hazardous materials, we focused on a small set of descriptive data that would allow for a clean comparative analysis. These data were collected from the 5800.1s, PHMSA follow-up surveys, and PARs. When data between sources were discrepant, we relied upon the PAR (see Table 2 below). These data were supplemented with safety performance data retrieved from the MCMIS database for the drivers and carriers identified in the PARs.

Table 2. Descriptive Data Collected for 2012-2013 Case Studies

Incident Data	**Vehicle Data**	**Roadway Data**	**Driver Data**	**Carrier Data**
Date	Tank Structure	Speed limit	Age	Carrier Name
Time	Rollover Protection Devices	Type of Road	Gender	Carrier DOT number
Light Condition	Advanced Safety Technology	On/off ramp details	State of license	Carrier HQ state
Injuries	Cargo Type	Presence of Guardrail	Driver safety record	Carrier safety record
Fatalities	Cargo Amount	Road surface condition		
# of vehicles and vehicle types	Cargo Capacity			
Recorded speed				

Along with the data described above, additional data were used for the analyses. We analyzed GES data for tank truck rollover occurrences between 2011 and 2014 (from a sample of all cargo tank rollovers rather than just hazmat tank rollovers) to determine if there were any changes in trends since the 2007 Battelle study regarding crash statistics and the circumstances surrounding the rollovers. We were unable to use data from the TIFA database because it only contains data for fatal accidents that occurred between 1999 and 2010, which are outside of our date range. Further, we chose not to use data from LTCCS for our analysis because those data could not be disaggregated to identify Class A and B tank vehicles.

Special emphasis was placed on updating Tables ES-1, ES-2, and ES-3 from the 2007 Battelle report. Table ES-1 showed statistics regarding the vehicle configuration of those vehicles involved in rollovers. Table ES-2 provided statistics about the number of rollovers that occurred on different types of roadways. Table ES-3 shows statistics regarding the number of rollovers that occur with other kinds of crashes. We also updated additional tables based on GES data from the Crash Statistics section where we had more recent data, including a subset of the tables from Table 2-1 through Table 2-44.

This update of prior statistics is supplemented with a new analysis based on the additional circumstance data collected from the content coding of PARs and related sources.

4.3 Development of the Risk Framework

4.3.1 Short Summaries

To begin, we read through the narrative description of each accident (when provided) from the PHMSA incident database. Each incident was given a brief description to better understand what happened in each case. The objective of this exercise was to understand the breadth of the dataset to better narrow down appropriate potential contributing factors. Brief summaries included descriptions such as "caused by other vehicle," "vehicle issue," "animal in road," "impaired driver," and in some cases "no information provided." One reviewer performed this broad overview summary of the data and circulated it to other team members to familiarize them with the data.

4.3.2 Detailed Reviews Using a Subset

Next, we conducted an in-depth review of a subset of the incidents. We chose seven cases, which had detailed narrative descriptions, PARs, PHMSA follow-up surveys and in some cases other supporting documentation. We chose seven cases that were quite different from one another. We used these criteria to develop a framework, which we could adapt as necessary after reviewing the entire dataset. Five human factors experts independently reviewed the material provided for each case. The review focused on describing what happened, how it happened, and potential explanations of why the rollover occurred. Our focus was on human factors issues, but when applicable we recorded other factors as well. We held discussion sessions to review each case as a group. After discussing each reviewer's interpretation of the case together, the team decided on the contributing factors. We listed the contributing factors in a matrix and began expanding other types of potential contributing factors based on the types of information we reviewed in these first seven cases.

4.3.3 Incorporated Existing Classification Systems

Our next step was to adapt our matrix for each incident using terminology and concepts from previous crash classification systems. We developed new classification items when necessary and deleted items that were not germane to the research goals. The previous crash classifications systems that we used and adapted are discussed in more detail in Section 4.3.5. After updating and adapting our matrix, we re-analyzed the original seven cases and the broad descriptions of the entire set to ensure we had an inclusive classification system.

4.3.4 Finalizing the Matrix

This matrix was de-constructed into individual coding questions for a thorough analysis of all 93 cases. Categorization options obtained from previous classification systems were substantially simplified based on the purpose of this research. The first step in creating the detailed options for each question was to review all data sources and categorization options and create an exhaustive list. We refined the list based on the current dataset, tasking, and research goals. We also aimed to shorten list of potential categorization items due to the size of our dataset. With only 93 cases, a small, refined set of data would likely yield more patterns in the data than an exhaustive list of all potential classification items. By creating a coding survey, we were able to create a logical order to each case analysis and were able to analyze the data as systematically as possible considering the varying sources and amounts of data for each case. The coding survey will be discussed in more detail below. Data from the coding surveys were analyzed, collated and placed back into the risk matrix to determine the most common risk factors associated with tanker rollovers.

4.3.5 Categorizing Crashes for Using the Risk Matrix

As a basis for analytic categories and terminology when evaluating the rollover case studies, we began with previous crash analysis work and supplemented it with our own work. We read through the crash analysis methodology, classification system logic and terminology used by previous work and decided whether or not it was useful for our analysis. We incorporated logic and terminology from a variety of sources where relevant and created our own classification factors and terms when we needed something new or unique.

Starting with the 2007 Battelle study (Pape, et al., 2007), we incorporated previous work for both classifying the crashes and classifying the contributing human factors. For analyzing crashes, we incorporated information from the 2005 Battelle study (Battelle, 2005), HMCRP #7 (Pape, Murray, Abkowitz, & Fleming, 2012), the Large Truck Crash Causation Study (Starnes, 2006), the UMTRI comparison of LTCCS and TIFA variables (Blower, 2007), and the 2009 National Transportation Safety Board (NTSB) Indianapolis investigation report (National Transportation Safety Board, 2009). The categories used by databases such as MCMIS, GES, and TIFA were also incorporated.

To better categorize the human factors issues associated with these rollovers, we adapted the Human Factors Analysis and Classification System or HFACS (Weigmann & Shappell, 1997). We used information from the PHMSA/FMCSA Cargo Tank Truck Rollover Prevention Training video to inform the driver factors terminology. We merged some of this information and the driver error categories as identified by MCMIS to create our own classification system to analyze hazmat tanker rollover case studies for contributing human factors.

4.4 Framework Elements

The framework is comprised of five different elements: Accident Type, Specific Critical Event, Driver-related Error, Vehicle-related Factors, and Contributing Factors.

4.4.1 Accident Type

Various aspects were captured to develop a detailed picture of each crash, including actions that may have led to the rollover. Details were captured about both the events that occurred before the accident happened, and during the accident. A description of the tank's trajectory before the rollover is referred to as the Last Pre-crash Movement. This is the last point in the trip where everything was still going as planned. See Table 3 below for a breakdown of the Last Pre-crash Movement variable.

Table 3. Last Pre-Crash Movement Categories

Last Pre-crash Movement ***Tanker was…***
Going Straight
Turning
Decelerating in traffic lane
Accelerating in traffic lane (suddenly speeding up)
Passing or overtaking another vehicle
Backing Up
Making a U-turn
Negotiating a curve
Changing lanes
Merging
I Don't Know
Other (please specify)

Each rollover was either a single or multiple vehicle crash. Table 4 and Table 5 below describe the data that were captured for each type of rollover. Note, when rollovers are single vehicle incidents, it implies that the tank truck was the only vehicle that crashed. However, there may have been other vehicles that induced the rollover that did not crash. Multiple vehicle data describes incidents in which the tank truck and at least one other vehicle were impacted during the rollover event. These variables are mutually exclusive; only one set of attributes applies to each crash.

Table 4. Single Vehicle Accident Details Describe What the Tank Truck was Doing when the Accident Occurred

Single Vehicle Accident ***Tanker was…***
Control/traction loss
Left roadside departure
Right roadside departure
Succeeded in avoiding collision with other vehicle or other object but still rolled over
Struck vehicle, pedestrian, animal or other object
N/A
Other (please specify)

Table 5. Multiple Vehicle Accident Details Describe What the Tank Truck and the Other Vehicle were Doing when the Accident Occurred

Multiple vehicle accidents. ***Tanker and V2 were traveling…***
Opposite directions
Same lane, same direction
Same trafficway, same direction (more than one lane)
Perpendicular (i.e., at an intersection)
N/A
Other (please specify)
Multiple vehicle accidents. ***Tanker…***
Control/Traction Loss
Left Roadside Departure
Right Roadside Departure
Rear End
Sideswipe/Angle
Accident due to actions of other driver
N/A
Other (please specify)

Finally, the type of rollover was captured in regards to whether or not the vehicle was tripped or un-tripped. Tripped rollovers occur when a vehicle rolls over after the tires strike a curb, an object in the road, uneven pavement, a pothole, etc. Instead of an object serving as a tripping mechanism for the tires, an un-tripped rollover usually occurs during high-speed collision, from avoidance maneuvers or from taking a turn too fast.

4.4.2 Critical Event

The event that led to the rollover is referred to as the Critical Event. We identified six general Critical Event types. Each General Critical Event can be further categorized by a Specific Critical Event. The specific Critical Event categories provide more detail about what exactly caused the rollover rather than a general idea of the cause. Table 6 provides a list of all General and Specific Critical Event categories.

A vehicle-related loss of control was the Critical Event when the rollover occurred due to some type of vehicle difficulty (e.g., flat tire) or an interaction between the vehicle and the environment (e.g., a pothole).

When the tanker was traveling in some way that caused an accident, “Tanker is Traveling” was coded as the general Critical Event. Then, a more specific event description would further clarify in which way the “Tanker is Traveling” (i.e., “off the edge of the road,” or “over the lane line of travel”) to cause a crash.

Our third general Critical Event category was “Other Motor Vehicle in Lane,” which refers to situations in which there is a second vehicle that is in the same lane that the tank truck is traveling. Similarly, “other motor vehicle encroaching in lane,” is used to categorize situations in which there is a second motor vehicle entering the lane of travel that the tank truck is occupying. Specific event descriptions are also categorized for each of these Critical Events.

The final two general Critical Event categories describe situations in which something in the roadway causes the rollover (pedestrian or cyclist, and object or animal).

Table 6. General and Specific Critical Event Categories

General	Specific
Vehicle-related loss of control	• Blow out / flat tire • Disabling vehicle failure (e.g., wheel fell off) • Non-disabling vehicle problem (e.g., hood flew up) • Poor road conditions (puddle, pothole, ice, etc.) • Cargo sloshing/surging • N/A • Other (please specify)
Tanker is traveling	• Over the lane line of travel lane • Off the edge of the road • Past End of road • Turning at intersection • Crossing over (passing through) intersection • Decelerating • Accelerating • N/A
Other motor vehicle in lane	• Other vehicle stopped • Traveling in same direction • Traveling in opposite direction • Backing • N/A • Other (please specify)
Other motor vehicle encroaching into lane	• From adjacent lane (same direction) over lane line • From opposite direction over lane line • From crossing street/driveway, across path • From crossing street/driveway, turning into same direction • From crossing street/driveway, turning in opposite direction

General	Specific
	• N/A • Other (please specify)
Pedestrian, cyclist, or other non-motorist	• Pedestrian in or near roadway • Cyclist or non-motorist in or near roadway • N/A
Object or animal	• Object in roadway • Animal in roadway • N/A

4.4.3 Driver Related Error

A major goal of the current research was to determine any human factors associated with tank truck rollovers. The Driver Related Error variables allowed us to categorize rollovers based on potential errors made by the drivers when applicable. Six driver-related variables were identified and categorized: Driver Decision Errors, Driver Performance Errors, Driver Non-performance Errors, Driver Recognition Errors, Driver Experience Deficiency, and Driver Safety Culture. Table 7 provides a definition of each type of driver error and additional details that could describe the driver’s behavior/state for each crash.

Table 7. Driver Error Categories, Definitions, and Descriptions

Error	Definition	Description
Driver Decision Error	Driver makes an error of judgment/chooses to make wrong maneuver.	• Too fast for conditions • Misjudgment of gap or other's speed (merging decision error) • Following too closely to respond to unexpected actions • Illegal Maneuver • N/A • Other (please specify)
Driver Performance Error	Driver fails to operate vehicle with skill normally expected.	• Startle reaction • Overcompensation (overcorrection) • Poor directional control (weaving or drifting) • N/A • Other (please specify)
Driver Non-performance Error--	Driver fails to operate vehicle normally/fails to respond to need for action	• Driver fatigued asleep or drowsy • Under the influence of drugs or alcohol • Incapacitated by illness

Error	Definition	Description
		• N/A • Other (please specify)
Driver Recognition Error	Driver fails to perceive need for decision/action	• Internal distraction (specify in text box) • External distraction (specify in text box) • Failure to maintain Situational Awareness • N/A • Other (please specify)
Driver Experience Deficiency	Driver is unfamiliar with some aspect of the scenario that may have resulted in safety deficiency.	• Unfamiliarity with route • Unfamiliarity with vehicle • Unfamiliarity with load type • N/A • Other (please specify)
Driver Safety Culture **Note, this variable was ultimately collected from MCMIS to improve accuracy and eliminate manual errors from coders searching in the public SMS site.*		• Above threshold on Unsafe Driving • Above threshold on Alcohol

4.4.4 Vehicle-Related Factors

Rollovers that were caused by vehicle-related difficulties or failures were also further categorized based on the type of vehicle-related factor that caused the issue. Seven specific vehicle-related factors were identified (listed below). Any vehicle-related failure that is not captured by these factors was categorized as "other."

- Tire, wheel, or tie rod failure
- Brake failure
- Steering failure
- Trailer attachment failure
- Leaking cargo
- Vehicle failure– unknown or unable to classify
- Fire (before crash)
- Other

4.4.5 Contributing Factors

Rollovers caused by factors other than the driver or the vehicle are categorized using the following contributing factors: Environment Related, Weather/Visibility Related, Other Driver Induced, and Carrier Safety Culture Related. The specific detailed variables that make up each of these categories are provided in Table 8.

Table 8. Other Rollover Contributing Factors

Contributing Factor	Details
Environment-Related	• Signs or signals defective or erroneous • Pedestrian on roadway • Animal on roadway • Object on roadway • Inadequate roadway maintenance (e.g., potholes) • Designated detour • Work zone • Other
Weather/Visibility-Related	• Rain • Snow • Fog • High crosswinds • Sudden change in illumination • Glare • Dust, debris, or smoke aloft • Other
Other Vehicle Induced	• Unable to avoid accident involving others • Lane change to avoid oncoming vehicle collision • Human error -- driver other vehicle • Mechanical failure on other vehicle • Same trafficway, same direction: lane change to avoid vehicle attempting to pass • Other
Carrier Culture Related	• CSA Unsafe Driving BASIC score ≥ threshold value • CSA HOS BASIC score ≥ threshold value • CSA Vehicle Maintenance BASIC score ≥ threshold value • CSA Drugs/Alcohol BASIC score ≥ threshold value • CSA Driver Fitness BASIC score ≥ threshold value • Other

4.5 Data Analysis

4.5.1 Data Coding

As noted above, the risk matrix was de-constructed into 46 coding questions (e.g., what was the driver's age? What was the speed limit? What as the tank structure? etc.). Coding response options were created using established classification systems and SME additions from our team as described above. Again, to simplify the response options in the matrix we reviewed all data sources and categorization options and created an exhaustive list. We refined the list based on the current dataset, tasking, and research goals. We aimed to shorten list of potential categorization items due to the size of our dataset. With only 93 cases, a small, refined set of data are more likely to yield patterns in the data than an exhaustive list of all potential classification items.

Once the coding questions and response categories were finalized, we developed a coding survey in an off-the-shelf survey software program (SurveyMonkey) to help mitigate manual errors and encourage consistency across coders (see Appendix C for a screenshot of the coding survey on SurveyMonkey). The raw data coded in SurveyMonkey can be exported into an Excel database that can be easily analyzed. A codebook was developed as a guide for coders to answer each question (see Appendix D). The codebook contained specific directions for each question including where to find the information (i.e., 5800.1, PAR, etc.), definitions, cautions for tricky situations, and guidance on how to use "Other", "N/A", and "I don't know" response options for each question. No personally identifiable information was entered into SurveyMonkey. Coders used unique identification numbers for each rollover to ensure data confidentiality in the event of a cyber security issue. The SurveyMonkey account that we used is owned by the Volpe Center and was password protected.

A coder-tracking sheet was provided to the coders to ensure that two separate individuals reviewed each case. Because this research is focused on hazmat tank trucks, the first item on the tracking sheet reminded coders to verify that the case involved that type of vehicle. The coder-tracking sheet also allowed coders to match the incident number with the unique, de-identified ID number. The unique ID contained fewer characters than the incident numbers, which helped minimize manual entry error. The coder-tracking sheet provided an area for the coder to document notes to the analysts to record anything they found to be unique, confusing, and/or reportable.

Four researchers held a two-hour hands-on training session with the three coders. Coders had previous experience coding transportation incidents. We held a one-hour training follow-up after the coders had reviewed the first four cases. A third human factors analyst itemized, reviewed, and resolved all issues documented by the coders in the tracking sheet. Two human factors analysts then reviewed and resolved coding for discrepancies between coders. Any remaining items were resolved during a team working session or by an SME.

The coding protocol consisted of 46 questions. Each question was programmed to force coders to respond, ensuring that coders did not skip items inadvertently. When developing the protocol, we strategically placed an "Other" option with a text box to elaborate when the options given did not describe the incident; we expected these to be used infrequently. We also provided an option for coders to choose "I don't know" when there was not enough detail provided in the report to respond appropriately. An option for coders to choose "N/A" was for situations when the question or category did not apply to the incident. The last question provided an area for coders to document anything that was not covered by the coding protocol.

4.5.2 Data Cleaning

4.5.2.1 Coded PAR, PHMSA Survey, and 5800.1 Data

At the completion of the coding process, rollover cases were eliminated if they had insufficient or inadequate documentation to determine the sequence of events that resulted in a rollover. The final sample size was 93 rollovers with sufficient data across these sources. The coded data was reviewed extensively during the review process, so the majority of issues with missing data or data quality were addressed at that stage. Text entry responses using the "Other" option were analyzed and any patterns that emerged were compiled into coding categories missing from our original coding scheme. Several derived variables were computed from the coded variables. Coded data was merged into a single dataset along with the corresponding MCMIS data for the drivers and carriers identified, matched on the basis on driver's license number or carrier's DOT number.

4.5.2.2 NASS GES Data

We replicated the same selection criteria that were used in the 2007 Battelle report. As summarized, in Table 9, in some cases the coding schemes for variables had changed since the previous report, such that the response options referred to no longer existed; in these cases, we used the closest equivalent selection criteria available under the current coding scheme. A total of 88 crashes occurring between 2011 and 2014 met these selection criteria.

Table 9. Selection Criteria for Cargo Tank Rollover Crashes in GES Database

	Body Type	**Cargo Body Type**	**Rollover**
2007 Battelle Report	Single Unit Straight Truck Truck-Tractor Unknown Medium/Heavy Truck	Cargo Tank	10 – Untripped Rollover 20 – Tripped rollover – by curb 21 – Tripped rollover – by guardrail 22 – Tripped rollover – by ditch 23 – Tripped rollover – by

	Body Type	Cargo Body Type	Rollover
			soft soil 28 – Tripped rollover – other 29 – Tripped rollover – unknown 99 – Rollover, unknown whether untripped or tripped
Current Report	61 – Single-unit straight truck or Cab-Chassis (10,000 lbs. < GVWR < or = 19,500 lbs.) 62 – Single-unit straight truck or Cab-Chassis (19,500 lbs. < GVWR < or = 26,000 lbs.) 63 – Single-unit straight truck or Cab-Chassis (GVWR > 26,000 lbs.) 64 – Single-unit straight truck or Cab-Chassis (GVWR unknown) 66 – Truck-tractor (Cab only, or with any number of trailing unit; any weight)Unknown 67 – Medium/Heavy Truck	2 – Cargo Tank	1 – Rollover, tripped by object/vehicle 2 – Rollover, untripped 9 – Rollover, unknown type

4.5.3 Results

4.5.3.1 Updating the 2007 Executive Summary Tables

The initial goal of the analysis was to review the most recent data from the GES database in order to determine how the data reported in the executive summary had changed since the 2007 Battelle report. For all 2011-2014 GES data presented below, our analyses are based on our sample of 88 cases that fit our selection criteria. However, the GES database is intended to be a nationally representative sample, and the database provides case weights indicating their national estimates of the true population value their sample of PARs is estimated to represent. Rather than being calculated out of a total of 88, percentages were based on the case weights provided in the GES database. Thus, they are based on a population of roughly 4219 rollovers that the GES estimates occurred across the country during this time period on the basis of their national sampling method.

For any summary statistics that were a binomial proportion, they are accompanied by the Wilson score 95% confidence interval. Values indicated with an asterisk indicate that there is a significant difference (at the $p<.05$ level) between the 2000-2004 and 2011-2014 timeframes, as based on whether the 2000-

2004 point estimate falls within the 2011-2014 95% confidence interval.

Table 10 updates 2007 Table ES-1, summarizing the configurations of cargo tank vehicles in rollover crashes in recent years in comparison to the 2000-2004 data. Regardless of the vehicle configuration described in the table, all vehicles were carrying some form of cargo tank. Percentages are calculated from estimated number of rollovers based on case weights, not from the actual number of sampled reports. Data are consistent with those previously reported, with tractor-semitrailer combinations compromising the majority of the rollovers.

Table 10. Proportion of Rollovers by Vehicle Body Type and Number of Trailing Units

Vehicle Configuration	Percent of Rollovers 2000-2004	Percent of Rollovers 2011-2014
Tractor, One Trailer	55.6%	62.7%
Tractor, Two Trailers	3.9%	0.2%
Straight Truck, No Trailer	30.9%	24.9%
Straight Truck, One Trailer	5.2%	7.8%
Other or Unknown	1.7%	4.4%
Total	100.0%	100.0%

Table 11 updates 2007 Table ES-2, summarizing the location type of cargo tank vehicle rollovers. The large difference in the raw number of rollovers between the 2002 and 2011-2014 timeframes is due to the data being drawn from different databases, using different selection criteria for cases. Data provided for 2002 reproduces that reported in the Battelle 2007 report; their methodology indicates that the total number of rollovers here is a sample limited to hazmat rollovers reported in the MCMIS database for 2002. In contrast, the 2011-2014 values are based on the GES database; the estimated total number of rollovers is based on case weights, not on the actual number of sampled reports. Furthermore, GES data included all cargo tank rollovers, not just those carrying hazmat. This in the only instance in which we were required to make a direct comparison across separate databases; in all other results, we used directly comparable data drawn from the same source.

The type of location where the rollovers occurred is similar to that reported in the previous study. Undivided highways remain a more frequent location for rollover crashes than divided highways, but the gap between the two is smaller. The noteworthy changes driving this shift in location are that more rollovers occurred on a divided highway, not near an interchange, while fewer rollovers occurred on an undivided highway, close to an intersection. However, this change should be interpreted with caution. These two sources use different coding schemes for accident locations, so there is a potential for error when matching location categories from one database to the other.

Table 11. Percent and Number of Rollovers by Type of Highway

	2002		2011-2014		
Location of Accident	**Total Rollovers**	**Percent of All Rollovers**	**Estimated Number of Rollovers**	**Percent of Estimated Rollovers**	**95% CI**
	11	4.6%	94	2.2%	(0.6%, 7.8%)
Not at Interchange	45	19.0%	1232	29.2%*	(20.7%, 39.4%)
On or Off Ramp	17	7.2%	421	10.0%	(5.3%, 18.0%)
Total Divided Highway	74	31.2%	1747	41.4%*	(31.7%, 51.8%)
Close to Intersection	82	34.6%	726	17.2%*	(10.7%, 26.4%)
Not at Intersection	81	34.2%	1436	34.0%	(25.0%, 44.4%)
Not on Roadway	0	0%	95	2.2%*	(0.6%, 7.8%)
Railroad Grade Crossing	0	0%	0	0.0%	-
Total Undivided Highway	163	68.8%	2257	53.5%*	(43.2%, 63.6%)
Unknown Location	0	0%	215	5.1%*	(2.1%, 11.9%)
Total	237	100.0%	4219	100.0%	

Table 12 updates 2007 Table ES-3, summarizing the kind of crash involving a rollover – i.e., whether it was a rollover alone or another type of crash that resulted in a rollover. The estimated annual number of cargo tank rollovers between 2011 and 2014, averaged from case weights from the GES data, is 1055, nearly a 20% reduction in the annual number of rollovers estimated for 2000 to 2004. However, the distribution across kinds of crash appears to be similar for the two timeframes.

Roughly half of all rollovers are a single vehicle roadway departure (SVRD) resulting in a tripped rollover. There appears to be a reduction in untripped rollovers, whether from SVRD or other causes, and an increase in rollovers resulting from a lane change or merge. Some caution is advised when interpreting Table 12; there is some ambiguity in how the previous study defined rollovers resulting from lane change and merge as compared to those resulting from “other” kinds of crashes. Given the large proportion of rollovers involved SVRD, the prior study highlighted “drowsiness, inattention, and speed” as important contributing factors in many rollovers. The GES database provides little insight into when these contributing factors were involved in a rollover, but we will discuss these contributing factors in greater detail later on in the context of the PAR data.

Table 12. Percent and Number of Crash Types Resulting in a Rollover

Kind of Crash	2000-2004		2011-2014	
	Total Rollovers	Percent of Rollovers	Total Rollovers	Percent of Rollovers
	65	5.1%	0	0%
SVRD with untripped rollover	113	8.9%	64	6.1%
SVRD with tripped rollover	599	47.4%	566	53.6%
Lane Change Merge	5	0.4%	71	6.7%
Rear End	12	0.9%	19	1.8%
Other	471	37.2%	335	31.8%
Total	1265	100%	1055	100.0%

4.5.3.2 Summary GES Statistics Tables

The executive summary tables provide a brief picture of cargo tank rollover accidents, including what types of vehicles rolled over, where rollovers occurred, and what types of accidents resulted in rollovers. However, these three tables alone are insufficient to gain a complete understanding of the circumstances contributing to cargo tank rollover accidents. Therefore, we supplemented these data by updating all of the other tables in the prior study that were derived from GES data.

The following analyses are presented below:

- Comparison: Estimated Number and Percentage of Rollovers by Year and Body Type
- Comparison: Rollover Crash Primary Reason Leading to Rollover
- Comparison: Average Annual Number of Cargo Tank Rollovers, by Crash Type and Preceding Conflict
- Comparison: Rollover Crash Pre-crash Maneuver Category
- Comparison: Rollover Crash Configuration
- Comparison: Rollover Crash Mechanical Problem Category
- Comparison: Rollover Crash Road Type Category
- Comparison: Rollover Crash Roadway Surface Condition Category
- Comparison: Rollover Crash Roadway Curvature Category
- Comparison: Rollover Crash Location Relative to Junction Category
- Comparison: Rollover Crash Age Category
- Comparison: Rollover Crash Speed Category
- Comparison:
- Rollover Crashes Involving Hazmat

4.5.3.2.1 Comparison: Estimated Number and Percentage of Rollovers by Year and Body Type

Table 13 updates Table 2-4, summarizing the percentage and estimated number of cargo tank rollovers by body type and year, along with the confidence intervals for these estimates. All vehicles represented in the table are defined as Medium/Heavy Trucks as per the GES database, based on a GVWR greater than 4,536 KG. The 2007 report noted a downward trend over time in the total number of cargo tank rollovers; this trend seems to have halted since 2004, with the estimated number of rollovers per year from 2011 to 2014 falling in the same range as observed from 2001 to 2004. Class A combination vehicles (tractor plus tank trailer) remain the most common body type of cargo tank vehicles in rollover crashes, accounting for an especially high percentages in 2011 and 2012, although never reaching the extraordinarily high percentage reported for 1999.

Table 13. Percent and Number of Rollover Crashes by Body Type and Year

Year of Crash	Body Type	Number of Records	Percent	95% CI	Estimated Number of Rollovers	Standard Error
1999	Single-unit Straight Truck	6	7.59	(2.77, 19.15)	129.34	70.56
2000		10	45.6	(16.90, 77.55)	880.62	517.03
2001		14	33.66	(22.31, 47.27)	428.84	148.33
2002		12	32.54	(20.07, 48.09)	429.87	185.97
2003		12	47.14	(17.96, 78.41)	543.58	269.57
2004		12	37.38	(14.91, 67.04)	241.2	134.23
2011		9	28.73	(20.32, 38.92)	231.33	-
2012		12	21.35	(14.08, 31.01)	284.36	-
2013		5	42.48	(32.68, 52.91)	330.27	-
2014		6	41.13	(31.43, 51.57)	536.46	-
1999	Truck Tractor	34	85.6	(71.72, 93.30)	1458.18	366.75
2000		36	54.4	(22.45, 83.10)	1050.63	336.93
2001		28	66.34	(52.73, 77.69)	845.12	391.73
2002		26	67.46	(51.91, 79.93)	891.26	294.01
2003		25	52.86	(21.59, 82.04)	609.55	258.53
2004		20	56.45	(29.73, 79.88)	364.26	115.15
2011		15	71.27	(61.08, 79.68)	573.75	-
2012		24	76.10	(66.22, 83.80)	1013.53	-
2013		6	57.52	(47.09, 67.32)	447.15	-
2014		9	54.71	(44.33, 64.70)	713.58	-
1999	Unknown Medium/Heavy Truck	5	6.81	(2.22, 19.00)	115.93	56.16
2000		0	0	-	0	0
2001		0	0	-	0	0
2002		0	0	-	0	0
2003		0	0	-	0	0

Year of Crash	Body Type	Number of Records	Percent	95% CI	Estimated Number of Rollovers	Standard Error
2004		2	6.18	(1.16, 27.01)	39.85	31.41
2011		0	0	-	0	-
2012		1	2.54	(0.74, 8.31)	33.89	-
2013		0	0	-	0	-
2014		1	4.16	(1.57, 10.59)	54.29	-
1999	Total	45	100	-	1703.45	385.52
2000		46	100	-	1931.25	575.47
2001		42	100	-	1273.96	517.07
2002		38	100	-	1321.13	440.07
2003		37	100	-	1153.13	342.46
2004		34	100	-	645.31	184.14
2011		24	100	-	805.08	-
2012		37	100	-	1331.78	-
2013		11	100	-	777.42	-
2014		16	100	-	1304.34	-
Grand Total		88			4218.62	

4.5.3.2.2 Comparison: Rollover Crash Primary Reason Leading to Rollover

Table 14 updates Table 2-7, summarizing the critical events leading to the rollovers, compared across years. Note that when investigating accident root causes, a more complete understanding is gained by taking into account *all* contributing factors; however, as coded in the GES database, only a single critical event is allowed for each vehicle. Thus, it cannot capture an event where, for example, a vehicle was travelling too fast for conditions *and* there was an animal in the roadway. If both of these factors were present in the original PAR, the GES coders selected one of them as the critical event and omitted the other. The analysis of coded PAR data, presented in the next section, provides more detail regarding rollovers involving more than one contributing factor.

Overall, the critical events retain the same rank order as identified in the prior study. Driver-related critical events are the most common by far, followed by Other, Vehicle, and Road-related critical events. Several critical events and categories of critical events significantly changed in distribution between these sets of years, based on the 95% confidence intervals provided in the 2007 analysis. There were significantly more vehicle-related critical events in recent years, driven by increases in the frequency of disabling vehicle failures and blow out/flat tires. Despite the overall increase in vehicle related critical events, there were fewer rollovers involving another vehicle that was stopped.

There was not an overall significant change in the frequency of Driver-related critical events, but there was a significant increase in loss of control due to other causes, and a significant decrease in left roadside departures.

There was not a significant change in Other critical events, but within this category, there were significantly more critical events involving another driver turning right at a junction, and significant fewer involving another driver encroaching from the left or an animal in the roadway.

Several other categories of critical events were identified in the recent data that were not reported in the 2007 study: another vehicle encroaching from the left, another vehicle in the same lane (travelling slower or decelerating) and an unspecified encroachment by another vehicle.

Table 14. Rollover Crash Critical Event Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	**95% CI**	**Estimate**	**95% CI**
Blow out/flat tire	1.05%	(0.3, 3.8)	6.37%*	(2.9, 13.5)
Disabling vehicle failure (e.g., wheel fell off)	0.07%	(0.0, 0.6)	8.22%*	(4.1, 15.9)
Non-disabling Vehicle Failure	0.05%	(0.0, 0.4)	0.00%	-
Other vehicle stopped	4.54%	(1.9, 10.6)	0.13%*	(0.0, 4.4)
Total Vehicle	5.71%	(2.5, 12.4)	14.72%*	(8.8, 23.6)
Poor road conditions (puddle, pothole, ice, etc.)	0.94%	(0.4, 2.5)	2.22%	(0.6, 7.8)
Total Road	0.94%	(0.4, 2.5)	2.22%	(0.6, 7.8)
Traveling too fast for conditions	28.40%	(16.1, 45.1)	21.74%	(14.4, 31.4)
Other cause of control loss	4.44%	(2.3, 8.4)	8.47%	(4.3, 16.2)
Unknown cause of control loss	0.53%	(0.1, 2.0)	1.87%	(0.5, 7.3)
Over the lane line on left side of travel lane	3.79%	(1.4, 9.9)	5.39%	(2.3, 12.2)
Over the lane line on right side of travel lane	0.67%	(0.1, 3.2)	2.50%*	(0.8, 8.4)
Off the edge of the road on the left side	12.04%	(6.1, 22.3)	0.92%*	(0.1, 5.8)
Off the edge of the road on the right side	23.75%	(16.6, 32.8)	25.65%	(17.7, 35.7)
Total Driver	73.62%	(58.9, 84.4)	66.53%	(56.2, 75.5)
Turning left at junction	0.61%	(0.1, 2.6)	2.13%	(0.6, 7.7)
Turning right at junction	0.07%	(0.0, 0.6)	2.40%*	(0.7, 8.1)
Crossing intersection	3.73%	(1.6, 8.4)	1.29%	(0.2, 6.4)
Encroaching vehicle left	13.36%	(6.4, 25.8)	1.50%*	(0.3, 6.7)
Encroaching vehicle right	0%	-	2.48%*	(0.7, 8.2)
Other vehicle travelling in same direction	0%	-	3.92%*	(1.4, 10.3)
Encroachment by other vehicle - details unknown	0%	-	2.50%*	(0.7, 8.2)
Animal in roadway	1.02%	(0.2, 5.1)	0.00%*	-
Other critical precrash event	0.93%	(0.3, 2.8)	0.32%	(0.0, 4.8)
Total Other	19.73%	(10.9, 33.1)	16.53%	(10.2, 25.7)
Total			100.00%	

4.5.3.2.3 Comparison: Average Annual Number of Cargo Tank Rollovers, by Crash Type and Preceding Conflict

The number of cargo tank rollovers per year, by rollover type, crash type, and driving conflict, is summarized in Table 15, updating the data from 2007 Table 2-8. Estimated total yearly rollovers are based on four years of GES samples data. Rollover type is based on the GES Rollover variable, where an Untripped rollover corresponds to a value of 2 (as of the 2000-2004 data, Untripped rollovers previously corresponded to a value of 10). Crash type is based on the GES Crash Type variable (formerly the Accident Type variable). Finally, driving conflict is based on a combination of the GES variables for Pre-Event Movement and Critical Event.

The crash type “Untripped Rollover” in the 2000-2004 data corresponds to rollovers where the rollover type was untripped, but the crash type was unspecified. The crash type did not appear in the 2011-2014 data. In general, the more recent GES data regarding rollovers seems to be better defined; in the older data, 42% of rollovers are “other” or “unspecified” crash types, while in the more recent data this drops to 32%. Therefore, in part, some of these changes in the types of crashes and driving conflicts in more recent rollovers compared to the older data may stem from previous missing data that fall into more clearly established categories in the current analysis.

The most common type of rollover crash in both timeframes was a single vehicle roadside departure. This accounted for 56% of rollovers 2000-2004 and 60% of rollovers 2011-2014. However, the most common type of *driving conflict* resulting in an SVRD did change: Previous, the most common driving conflicts involved a truck rolling over while turning or negotiating a curve (possibly at excessive speed), while more recently the most common driving conflict involved a truck travelling straight, at a constant speed, travelling off the edge of the road.

The next most common type of rollover crash in 2011-2014 was a rollover crash resulting from a conflict during a lane change or merge. This type of crash increased dramatically since 2000-2004. The GES data alone are insufficient to determine the cause of this change. It is possible that it is a result of changes in the contributing factors leading to rollovers, but we cannot rule out that it is an artifact of better data collection resulting in fewer unspecified or other crash types.

Table 15. Average Annual Number of Cargo Tank Rollovers, by Crash Type and Preceding Conflict

Crash Type: Rollover and…	**Driving Conflict**	**2000-2004**		**2011-2014**	
		All Rollovers	**Untripped Rollovers**	**All Rollovers**	**Untripped Rollovers**
	1.1 Truck is travelling at constant speed and travels over the edge of the road	138	16	227	19

Crash Type: Rollover and…	Driving Conflict	2000-2004		2011-2014	
		All Rollovers	Untripped Rollovers	All Rollovers	Untripped Rollovers
SVRD	1.2 Truck is turning or negotiating a curve and travels over the edge of the road	195	17	85	42
	1.3 Truck is travelling at constant, excessive speed and loses control	23	0	39	0
	1.4 Truck is turning or negotiating a curve at excessive speed and loses control	185	72	67	3
	1.5 Truck loses control due to vehicle related failure	41	0	83	0
	1.9 Other	129	8	129	0
	Subtotal	712	113	630	64
Rear-End	2.4 Truck encounters a stopped vehicle in lane	11	0	1	0
	2.9 Other	1	0	18	0
	Subtotal	12	0	19	0
Lane Change/ Merge	3.2 Both vehicles are travelling in the same direction and the other vehicle encroaches into the truck's lane while truck is travelling at constant speed	4	0	32	0
	3.4 Truck is travelling at a constant speed and another vehicle encroaches into its lane from a yield	1	0	0	0
	Both vehicles are in the same trafficway, travelling in opposite directions	0	0	39	0
	3.9 Other	1	0	0	0
	Subtotal	5	0	71	0
Untripped Rollovers	4.1 Truck is travelling at constant speed and travels over the edge of the road	5	5	0	0
	4.4 Truck is turning or negotiating a curve at excessive speed and loses control	55	55	0	0
	4.9 Other	5	5	0	0
	Subtotal	65	65	0	0
Other	5.9 Other	471	0	335	250

Crash Type: Rollover and…	Driving Conflict	2000-2004		2011-2014	
		All Rollovers	Untripped Rollovers	All Rollovers	Untripped Rollovers
	Subtotal	471	0	335	250
Total		1265	178	1055	314

4.5.3.2.4 Comparison: Rollover Crash Pre-crash Maneuver Category

Table 16 updates 2007 Table 2-11, summarizing the last pre-crash movement of the truck prior to the critical event. In the more recent rollovers, a significantly greater proportion of cargo tankers are going straight prior to the critical event, while fewer cargo tankers are negotiating a curve, although not significantly fewer. This falls in line with the results from Table 15 discussed above, where fewer rollovers involved an SVRD during a turn or while negotiating a curve. However, the categories of last pre-crash movement have retained the same rank order since the prior analysis, with the largest proportion of cargo tankers going straight prior to the critical event, following by negotiating a curve, turning right, and turning left. These categories account for the majority of all cargo tanker rollovers, with the remainder of categories together accounting for fewer than 5% of all rollovers.

Table 16. Rollover Crash Pre-crash Maneuver Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
Going Straight	41.46%	(28.0, 56.3)	56.41%*	(46.0, 66.3)
Decelerating in traffic lane	1.86%	(0.5, 7.3)	0.00%*	-
Passing or Overtaking Another Vehicle	1.48%	(0.3, 6.1)	2.50%	(0.7, 8.2)
Turning Right	11.69%	(4.7, 26.3)	11.04%	(6.1, 19.3)
Turning Left	10.46%	(4.5, 22.6)	8.51%	(4.3, 16.2)
Negotiating a Curve	31.77%	(18.6, 48.6)	19.56%*	(12.6, 29.0)
Changing Lanes	0.90%	(0.2, 5.2)	0.53%	(0.1, 5.1)
Successful Avoidance Maneuver to a Previous Critical Event	0%	-	1.46%*	(0.3, 6.7)
Other	0.31%	(0.0, 2.2)	0.00%	-

4.5.3.2.5 Comparison: Rollover Crash Configuration

Table 17 updates 2007 Table 2-14, summarizing changes in the involvement in rollovers of vehicles with differing configuration since the prior study. A truck-tractor configuration with a single trailing unit still accounts for the most common vehicle involved in rollover, followed by a single-unit straight truck with no trailing units (although this latter configuration is significantly less common). Significantly more rollovers involve a single-unit straight truck with one trailing unit, while significantly fewer involve a truck-tractor with two trailing units. There were some changes in the remaining configurations, but collectively they account for less than 5% of rollovers.

Table 17. Rollover Crash Configuration Relative Frequency

Configuration	Number of Trailing Units	2000-2004		2011-2014	
		Estimate	95% CI	Estimate	95% CI
Single-Unit Straight Truck	None	39.76%	(25.36, 56.18)	24.91%*	(17.1, 34.9)
	1	0.15%	(0.02, 1.15)	7.76%*	(3.8, 15.3)
	2	0%	-	0.11%	(0.0, 4.4)
Truck-Tractor	None	0%	-	0.00%	-
	1	55.58%	(43.32, 67.2)	62.71%	(52.3, 72.1)
	2	3.88%	(0.81, 16.6)	0.19%*	(0.0, 4.5)
	3+	0%	-	2.24%	(0.6, 7.9)
Medium/Heavy Truck	None	0.16%	(0.02, 1.27)	0.80%	(0.1, 5.6)
	1	0.47%	(0.06, 3.61)	0.00%*	-
	2	0%	-	0.00%	-
	Unknown	0%	-	1.29%*	(0.2, 6.4)

4.5.3.2.6 Comparison: Rollover Crash Mechanical Problem Category

Table 18 updates 2007 Table 2-26, summarizing the involvement of vehicle failure in rollovers. As in the previous study, the vast majority of rollovers overall do not involve vehicle failure. However, we found that both tire failure and brake failure were involved in a significantly greater proportion of recent rollovers. It is unclear whether this indicates an improvement in reporting rather than an increase of failure in these components, because the percentage of reported “unknown” vehicle failure fell from 8% to nearly 0%.

Table 18. Rollover Crash Mechanical Problem Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
None	84.33%	(77.4, 89.4)	82.60%	(73.4, 89.1)
Tires	2.51%	(0.9, 7.0)	8.26%*	(4.1, 15.9)
Brakes	1.21%	(0.3, 4.4)	8.82%*	(4.5, 16.6)
Other	3.85%	(1.3, 10.5)	0.00%*	-
Unknown	8.10%	(5.4, 11.9)	0.32%*	(0.0, 4.8)

4.5.3.2.7 Comparison: Rollover Crash Road Type Category

Table 19 updates 2007 Table 2-30, summarizing the types of roadways on which rollovers occurred. Significantly more of the recent rollovers occurred on divided highways, while significantly fewer occurred on non-divided highways, compared with 2007 data. However, there is a substantial caveat in interpreting this comparison. The GES coding of divided highways has change since the 2007 analysis; previously, the trafficway description variable only distinguished between divided, non-divided, and one-way trafficways. After 2010, it now separates out entrance and exit ramps as a separate category. Therefore, our “Other” category includes a large number of cases that might have been classified differently at the time of the 2007 report.

Table 19. Rollover Crash Road Type Category

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
Not Divided	66.24%	(52.4, 77.7)	46.99%*	(36.9, 57.3)
Divided	21.87%	(15.3, 30.3)	32.78%*	(23.9, 43.1)
One Way	6.57%	(2.6, 15.4)	4.25%	(1.6, 10.7)
Unknown	5.32%	(1.1, 21.8)	5.09%	(2.1, 11.8)
Other	0%	-	10.88%*	(5.9, 19.1)

4.5.3.2.8 Comparison: Rollover Crash Roadway Surface Condition Category

Table 20 updates 2007 Table 2-35, summarizing the atmospheric conditions at the time of the rollover. The categories in the two timeframes held the same rank order; the only significant change was a complete lack of rollovers during fog, which was nonetheless still rare in the prior analysis.

Table 20. Rollover Crash Roadway Surface Condition Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
No Adverse Atmospheric Conditions	82.67%	(71.7, 90.0)	89.72%	(81.6, 94.5)
Rain	8.38%	(3.0, 21.1)	8.13%	(4.0, 15.7)
Snow	7.31%	(2.1, 22.2)	2.15%	(0.6, 7.7)
Fog	1.65%	(0.2, 12.3)	0%*	-

4.5.3.2.9 Comparison: Rollover Crash Roadway Curvature Category

Table 21 updates 2007 Table 2-37, summarizing the incidents of rollovers on roads that were straight versus curved. Compared to the prior analysis, more rollovers occurred on straight roadways. This was not a statistically significant change, but it falls in line with the results discussed above in Table 15 and Table 16 regarding fewer rollovers occurring while negotiating a curved road.

Table 21. Rollover Crash Prevalence on Straight vs. Curved Roadways

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
Straight	59.07%	(43.4, 73.1)	70.73%*	(60.5, 79.2)
Curve	40.93%	(26.9, 56.6)	27.03%*	(18.9, 37.1)
Other	0%	-	2.24%*	(0.6, 7.9)

4.5.3.2.10 Comparison: Rollover Crash Location Relative to Junction Category

Table 22 updates 2007 Table 2-39, summarizing the location of rollovers relative to a junction, including an intersection, interchange or ramp. The Entrance or Exit Ramp category includes all rollovers identified in the GES database as occurring on a ramp. The Interchange category includes all rollovers identified in the GES database as occurring at a junction or interchange, excluding those already identified as occurring on a ramp. The majority of rollovers did not occur near an interchange or ramp. There were no significant changes since the previous analysis.

Table 22. Rollover Crash Location Relative to Junction Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
Non-interchange	92.45%	(83.9, 96.6)	88.22%	(79.8, 93.4)
Interchange	1.27%	(0.3, 4.5)	3.64%*	(1.3, 9.9)
Entrance or Exit Ramp	6.28%	(3.0, 12.8)	8.14%	(4.0, 15.8)

4.5.3.2.11 Comparison: Rollover Crash Age Category

Table 23 updates 2007 Table 2-40, summarizing the age of drivers operating cargo tankers the rolled over. There has been a significant demographic shift in drivers since the prior study, such that ages are generally increasing; while not every age bracket changed significantly, there were fewer drivers involved in rollovers under the age of 35, and more drivers who were over 45 – and, notably, over 65.

Table 23. Rollover Crash Age Category Relative Frequency

Drivers Age (years)	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
<25	7.74%	(2.4, 22.4)	5.29%	(2.2, 12.1)
25-35*	23.97%	(16.6, 33.3)	13.60%*	(7.9, 22.3)
36-45	32.29%	(14.4, 57.5)	32.02%	(23.2, 42.3)
46-55	24.83%	(15.4, 37.6)	33.14%	(24.2, 43.5)
56-65	9.18%	(5.6, 14.8)	8.70%	(4.4, 16.4)
>65*	1.98%	(0.7, 5.3)	7.25%*	(3.4, 14.6)

4.5.3.2.12 Comparison: Rollover Crash Speed Category

Table 24 updates table 2-44, summarizing the percent of rollovers in which the tank truck was travelling above the speed limit. There was not a significant change in the percentage of rollovers occurring at excessive speed since the 2007 study. Note that this does not indicate whether the rollover crash itself was judged to be speed related, merely that the tanker truck was travelling in excess of the posted speed limit.

Table 24. Rollover Crash Speed Category Relative Frequency

Category	2000-2004		2011-2014	
	Estimate	95% CI	Estimate	95% CI
Not Speeding	59.67%	(42.6, 74.7)	54.42%	(44.0%, 64.4%)
Speeding	38.34%	(23.3, 56.0)	43.40%	(33.5%, 53.8%)
No Driver	1.99%	(0.6, 6.3)	0%*	-
Not Reported	0.00%	-	2.18%*	(0.6%, 7.8%)

4.5.3.2.13 Comparison: Rollover Crash Driver Physical Impairment, Distracted, and Vision Obscured

Table 25 updates 2007 Table 2-44, summarizing driver factors contributing to a cargo tank rollover crash. Physical impairment, Distracted, and Vision Obscured are based each based on the corresponding GES data tables of the same names. These tables are based on whether these contributing factors are reported in the PARs sampled by the GES database. The Physical Impairment data identifies the driver's physical or mental impairment that may have contributed to the cause of the accident. The Distracted data identifies a distraction that may have influenced driver performance and contributed to the cause of the crash. The distraction can be either inside the vehicle (internal) or outside the vehicle (external). The Vision Obscured data identifies visual circumstances that may have contributed to the cause of the crash, including but not limited to weather, solar glare, or buildings that obscured the driver's vision.

The driver factor data remain similar to what was reported in the 2007 study. The majority of rollovers did not report any physical impairment of the driver; driver fatigue was the most common physical impairment reported.

Our recent data on driver distraction are substantially different from what was reported in the 2007 study. Only 5% of the rollover crashes from 2011-2014 involved any form of driver distraction; in contrast, the prior study reported 24% of rollover crashes involving some form of driver distraction, and another 32% where it was unknown whether the driver was distracted. In part, this change may be a result of changes in GES data reporting; in the 2000-2004 data, 6.63% of driver physical impairment involves fatigue, and similarly 6.68% of driver distraction involves a sleepy driver. In contrast, in the 2011-2014 data, 10.03% of drivers were fatigued, while none were sleepy. While it is not documented in the GES data manual, it may be the case that they have moved to avoid the use of overlapping factors across variables.

While there were significant changes in the vision impairment category of driver factors, it does not appear that the changes were meaningful. There was no significant change in the (small) percentage of rollovers involving visual impairment; rather, reporting seems to have shifted away from using the "unknown" category.

Table 25. Rollover Crash Driver Physical Impairment, Distracted, and Vision Obscured Category Relative Frequency

Physical Impairment

Category	**2000-2004**		**2011-2014**	
	Estimate	**95% CI**	**Estimate**	**95% CI**
None	83.53%	(78.0, 87.9)	84.28%	(75.3, 90.4)
Drowsy, Sleepy, Fell Asleep, Fatigued	6.63%	(4.0, 10.9)	10.03%	(5.3, 18.1)
Ill, Blackout	2.50%	(0.7, 8.2)	3.55%	(1.2, 9.7)
Other Physical Impairment	0.31%	(0.0, 2.2)	0.00%	-
Unknown If Physically Impaired	7.02%	(2.7, 17.1)	2.14%	(0.6, 7.7)

Distracted

Category	**2000-2004**		**2011-2014**	
	Estimate	**95% CI**	**Estimate**	**95% CI**
None	43.94%	(24.9, 64.9)	94.75%*	(88.0, 97.8)
Inattentive	13.90%	(5.6, 30.4)	1.76%*	(0.4, 7.1)
Sleepy	6.68%	(4.0, 11.0)	0.00%*	-
Adjusting Music/Other Devices	1.72%	(0.3, 9.4)	0.00%*	-
Other Person/Object	1.66%	(0.3, 9.7)	1.42%	(0.3, 6.6)
Other	0.19%	(0.0, 0.8)	1.24%*	(0.2, 6.3)
Unknown	31.91%	(16.3, 52.9)	0.83%*	(0.1, 5.7)

Vision Obscured

Category	**2000-2004**		**2011-2014**	
	Estimate	**95% CI**	**Estimate**	**95% CI**
No	74.59%	(60.6, 84.9)	96.11%*	(89.8, 98.6)
Yes	6.35%	(1.5, 23.5)	3.89%	(1.4, 10.2)
Unknown	19.06%	(9.8, 33.7)	0.00%*	-

4.5.3.2.14 Rollover Crashes Involving Hazmat

We selected GES data from the 2011-2014 timeframe on the basis of cargo tank rollover, not limited exclusively to cargo tank trucks carrying hazmat (The 2007 study did not report GES data on hazmat involvement). Table 26 summarizes the number of cargo tank rollovers that involved either hazmat or non-hazmat cargo, showing how many of these resulted in injury or fatality. The percentages presented in parentheses are calculated out of each column total.

Asterisks indicate that the proportions in the hazmat and non-hazmat columns are significantly different, based on the results of a z-test with a Bonferroni correction (*p*<.05). While the percentage of hazmat and non-hazmat rollovers resulting in injury are similar (56.5% and 59.9% respectively), there was a significantly larger percentage of fatalities among non-hazmat rollovers than among hazmat rollovers (5.9% vs. 1.0%), and a significantly smaller percentage of "No Apparent Injury" rollovers (34.2% vs. 42.6%).

Table 26. Hazmat vs. Non-Hazmat Involvement in Injury and Fatality

Maximum Injury Severity in Rollover	Cargo		Total
	Non-Hazmat	Hazmat	
No Apparent Injury	1155 (34.2%)*	356 (42.6%)*	1511
Non-Fatal Injury, Any Severity	2026 (59.9%)	472 (56.5%)	2498
Fatal Injury	201 (5.9%)*	8 (1.0%)*	209
Total	3382 (100.0%)	836 (100.0%)	4218

4.5.3.3 Analysis of Case Studies

We conducted an analysis of multiple data sources reporting crash data, and coded their content using the risk structure we developed, as discussed above in section 4.5.1. Results discuss the contributing circumstances we identified through the coding process; then, they detail other accident data we collected; and finally, they discuss rollover causation by cutting across multiple factors to determine how they jointly contribute to rollovers.

4.5.3.3.1 Contributing Circumstances

Forty-six questions assessing contributing circumstances were included in our risk framework. These were grouped into five major categories: driver factors, other vehicle induced factors, environmental factors, weather factors, and vehicle factors. The frequency of each of these categories is summarized in Table 27. A category of contributing circumstances was only counted once per accident, but might represent more than one contributing circumstance within the same category (i.e., the 77.4% of accidents contributed to by driver factors might contain one driver factor, or might contain multiple driver factors). Table 27 also summarizes how frequently these categories of contributing circumstances occurred alone or in conjunction with one another. More than one contributing circumstance could be identified in each accident, thus the total column adds up to more than 100%. The remaining columns detailing the frequency of one category of contributing circumstance or two categories of contributing circumstances occurring together also add up to slightly over 100%; in two reports (2.2% of the data), three separate categories of contributing circumstances were identified together (Driver, Weather, and Vehicle factors), thus these cases are represented twice in the table, and slightly inflate the total percentage across cells in the table. Since the combination of three categories together was so uncommon, we opted to leave it in rather than create a separate table for combinations of three circumstances together. In another three reports (3.2% of the data), no contributing circumstances were identified; these cases are not represented in the table, slightly lowering the total percentage across cells in the table.

Although we arrived at this value through different methods, it is interesting to note that our result of 77% of cargo tank rollovers involving driver factors is very similar to the estimate of 74% from the GES data, as shown in table 2-7. What our data adds to that table is that driver factors do not always occur alone; frequently, they occur in conjunction with other types of contributing factors.

Table 27. Frequency of Categories of Contributing Circumstances

	Total	Single Contributing Factor	Driver Factors	Other Vehicle Induced	Environmental Factors	Weather Factors	Vehicle Factors
Driver Factors	77.4%	51.6%	-				
Other Vehicle Induced	20.4%	7.5%	8.6%	-			
Environmental Factors	7.5%	1.1%	5.4%	1.1%	-		
Weather Factors	15.1%	3.2%	8.6%[1]	3.2%	0.0%	-	
Vehicle Factors	8.6%	3.2%	5.4%[1]	0.0%	0.0%	2.2%[1]	-

[1] In these cells, 2.2% of the data represents cases with three contributing circumstances

Driver factors were the most frequently identified contributing circumstance in cargo tank rollovers. Table 28 summarizes the frequency of all of the contributing circumstances within the driver factor category. Given that driver factors made up the greatest number of contributing circumstances, they were grouped into several subcategories: driver performance errors, driver decision errors, driver recognition errors, and driver experience deficiency. The most commonly identified driver errors were poor directional control and driving too fast for roadway conditions. Driver performance errors were the most frequent type of driver errors (49.5% of all cases), and poor directional control was the most frequent performance error (32.3% of all cases). The second most common performance error was overcompensation (20.4% of all cases). The second most frequent type of driver error was driver decision error (35.5% of all cases), which in nearly all cases involved driving too fast for conditions (32.3% of all cases, and 90.9% of all cases of driver decision error).

It is also worth highlighting a result we will return to later; in only 8.6% of cargo tank rollovers was driver fatigue identified as a contributing factor.

Table 28. Frequency of Driver Contributing Factors

Factor	Percent	95% CI
Performance	49.5%	(39.6, 59.5)
Poor directional control (weaving or drifting)	32.3%	(23.7, 42.3)
Overcompensation (overcorrection)	20.4%	(13.5, 29.7)

Factor	Percent	95% CI
Startle reaction	8.6%	(4.4, 16.1)
Other	2.2%	(0.6, 7.6)
Decision	35.5%	(26.5, 45.6)
Too fast for conditions	32.3%	(23.7, 42.3)
Following too closely to respond to unexpected actions	3.2%	(1.1, 9.0)
Illegal maneuver	2.2%	(0.6, 7.6)
Misjudgment of gap or other's speed (merging decision error)	1.1%	(0.2, 5.9)
Other	1.1%	(0.2, 5.9)
Recognition	25.8%	(18.0, 35.5)
Failure to maintain Situational Awareness	12.9%	(7.5, 21.2)
Internal distraction	10.8%	(6.0, 18.7)
External distraction	3.2%	(1.1, 9.0)
Driver inattention	3.2%	(1.1, 9.0)
Unknown distraction	2.2%	(0.6, 7.6)
Other	1.1%	(0.2, 5.9)
Non-Performance	10.8%	(6.0, 18.7)
Driver fatigued, asleep or drowsy	8.6%	(4.4, 16.1)
Other	2.2%	(0.6, 7.6)
Under the influence of drugs or alcohol	0%	-
Incapacitated by illness	0%	-
Experience Deficiency	3.2%	(1.1, 9.0)
Unfamiliarity with route	2.2%	(0.6, 7.6)
Other	1.1%	(0.2, 5.9)
Unfamiliarity with vehicle	0%	-
Unfamiliarity with load type	0%	-

The second most frequent category of contributing circumstances were rollovers induced by the actions of a vehicle other than the cargo tank that overturned, contributing to 20% of cargo tank rollovers. These factors are summarized in Table 29. The most frequent factor in this category was human error by the driver of the other vehicle (11.8% of all cases).

Table 29. Frequency of Other Vehicle Induced Factors

Factor	Percent	95% CI
Human error - driver other vehicle	11.8%	(6.7, 19.9)
Unable to avoid accident involving others	6.5%	(3.0, 13.4)
Other	5.4%	(2.3, 12.0)
Mechanical failure on other vehicle	3.2%	(1.1, 9.0)
Same trafficway, same direction: lane change to avoid vehicle attempting to pass	2.2%	(0.6, 7.6)

Factor	Percent	95% CI
Lane change to avoid oncoming vehicle collision	1.1%	(0.2, 5.9)

Environmental contributing factors were uncommon, only being reported in 7.5% of cargo tank rollovers. These factors are summarized in Table 30.

Table 30. Frequency of Environmental Contributing Factors

Factor	Percent	95% CI
Animal on roadway	4.3%	(1.7, 10.5)
Other	4.3%	(1.7, 10.5)
Inadequate roadway maintenance (e.g., potholes)	1.1%	(0.2, 5.9)
Signs or signals defective or erroneous	0%	-
Pedestrian on roadway	0%	-
Object on roadway	0%	-
Designated detour	0%	-
Work Zone	0%	-

Weather related factors were reported in 15% of cargo tank rollovers. These factors are summarized in Table 31.

Table 31. Frequency of Weather Contributing Factors

Factor	Percent	95% CI
Rain	7.5%	(3.7, 14.7)
Snow	4.3%	(1.7, 10.5)
High crosswinds	2.2%	(0.6, 7.6)
Other	2.2%	(0.6, 7.6)
Fog	1.1%	(0.2, 5.9)
Sudden change in illumination	0%	-
Glare	0%	-
Dust, debris, or smoke aloft	0%	-

Vehicle related factors were uncommon, reported in only 8.6% of cargo tank rollovers. These factors are summarized in Table 32.

Table 32. Frequency of Vehicle Contributing Factors

Factor	Percent	95% CI
Tire, wheel, or tie rod failure	2.2%	(0.6, 7.6)
Brake failure	2.2%	(0.6, 7.6)

Factor	Percent	95% CI
Trailer attachment failure	2.2%	(0.6, 7.6)
Other	2.2%	(0.6, 7.6)
Steering failure	0%	-
Leaking cargo	0%	-
Vehicle failure– unknown or unable to classify	0%	-
Fire (before crash)	0%	-

4.5.3.3.2 Other Data from PARs

Table 33 summarizes the types of roadways on which rollover accidents occurred. The majority of rollovers occurred on a two-way trafficway; more than half of rollovers were not on divided roads.

Table 33. Roadway Configuration

Roadway	Percent	95% CI
One-way trafficway not divided	6.5%	(3.0%, 13.4%)
Two-way trafficway divided positive barrier	20.4%	(13.5%, 29.7%)
Two-way trafficway divided unprotected median	22.6%	(15.3%, 32.1%)
Two-way trafficway not divided	50.5%	(40.6%, 60.5%)

Table 34 summarizes the Last Precrash action of the cargo tank truck, prior to the critical action that resulted in a rollover accident. The majority of trucks were travelling straight prior to the critical event; a total of 20.4% of rollovers involved a truck performing another action such as making a turn or negotiating a curve. Although it is not displayed as a separate action in this table, this number includes the 10.7% of rollovers that occurred on a highway entrance or exit ramp.

Table 34. Last Precrash Action Prior to Critical Event

Last Precrash Action	Percent	95% CI
Going straight	79.6%	(70.3%, 86.5%)
Negotiating a curve	8.6%	(4.4%, 16.1%)
Turning	4.3%	(1.7%, 10.5%)
Decelerating in traffic lane	2.2%	(0.6%, 7.5%)
Passing or overtaking another vehicle	1.1%	(0.2%, 5.8%)
Merging	1.1%	(0.2%, 5.8%)
Making a 3-point turn	1.1%	(0.2%, 5.8%)
Negotiating a roundabout	1.1%	(0.2%, 5.8%)
I don't know	1.1%	(0.2%, 5.8%)

In 32.3% of rollovers, the driver was identified as travelling “too fast for conditions”. We also collected information on the recorded speed at the time of the rollover, and the posted speed limit on the road

where the rollover occurred. Figure 1, Figure 2, and Figure 3 provide histograms for each of these variables.

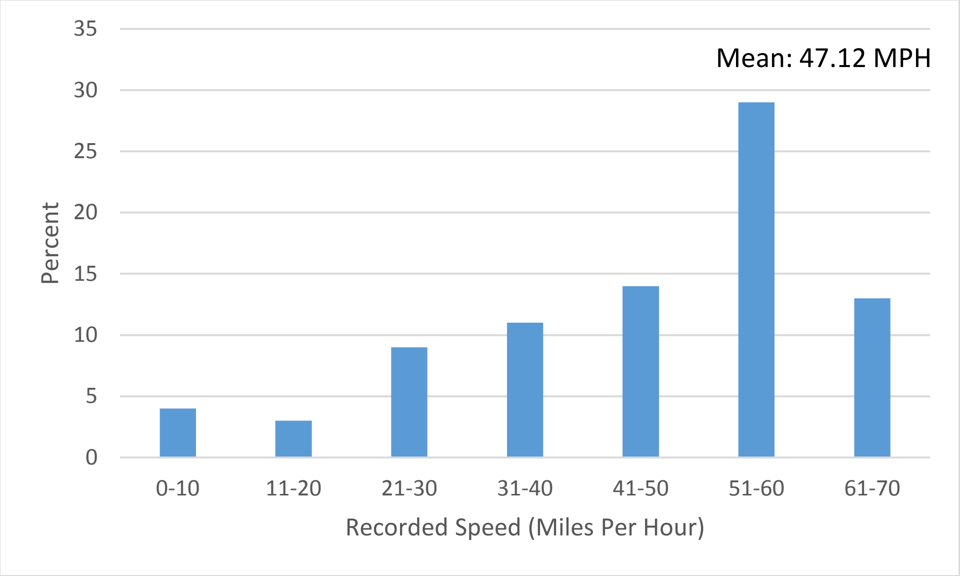

Figure 1. Recorded Speed

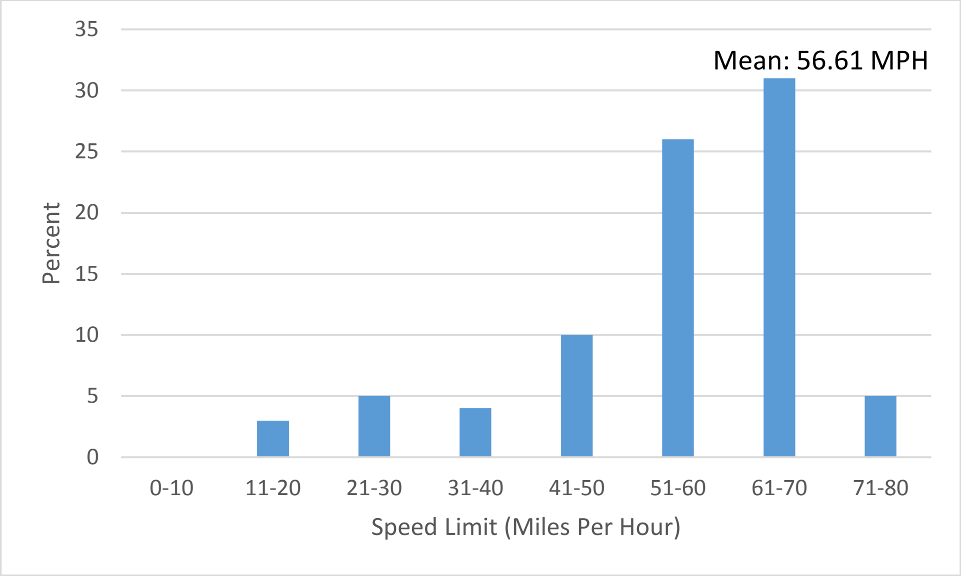

Figure 2. Speed Limit

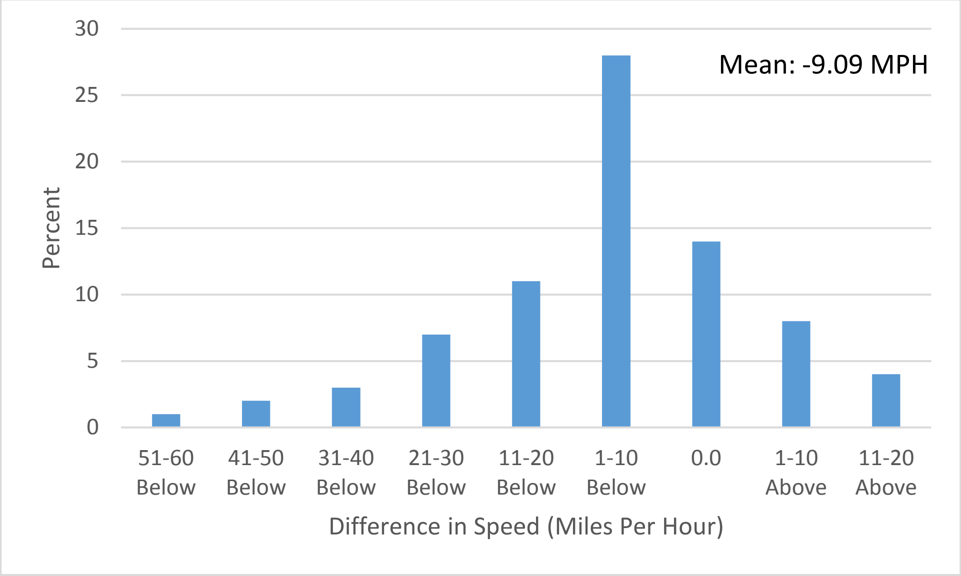

Figure 3. Recorded Speed Relative to Speed Limit

While in 32.3% of rollovers the PAR identified that the driver was going too fast for conditions, only 15.4% of trucks were actually travelling above the posted speed limit at the time of the accident. A further 17.9% were travelling at the speed limit. The remaining 66.7% were travelling under the speed limit. This suggests that the decision by a police officer to report speed as a factor in an accident is based on the roadway, weather, and traffic conditions, and not solely on the actual speed of the vehicle relative to the posted speed. It is worth noting that posted speed limits are intended as guidance for light vehicles not for heavy trucks so using those as a metric to determine safe speed for tank trucks is not necessarily accurate. Even when reduced speed signs are posted for large trucks on curves or turns, they are intended for tractor-trailers, not tank trucks, which require even more conservative speeds on curves to account for slosh and surge. Finally, the officer generally reports the posted speed limit on the PAR not any other suggested speeds posted for heavy trucks.

Table 35 and Table 36 summarize the usage of rollover protection and advanced safety technologies among cargo tank vehicles that overturned. Table 36 suggests that advanced rollover protection technologies are rare among vehicles that overturned. We lack a comparison to comment on whether these technologies are more or less common among vehicles that overturned than they are among the overall population of cargo tankers. We should also note that almost half of the cases we reviewed (48.4%) did not indicate if the vehicle had rollover protection or not and an even higher percentage of cases did not indicate if the truck had advanced safety technology or not (91.4%).

Table 35. Rollover Protection

	Percent	95% CI
I Don’t Know	48.4%	(38.5, 58.4)
Longitudinal Rails	24.7%	(17.1, 34.4)
Box	17.2%	(10.9, 26.1)
Other	10.8%	(6.0, 18.7)
Tombstone	3.2%	(1.1, 9.0)
Roll Pipe	2.2%	(0.6, 7.6)

Table 36. Presence of Advanced Safety Technologies

	Percent	95% CI
I Don't Know	91.4%	(83.9, 95.6)
None	2.2%	(0.6, 7.6)
Rollover Stability Control	2.2%	(0.6, 7.6)
Electronic Stability Control	1.1%	(0.2, 5.9)
Collision Avoidance Systems	1.1%	(0.2, 5.9)
Data Analysis models that produce driver scorecards, or fleet risk profiles, or flag safety-critical vehicle maintenance needs (e.g., QUALCOMM)	1.1%	(0.2, 5.9)
Onboard Event Recording	1.1%	(0.2, 5.9)
Forward Collision Warning System	0%	-
Lane Departure Warning System	0%	-
Brake Stroke Monitoring and Crash Imminent Braking	0%	-
Backup awareness and Blind Spot monitoring technologies	0%	-
Drowsy driver monitoring and warning systems	0%	-

Table 37 summarizes casualties and injuries resulting from cargo tank rollover accidents. Most commonly (44% of rollovers), rollover crashes resulted in the tanker driver being injured. A smaller percentage (12%) of rollovers were fatal for the tanker driver.

Table 37. Injuries

Injuries	**Fatalities**				
	0 fatalities	**1 fatality: tanker driver**	**1 fatality: other driver**	**>1 fatality including tanker driver**	**Total**
0 injuries	28%	12%	0%	1%	41%
1 injury: tanker driver	44%	0%	1%	0%	45%
1 injury: other driver	1%	1%	0%	0%	2%
>1 injury including tanker driver	4%	0%	0%	0%	4%

Injuries	Fatalities				
>1 injury not including tanker driver	0%	1%	0%	0%	1%
I Don't Know	6%	0%	0%	0%	6%
Total	84%	14%	1%	1%	100%

4.5.3.3.3 Crosscutting factors

Driver factors were the most commonly reported type of contributing factor to rollovers. However, it is unclear how well they are reported in police accident reports. In the case of many driver factors, identifying whether they contributed to the occurrence of a rollover relies on a self-report from the driver. In order to approach these contributing factors from a different angle, we looked at crash causation from the opposite side. Many of the rollovers could be, in part, attributed to factors external to the driver. We attempted to determine the proportion of rollovers that were explained by any external contributing factors. By process of elimination, the remaining rollovers had no obvious explanation other than the driver or vehicle.

As external contributing factors, we considered involvement of other drivers, inclement weather conditions, or environmental factors. In 61.2% of the rollovers that occurred, none of these factors were identified.

We further considered a second set of criteria, which roadway configuration factors that might contribute to a rollover: turning, negotiating a curved roadway, travelling on a highway on/off ramps, and turning at an intersection. These were judged to be roadway configurations that might contribute to a rollover, especially if performed at a high speed. 74.2% of rollovers lacked any of these roadway configurations that might contribute to a rollover.

Combining these two sets of criteria, we found that in 38.7% of rollovers there were no clear external factors contributing to a rollover; weather, environment, roadway configuration, and other drivers did not appear to contribute to the occurrence of an accident. Therefore, in just over one third of all cargo tanker rollover crashes, there are no vehicle or external factors to explain why the crash occurred.

4.5.3.4 MCMIS Data

The GES data and PAR data described above contained substantial information regarding the crash itself, but neither of these data sources contain any information about the safety history of the drivers or carriers involved in the rollover crashes. We were particularly interested in the safety history of the carrier to identify any carriers with a pattern of unsafe operations, an indication of a poor safety culture. Rollovers could be the result of poor carrier safety culture instead of something directly in the control of the driver. We were also interested in the driver's safety history to identify drivers who are habitually unsafe.

A small set of supplemental data from the MCMIS database was retrieved to match drivers and carriers identified in PARs. MCMIS data are based on inspections; therefore, data only exists for drivers or carriers with a previous inspection history. This means there was extensive missing data for the drivers and carriers of interest to the current study. After some consideration of missing data, the percentages below are presented out of cases without missing data, rather than total cases. Missing data for carriers varies across variables, so sample size is indicated in parentheses.

4.5.3.4.1 Carriers

The majority of carriers were interstate (90.6%, N=86) rather than intrastate. As shown in Figure 4, a wide range of carrier sizes were represented among the rollovers, ranging from carriers with a single power unit up to 3598 power units (mean=214.1; median=76.5; N=86).

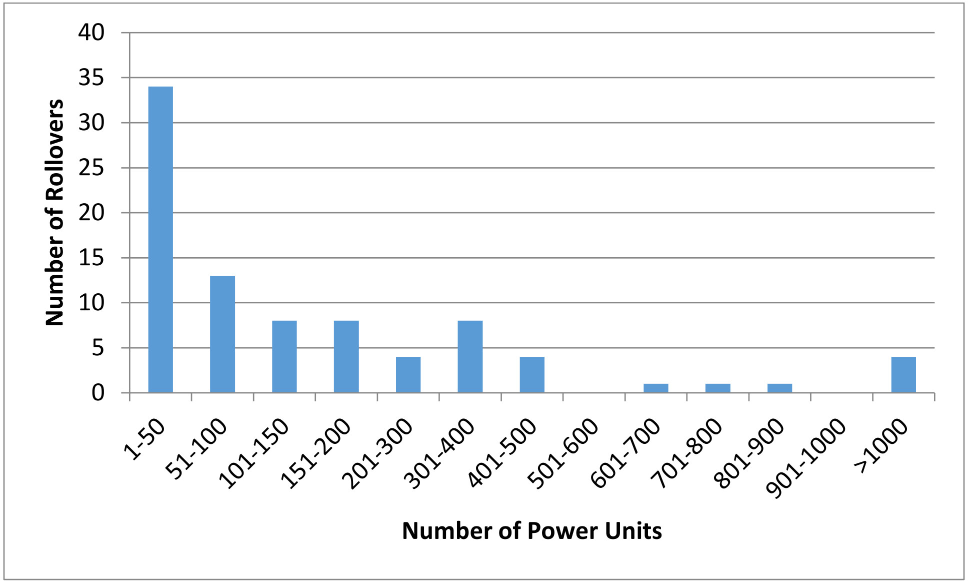

Figure 4. Histogram of Carrier Power Units

Contrary to our expectations, the vehicles from the larger carriers were not the only ones to report the usage of advanced safety technologies. As shown in Table 38 out of the 6 cargo tank rollovers in which the PHMSA incident report identified the usage on an advanced safety technology, 4 of them were among carriers with 4 or fewer power units. Given the small number of vehicles reporting the usage of advanced safety technologies, it is unclear whether they are being consistently reported, so the values reported here should not be considered representative.

Table 38. Advanced Safety Technology Usage by Carrier Power Units

Carrier Power Units	Advanced Safety Technology	
	None	Any
1-50	33	1
51-100	10	3
101-150	8	0
151-200	8	0
201-300	4	0
301-400	7	1
401-500	4	0
501-600	0	0
601-700	1	0
701-800	1	0
801-900	1	0
901-1000	0	0
>1000	3	1

Across carriers, there was an average of 64,429 miles driven per vehicle per year (N=86). Carrier BASIC scores are intended to rate the safety performance of a given carrier in comparison to other carriers. Basic scores for carriers of cargo tank rollover are summarized in Table 39.

Table 39. Carrier BASIC Scores

BASIC Domain	% of Carriers With Violations
Unsafe Driving	4.8% (N=84)
Hours of Service Compliance	6.0% (N=84)
Driver Fitness	3.6% (N=84)
Drugs/Alcohol	0% (N=84)
Vehicle Maintenance	4.8% (N=84)
Hazardous Materials Compliance	8.6% (N=81)
Crash Indicator	18.6% (N=70)

There was not a significant correlation between a carrier's average miles driven per vehicle per year and a carrier's percentile in hours of service violations (N=52).

On average, carriers above the HOS threshold had more miles driven per vehicle per year than carriers below the threshold (78,955 and 61,628 miles respectively) however, the difference was not significant (N=84).

4.5.3.4.2 Drivers

While no direct equivalent for the BASIC score exists at the driver level, we sought to provide some sort of indication of safety history at the driver level to suggest whether a given driver is safe or unsafe based on their inspection history. Most of the data used to calculate BASIC scores for carriers are collected at the driver level; we were therefore able to pull data on these facets of driver safety. Several of the elements of the BASIC score do not make sense at the driver level, because they are the responsibility of the carrier, e.g. hazardous materials compliance. These were excluded from our analysis. On the other hand, some elements of the BASIC score are within the control of and under the responsibility of the driver; for example a driver is responsible for complying with their hours of service restrictions. To get some understanding of each driver's safety history, we looked at percentile scores for the following BASICS: Unsafe Driving, Controlled Substances/Alcohol, Crash Indicator, Hours of Service, and Driver Fitness because they are the most relevant to driver behavior

While there are some data available at the driver level, in contrast to the carrier, not a lot of information is available on each individual driver. For a given driver, information on their individual safety is available if they have been inspected and/or have received a roadside violation. Each driver is going to only have a limited number of inspections. Any given driver is only likely to have data on a certain subset of the BASIC elements, if they have any at all. Therefore, rather than providing driver level estimates for each element, we aggregated all violations into a single metric, indicating drivers with inspections and no violations, drivers with inspections and one violations, drivers with inspections and multiple violations, and driver with no inspection data.)

Driver safety was categorized based on unsafe driving, hours of service, driver fitness, and drugs/alcohol violations. The majority of drivers had no inspection data (56%). 28% of drivers had been inspected, and had no violations. 11% had been inspected and had a single violations of any of these types. 5% had been inspected at least twice and had multiple violations.

There were no significant differences in distribution of driver errors across drivers with no, one, or multiple violations (across all driver errors, as well as more specifically driver decision errors, driver performance errors, driver non-performance errors, driver recognition errors, and driver experience deficiency).

4.6 Summary

Below we summarize results from the GES data analysis first, and then we summarize the results from the PAR and MCMIS case study data analysis. For the GES analysis, only statistically significant ($p<0.05$) differences between the data in the 2007 Battelle report and the 2011-2014 data will be summarized. Because descriptive statistics rather than statistical comparisons were used for the case studies, statistical significance is not relevant.

4.6.1 Changes in Rollovers since 2007 Report (GES)

GES included rollovers crashes involving any cargo tank trucks, whether carrying hazmat and non-hazmat cargo. Since the 2007 report, there has been a reduction in the average number of cargo tank rollover crashes per year. To be more precise, in the 2000-2004 timeframe there was an estimated national average of 1265 rollovers per year, while in the 2011-2014 timeframe there were 1055 per year. However, this data source alone is insufficient to conclude that there is a genuine downward trend over time in number of rollovers. First, as shown in Table 13, the actual year-by-year estimates for 2011-2014 are somewhat volatile, with large variations up and down across years. Second, the GES data is a weighted sample, and does not contain an actual count of the full population of cargo tank rollovers in the nation.

There has also been some change in the configuration of cargo tank vehicles involved in rollover crashes. The type of vehicle remains similar to that reported in 2007, with roughly two-thirds truck-tractor vehicles and one-third single-unit straight trucks. However, fewer rollovers involved a straight truck without a trailing unit (from 40% to 25%), and more rollovers involved a straight truck with a trailer (from under 1% to 8%).

The largest proportion of cargo tank rollovers occurred on a roadway that was not divided (47%). The type of roadways and roadway configuration on which rollover crashes occur has shifted somewhat since the 2007 report. More occurred on divided highways (22% to 33%), while fewer occurred on undivided highways (66% to 47%). However, this change has the caveat that 11% of the rollovers may have been defined differently as of the 2007 report.

The majority of cargo tank rollovers occur on a straight road away from any intersections or junctions. These roadway characteristics have changed somewhat since the 2007 report. More rollover crashes occurred on a straight road, rather than a curved road (from 59% on straight roads to 71%). Most rollovers do not occur on a junction or ramp (88%). There was a small but significant increase in the number of rollovers at an intersection (1.2% to 3.6%).

In the majority of cargo tank rollovers, the last pre-crash maneuver by the cargo tank truck was travelling straight (56%). This is a significant increase since 2007 (from 41%). Fewer rollover crashes occurred while the vehicle was negotiating a curve (from 32% to 20%). The involvement of speed remains similar to that reported in 2007, with 43% of rollover crashes reporting excessive speed.

The majority of critical events resulting in a rollover crash are driver related (66%). There have been some significant changes since the 2007 report. There have been fewer left roadside departures by cargo tank truck drivers (12% to 1%), although right roadside departures remain roughly the same at 26%. The overall proportion of cargo tank rollovers caused by other drivers has stayed the same (19%), but there have been fewer rollovers caused by another driver encroaching on the cargo tank truck from the left (12% to 1.5%). Furthermore, there has been an increase in the number of cargo tank rollovers caused by vehicle failure (from 6% to 15%). This seems to be driven by an increase in the frequency of both tire and brake problems resulting in rollover crashes (from 2.5% to 8.3% and from 1.2 to 8.8% respectively).

A number of other factors are identified that may have contributed to the occurrence of cargo tank truck rollover crashes. Comparable to the 2007 report, weather was rarely identified as a contributing factor, with no adverse weather reported in most crashes (90%), and only a few crashes reporting rain (8%) or snow (2%). The majority of rollover crashes reported no involvement of driver physical impairment (84%), distraction (95%), or obscured vision (96%). Across these categories, the most frequent contributing factor was driver fatigue, which was reported in 10% of rollover crashes. In the 2007 report, driver inattention was reported as the most frequent contributing factor, but the involvement of this factor in rollovers has dropped significantly in the more recent data (from 14% to 1.8%).

It is also worth noting that there has been a shift in the demographics of cargo tank truck drivers since the 2007 report. The age of drivers represented in rollover crashes appear to be increasing. Fewer drivers fell into the 25-35 age range (24% to 14%), while more fell into the 46-55 (25% to 33%, although this was not a significant change) and 65+ age ranges (2% to 7%).

4.6.2 Results from PAR and MCMIS data

Only PARs involving crashes resulting in the rollover of a cargo tank truck carrying hazmat were included; crashes involving trucks with not-hazmat cargo are not represented in this sample. All summary statistics presented here are out of all cases, unless otherwise specified. According to the PAR data, driver factors were the most frequently identified contributing factor in rollover accidents (77%), followed by other vehicle induced factors (20%) and weather factors (15%). Furthermore, driver factors were commonly identified in conjunction with another contributing factor (26% of all cases). This suggests the possibility that even when other factors besides driver behavior contribute to a rollover accident, their effects may be exacerbated by the actions of the cargo tank truck driver.

A major focus of the current analysis was identifying human factors associated with tank truck rollovers. Among contributing factors involving the driver of the cargo tank truck, the most frequently identified categories were performance errors (50%), decision errors (36%), and recognition errors (26%). The most common performance errors were poor directional control (32%) and overcompensation (20%), either alone or together in combination. The majority of the driver decision errors identified were travelling driver's travelling too fast for conditions (32%). While this 32% of rollovers identified speed as a contributing factor, only in 15% of rollovers was the driver travelling in excess of the posted speed limit. The most common recognition errors were failure to maintain situational awareness (13%) and internal distraction (11%).

A portion of the cargo tank rollovers identified contributing human factors involving the driver of a vehicle other than the cargo tank truck that rolled over. Among other vehicle induced factors, the majority of them were human error by the driver of the other vehicle (12%).

Apart from human factors, the analysis also looked at characteristics of the cargo tank truck itself that may have contributed to the rollover accident. Vehicle contributing factors were rarely identified as a contributing factor (9%), and no single defect stood out as especially frequent. From the current data, we are unable to draw conclusions as to whether vehicle factors may have mitigated or prevented rollovers. About half of the cargo tankers in rollover crashes reported rollover protection (52%) of some type. In the remaining half, details of rollover protections were not reported. Even less data was available regarding Advanced Safety Technologies, with only a small number of cargo tankers reporting their usage (6%). In the case of many rollover crashes, there was no reported rollover protection or Advanced Safety Technology, but there was also insufficient detail to confidently conclude that it was absent.

Apart from the drivers or vehicles involved in the rollover crash, situational factors may have also contributed to the occurrence of a rollover, including trafficway design and conditions, along with weather conditions. Under the category of Environmental contributing factors, we evaluated the involvement of road maintenance, signage, and non-motorists or objects in the roadway. Weather and Environmental contributing factors were rare, identified in fewer than 10% of rollover accidents. No single factors stood out as especially frequent in either of these categories. In terms of trafficway design and geometry, rollover crashes occurred most frequently on two-way trafficways (94%), most often not divided (51%). Prior to the crash the cargo tank truck was usually travelling straight (80%).

The above analyses looked at each set of contributing factors one by one, but several types of factors may all have contributed to a given rollover crash. Since a major focus of the current analysis was identifying the involvement of human factors in rollover crashes, we also sought to estimate what portion of rollovers were explained exclusively by human factors involving the driver of the cargo tank truck, whether or not they were clearly reported in the PAR, versus rollovers that also involved other contributing factors. In 38.7% of rollovers, there were no reported involvement of contributing factors including weather, environment, or human error by another driver, nor did the rollover occur on curved roadways, highway on/off ramps, or intersection.

The current data is insufficient to identify factors that distinguish between safe and unsafe carriers or drivers, since there is no data for a comparison group of "safe" cargo tank trucks that have not been involved in rollover crashes. However, we can provide some description of the characteristics of carriers and drivers whose cargo tank trucks have been involved in rollover crashes.

The majority of carriers were interstate (91%); there was wide variance in the number of power units across carriers, but the median carrier had 77 units. Carrier BASIC scores identified hazardous materials compliance (9%), unsafe driving (5%), and vehicle maintenance as the most frequent violations (5%).

Less than half of the drivers had data from past inspections (44%). Roughly one quarter of drivers had a clean inspection record, with no violations identified (28%).

4.6.3 Comparison

Values in Table 40 are reproduced from Table 14 and Table 27. Categories across the two datasets are not entirely defined the same way, but are roughly similar. No weather category featured in Table 14; pulled the values from Table 20 instead. Used GES roadway category as a comparison for environmental factors from the PARs; it does not contain everything categorized as environmental factors in our risk matrix, but mostly overlaps. With the exception of vehicle factors, every other factor was identified more frequently in the PAR data than it was reported in the GES database. The PAR contributing factors add up to more than 100 percent, because we allowed for more than one contributing factor per rollover accident, while the corresponding GES variable only allowed for a single critical event. The fact that we identified nearly all of the factors more frequently than would be indicated by the GES critical event alone suggests that cargo tank rollovers may have more complex causation than can be captured by a single critical event alone

Table 40. Comparison of Contributing Factors Across Data Sources

Contributing Factor Category	GES	PARs
Driver	66.53%	77.4%
Other Vehicle Induced	16.53%	20.4%
Environmental	2.22%	7.5%
Weather	10.28%	15.1%
Vehicle	14.72%	8.6%

5. Advanced Safety Technologies

5.1 Overview

To better understand if advanced safety technologies can potentially reduce the incidence of rollovers, we describe changes that have occurred in advanced safety technologies since the publication of the 2007 Battelle study (Pape, et al., 2007). We will focus on the capability of safety technologies to aid in stability control, monitor drivers, and evaluate driver patterns. Furthermore, we will assess the availability and adoption of these technologies.

Prior to 2007, stability control systems and lane departure warning systems were the advanced safety technologies largely available and in use; driver monitoring technologies were in their early stages. Since then, not only have stability, lane departure warning, and driver monitoring technologies become more sophisticated, but also the range of safety technologies has further expanded to include collision mitigation and blind-spot protection systems. Fleet monitoring systems now provide fleets with extensive real-time data to enhance the efficiency of operations. Additional technologies that may ultimately also reduce the incidence of tank vehicle rollovers are in development. This section will discuss these technologies.

We will present a qualitative assessment of the potential for these technologies to mitigate tank vehicle rollovers, including a discussion of issues related to tank vehicle and operator adoption. One caveat concerning our description of the current state of advanced safety technologies is that the data available on technologies (e.g., their effectiveness, their market penetration, etc.) in almost all cases come from studies that did not distinguish between liquid-cargo tank vehicles and conventional freight tractor-trailers.

5.2 Stability Control Systems

Stability control technologies refer to those systems that are intended to help to reduce roll instability on curves and turns caused by excessive speed for those conditions. Two types of heavy vehicle stability control technologies have been developed. Roll stability control (RSC) monitors the risk of rollover and intervenes to prevent it. Electronic stability control (ESC), in addition to monitoring rollover risk, monitors performance for the loss of directional control that can result in jackknifing. RSC is designed primarily to mitigate on-road, untripped rollovers by decelerating the vehicle using braking and engine torque control. ESC not only includes the RSC functions but is also designed to mitigate loss-of-control (LOC) crashes caused by yaw instability by applying brake force at selected wheel-ends to help maintain directional control of a vehicle (Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles, 2015). Stability control technology is not only useful for preventing crashes;

it may also teach individuals to drive more conservatively. When drivers feel the stability control system activate, it serves as a signal to them that they may be driving unsafely. Continuous exposure to this feedback may help improve driver behavior (Britton, 2009).

5.2.1 Roll Stability Control (RSC)

RSC systems are available for truck tractors and for trailers. Tractor-based systems can be installed only at the factory as part of the build. They cannot be retrofitted because they need to be integrated with the sensors and internal communication system of the vehicle. They also need to be adjusted for the particular dynamics of each tractor, which is best done at the factory. Trailer-based systems can be retrofitted to existing trailers.

A tractor-based RSC system consists of an electronic control unit (ECU) that is mounted on a vehicle and continually monitors the vehicle's speed and lateral acceleration based on an accelerometer, and estimates vehicle mass based on engine torque information. The ECU continuously estimates the roll stability threshold of a vehicle, which is the lateral acceleration above which a combination vehicle will roll over.

When the vehicle's lateral acceleration approaches the roll stability threshold, the RSC system intervenes to reduce the vehicle's speed. Tractor-based roll stability systems (RSS) will apply brakes on the trailer as well as those on the tractor. Depending on how quickly the vehicle is approaching the estimated rollover threshold, the RSC system performs one or more of the following actions: decreases engine power, uses engine braking, applies the tractor's drive-axle brakes, or applies the trailer's brakes. When RSC systems apply the trailer's brakes, they use a pulse modulation protocol to prevent wheel lockup.

An RSC system can reduce rollovers, but is not designed to help to maintain directional control of a truck tractor. Nevertheless, RSC systems may provide some additional ability to maintain directional control in some scenarios, such as in a low-center-of-gravity scenario, where an increase in a lateral acceleration may lead to yaw instability rather than roll instability. However, since tank vehicles have a high center of gravity, this is not applicable for those vehicles.

In comparison, a trailer-based RSC system has an ECU mounted on the trailer. Because the trailer, in nearly all situations, begins to roll before the tractor does, trailer-based systems have a direct indication of the impending rollover when the roll angle becomes too great. A trailer-based RSC typically monitors the trailer's wheel speeds, the trailer's suspension to estimate the trailer's loading condition, and the trailer's lateral acceleration. A trailer-based RSC system works similarly to a tractor- based system. However, a trailer-based RSC system can only apply the trailer brakes to slow a combination vehicle, whereas a tractor-based RSC system can apply brakes on both the tractor and trailer.

5.2.2 Electronic Stability Control (ESC)

An ESC system incorporates all of the inputs of an RSC system. However, it also has two additional sensors to monitor a vehicle for loss of directional control, which may result due to either understeer or oversteer. The first additional sensor is a steering wheel angle sensor, which senses the driver's steering input. The other is a yaw rate sensor, which measures the actual turning movement of the vehicle. These system inputs are monitored by the system's ECU, which estimates when the vehicle's directional response begins to deviate from the driver's steering command, by either oversteer or understeer. An ESC system intervenes to restore directional control by taking one or more of the following actions: decreasing engine power, using engine braking, selectively applying the brakes on the truck tractor to create a counter-yaw movement to turn the vehicle back to its steered direction, or applying the brakes on the trailer. An ESC system enhances the RSC functions because it has the added information from the steering wheel angle and yaw rate sensors, as well as more braking power because of its additional capability to apply the tractor's steer axle brakes. Because ESC systems must monitor steering inputs from the tractor, ESC systems are not available for trailers.

5.2.3 Regulations

For a number of years, FMCSA promoted voluntary adoption of stability systems. In 2003, the U.S. Department of Transportation (USDOT) published an independent evaluation of the Freightliner Intelligent Vehicle Initiative (IVI) Field Operational Test (FOT) (Battelle, 2003). The report included a societal-benefit-cost analysis over a 20-year period of deployment for a stability system designed to prevent rollovers caused by excessive speed in a curve. A wide range of societal costs were included, such as the lost productivity of commuters caught in traffic jams caused by truck crashes, or costs of police, fire, and emergency rescue responses to crashes. While succeeding in identifying the societal costs that could be linked to CMV crashes, the study did not focus on the direct costs incurred by commercial motor carriers.

As part of an ongoing FMCSA effort to encourage voluntary adoption of stability control systems, a 2009 benefit-cost analysis built on the previous FOT by changing the focus of the benefit-cost analysis (BCA) from general societal costs to the costs incurred by the motor carrier industry—the end-users who are responsible for investment and deployment of the technology. The purpose of this BCA was to provide critical cost and return-on-investment information to the motor carrier industry in support of future decisions to purchase stability control systems. The motor carrier industry had confirmed that verifying associated costs and benefits of safety systems is critical to spur deployment, since these systems must prove to be beneficial, cost-effective investments that meet the users' needs (Federal Motor Carrier Safety Adminstration, 2009).

The potential benefit, in terms of crash cost avoidance, was measured against the purchase, installation, and operational costs of RSC systems in motor carrier operations. The primary data source for benefits came from information provided by insurance companies and motor carriers on actual expenses incurred in a CMV crash. The assessment thus incorporated actual motor-carrier-based benefit-cost data. The benefits of using the system over a period of five years outweighed the costs associated with each efficacy rate and for each Vehicle Miles Traveled (VMT) category (Federal Motor Carrier Safety Adminstration, 2009).

Nonetheless, adoption was slow, apparently due to a combination of unfamiliarity with the technologies benefits and resistance to the marginal additional cost of the technologies as optional equipment in new trucks and tractors. In June 2015, NHTSA issued a final rule establishing a new Federal Motor Vehicle Safety Standard No. 136 to require electronic stability control (ESC) systems on truck tractors and certain buses with a gross vehicle weight rating of greater than 11,793 kilograms (26,000 pounds) (Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles, 2015).

NHTSA reported that it considered requiring truck tractors and large buses to be equipped with RSC systems. Its analysis indicated that when compared to the ESC requirement in this final rule, RSC systems would cost less than ESC systems, be slightly more cost-effective, but would produce net benefits that are much lower than the net benefits from this final rule. This is because RSC systems are less effective at preventing rollover crashes and much less effective at preventing loss-of control crashes. The agency also considered requiring trailers to be equipped with RSC systems. Once again, their analysis showed that this alternative would save many fewer lives, would not be cost-effective, and would not result in net benefits.

However, the analysis did not analyze for the effects of either of the tractor-based technologies or the trailer-based technology on the potential for tank vehicle rollovers specifically. Notably, NTSB also notes adoption of ESC in their Most Wanted List amongst other safety technologies (discussed below) (National Transportation Safety Board, 2016).

5.2.4 Review of Stability Control Technologies

To better understand the types of systems currently available, the market penetration and the cost, we conducted interviews with a handful of stability control manufacturers (Meritor WABCO and Bendix). We also did a literature scan of their online marketing materials and manuals and summarized where appropriate.

5.2.4.1 Meritor WABCO Stability Control Systems

5.2.4.1.1 Meritor WABCO RSC

Meritor WABCO's Roll Stability Support (RSS) 2M system is built for trailers to reduce speed and lower lateral acceleration at the rollover threshold. This technology simultaneously monitors trailer wheel speed, lateral acceleration and suspension pressure or spring deflection. If the vehicle approaches its rollover threshold, RSS 2M automatically applies the trailer brakes as needed to help the driver bring the vehicle under control. This technology also provides Power Line Carrier (PLC) communications for the transfer of data to an in-cab PLC Display, and telematics capability for transmitting real-time trailer data to fleet headquarters.

RSS 2M does work with liquid bulk tank trailers; Meritor WABCO collected performance data on loaded tank vehicles). There is an option available for an alert light when the system is activated, but it is not mandatory because the driver can also feel the system slow the vehicle. This technology is intended for OEMs; the marginal cost of the technology is about 400 dollars per unit. The manufacturer's estimate of the overall freight carrier market penetration is about seven percent. The market penetration in the tank truck industry is unknown.

Carriers interested in training their drivers in the technology have two options. Meritor WABCO will provide training if requested and training literature is available online.

5.2.4.1.2 Meritor WABCO ESC

Meritor WABCO also offers SmartTrac™ electronic stability control technology for tractors. The tractor ECU compares the vehicle's movement to performance models using estimates for vehicle parameters (the mass of the vehicle, acceleration, and the engine force). The technology will continuously check and update the lateral acceleration of the tractor and compare it to a critical threshold beyond which the rollover may occur. Before the threshold is exceeded, SmartTrac™ intervenes by reducing engine torque and engaging the engine retarder while automatically applying drive axel and tractor brakes (and trailer brakes if necessary). The system is often activated before the operator is aware of the need.

According to the manufacturer, this technology may help reduce rollovers in slippery road conditions, on curves, and/or when drivers are taking some sort of evasive action because it automatically intervenes. This technology is also useful when the vehicle is going too fast for certain conditions, as it has the ability to control and reduce tractor-trailer speed when it is about to exceed lateral acceleration limits.

Meritor WABCO's ESC technology costs about $1100 per unit. It has been tested on tank trailers with varying amounts of liquid, including full tanks. The type of trailer (i.e., tank versus straight truck) is not communicated to the power unit itself; therefore, a conservative approach has been adopted to optimize the usefulness of the technology. Although the power unit cannot localize the center of gravity, it does know the mass, so the technology will intervene at 80,000 lbs. regardless of the type of cargo being hauled. The system will calculate the rollover threshold differently depending on whether the sensors are reading airbags or spring height suspension. Finally, Meritor WABCO's ESC technology does have data recording capabilities for numerous functions.

This technology is only available on new power units. Retrofit is not available.

5.2.4.2 Bendix® Stability Control Systems

The following sections describe three different types of Bendix® stability control systems. Bendix® technology is used by a variety of carriers, including Kenworth, Mack, Peterbilt, Navistar, Heil, Polar, Ridenhour, and Volvo. Training is available for all Bendix® components online for anyone who creates an account.

5.2.4.2.1 Bendix® TAB-6 Stability Control

As described by the manufacturer, the Bendix® TAB-6 Stability Control system automatically intervenes when it detects conditions that may lead to a rollover. This system is tank mountable but it is not designed for retrofit, and is available only on new tanks. The Bendix® TAB-6 costs approximately $1,500-$2,500 in addition to a basic ABS. Tank market penetration for TABS-6 is small, likely at least in part because tank trailers tend to stay in fleets longer than dry box trailers (approximately 15 to 20 years) because they are very specialized and expensive.

5.2.4.2.2 Bendix® ESP® Full Stability System

The Bendix® ESP® System combines an ABS with Electronic Stability Control using roll and yaw stability to help mitigate rollovers and loss of control scenarios using information including speed, engine speed, wheel speed; and inputs regarding brake application, airbag pressure, wheelbase, and tires. The manufacturer says that this technology will assist when the vehicle is being over or under steered, during loss of control events, and when traction is compromised due to snow, ice rain, dust, sand, or similar factors.

The Bendix® ESP® System is configurable for tank vehicles; each power unit's VIN determines the configuration. It is available on new equipment only, and cannot be retrofitted. This system costs about $1000 to $1500 in addition to the cost of an ABS. According to the manufacturer, large commercial fleets are typical adopters of this technology at this point in time.

5.2.4.2.3 Bendix® Wingman®

Bendix® Wingman® combines collision mitigation technology with Bendix® ESP® Electronic Stability, and the AutoVue® Lane Departure Warning System. Wingman® uses inputs from radar, video, and the braking system and is capable of road sign recognition (for example, if the system reads a 60 mph speed limit sign and the vehicle is traveling 70 mph, the technology will decelerate the truck). This technology costs $3,000-$3,500 per unit. We were unable to obtain information on market penetration.

5.2.4.3 Haldex TRS

Haldex's Trailer Roll Stability (TRS) system provides braking assistance and roll stability safety technology. TRS is designed for one- to three- or more axle trailers using air suspension. It provides braking adjustments for normal ABS braking events and situations in which rollover may be an imminent threat. Haldex's TRS system controls speed at the trailer by continually monitoring the trailer's movements using adaptive learning loop (ALL) technology. ALL allows the system's ECU to learn by calculating the trailer's lateral acceleration, vehicle speed, and air suspension and air system pressure. The system can provide the appropriate pressure at the wheel end, ensuring balanced braking and preventing wheel lock. When TRS senses that a rollover is imminent, the ECU will apply the service brakes at the trailer to slow and stabilize the vehicle. This will illuminate the trailer's brake lights to warn other drivers that the vehicle is slowing down.

5.3 Fleet Tracking Systems (Telematics)

Fleet tracking systems allow fleet managers to monitor potential safety issues in all vehicles in the fleet and receive the data. The amount and type of data available on each fleet varies based on the technology and the preferences of the carrier. In a 2015 article (Roberts, 2015), the vice president of automotive and transportation research for Frost & Sullivan suggested that adoption trends for this technology in North America are increasing rapidly. At that time he suggested that market penetration has increased by as much as 30% since these systems first became available on the market (he did not state the baseline level). Additionally, those fleets that already use this technology continue to do so when they purchase new vehicles about 95% of the time.

5.3.1 Bendix® SafetyDirect®

Bendix® SafetyDirect® is a telematics system that collects safety data and video. This system collects transmits data from the vehicle to the carrier in real time. This system allows fleet managers to identify driving trends, analyze safety critical events, and develop appropriate driver training based on the telematics data. We were not able to obtain information on the cost of this technology or degree of market penetration.

5.4 Driver Monitoring Systems

Previous research has identified driver fatigue and driver inattention as major contributors to rollover accidents. Drowsiness detection technology and/or lane-departure warning systems (LDWSs), both of which are intended to alert a driver before the vehicle is at great risk of leaving the road or the intended path, should help to reduce rollovers. We discuss lane departure warning systems in the context of collision mitigation (see below).

Driver monitoring technology can monitor a variety of driver behaviors such as eye closures, head movements, and driver inputs regarding steering, braking, and throttle to help assess fatigue.

A variety of driver monitoring technologies are on the market today. The following sections will summarize a few of those technologies. Because we were able to thoroughly discuss DriveCam with Lytx®, we have the most information about that technology. We briefly summarize a few others as well.

5.4.1 Lytx® DriveCam

Lytx® DriveCam is a telematics system with two cameras, one of which records the road and the other the driver. It captures four 4 seconds before and after a critical safety event. The system will send risky driving data (fast corners, hard braking, off nominal G-forces, and speed limit discrepancies) to the carrier as a teaching tool. The inward-facing camera captures driver distraction, drowsiness, and other human factors. The outward-facing camera captures road conditions and the position and behavior of other vehicles

When the video is triggered, a blinking light alerts the driver. The system independent, and does not require pre-existing telematics. It can integrate with existing active safety systems that indicate forward collision warnings and lane departure warnings to provide other risky driving data.

Lytx® provides two types of DriveCam technology, DC Enterprise SM and DC Protect SM. DC Enterprise SM collects and sends data from all trucks in the fleet. DC Protect SM is a comprehensive safety program collects and sends data from all trucks in the fleet. It combines predictive analytics, reporting, and prioritization of cases to help fleet management monitor and coach drivers on performance to prevent collisions.

DC Protect SM collects and sends data from the riskiest 20% of drivers. Lytx monitors the data and updates the carrier on the riskiest 20% of drivers each month. The other 80% of drivers still have videos recorded but the system does not actively send them to Lytx. Data can be retrieved within a few weeks of an event.

This technology is optimized for lean fleet operations with fewer than 350 power units and low insurance deductibles. Some insurance companies may subsidize the cost of DriveCam. Others may offer percentage discounts on insurance premiums.

The manufacturer suggested to us that some drivers dislike this technology due to the inward-facing cameras, because some companies use data from the cameras punitively, not for teaching. A survey done by Lytx® and FMCSA indicated that more than half of drivers have a negative opinion of the technology at first, but after 6 months, only 20% of drivers still have a negative opinion. Drivers eventually seem to appreciate the benefits of the technology (for example, drivers appreciate that the technology helps to corroborate their side of the story in the case of crash). Data from the outward-facing camera can also serve as proof during liability/legal disputes.

The DriveCam service package costs about $50.00-$60.00 per month per vehicle. Approximately 90% of carriers renew the service. The market penetration amongst the tank truck industry is high. Tanks are a large portion of the customer base for this technology.

A Lytx® team will provide training to the carriers, walking them through rollout and checking back monthly or quarterly.

5.4.2 Meritor WABCO SmartDrive

Meritor WABCO is partnering with SmartDrive Systems, investing $20 million in 2015 to jointly develop next-generation, video-based analytics solutions for commercial vehicle fleets (http://www.wabco-auto.com/media/media-center/press-releases/press-releases-single-view/news-article/wabco-makes-a-strategic-investment-in-smartdrive-systems-plans-to-jointly-develop-next-generation-s/, accessed 9/21/2016). SmartDrive asserts that it is the only system that has a personalized driver-training program, which minimizes collisions and increases fuel savings. This system uses video and vehicle data to identify critical safety issues. During unusual driving events, the system captures video of the driver in the cab and of the roadway. This video is then paired with data from the vehicle from that same time period. The SmartDrive Review Center then reviews the driving events, categories the data and provides a description of what the driver was doing immediately prior to the event. These analyses are then available to the fleet managers via the Web. This analysis quickly builds a driver performance profile so that training instructors can address the appropriate topics with the appropriate drivers. We were not able to obtain information on the cost of this technology or degree of market penetration.

5.4.3 SafetyDirect® by Bendix

SafetyDirect® by Bendix is a telematics system that collects and transmits safety data and video from the vehicle in real time, which allows carriers to analyze safety critical events immediately. The technology identifies driving trends, which may help develop targeted driver training. Unlike Lytx® DriveCam, this technology does not have an inward-facing camera that monitors the driver, nor are they currently planning to add it in the near future. This technology is smartphone compatible. We were not able to obtain information on the cost of this technology or degree of market penetration.

5.5 Collision Mitigation Technologies

Strictly speaking, collision mitigation technologies address collisions with objects in front of the truck in the same travel lane; they are also called rear-end collision systems. If they detect an object in front of the vehicle, forward-looking systems will try to avoid it by alerting the driver. Alternatively, or if the driver does not respond by braking, they will reduce vehicle speed before the collision to try to decrease the severity of the crash. In this report we are using the term more broadly to describe the array of technologies that, individually, and when bundled, operate to reduce the risk of collisions. It is important to think of these as mitigation technologies, rather than avoidance technologies. They can reduce the potential for collisions, but in many cases, collisions will still happen.

5.5.1 Benefits of Collision Mitigation Technologies

In June 2015, NTSB issued the report of an investigation into rear-end collisions and potential countermeasures (National Transportation Safety Board, 2015). The investigation found that currently available forward collision avoidance technologies for passenger and commercial vehicles show clear benefits that could reduce rear-end crash fatalities. NTSB asserted that more must be done to speed up deployment of these technologies in all vehicle types. As a result of these findings, the NTSB made six new recommendations, including:

- For manufacturers to install forward collision avoidance systems as standard features on all newly manufactured passenger and commercial motor vehicles, and
- For NHTSA to expand or develop protocols for the assessment of forward collision avoidance systems in passenger and commercial vehicles.

These findings notwithstanding, the extent of adoption without an explicit mandate to do so may be limited, in part, by the cost of the systems. Some experts believe that these systems will not be widely adopted in for-hire environments because they are cost prohibitive, but that there may be more aggressive adoption inside private fleets (Beach, 2011).

5.5.2 Types of Technology

The most promising technology-based countermeasures to rollovers and loss of control in CMV driver-related crashes overall (i.e., not focused specifically on tank vehicles) were identified by both the insurance industry and from NTSB investigations:

A 2012 Insurance Institute for Highway Safety (IIHS) study (Jermakian, 2012) concluded that four crash avoidance technologies had greatest promise, individually and jointly, for large truck crash prevention: side view assist for blind spot detection, forward collision warning/mitigation systems (FCWS), lane departure warning (LDWS), and vehicle electronic stability control (ESC).

The 2016 NTSB Most Wanted List included several technologies to improve transportation safety in both passenger and commercial vehicles (National Transportation Safety Board, 2016). The NTSB reported several technologies as proven to improve safety by enhancing drivers' road situational awareness and reduce reaction time: Lane Departure Warning (LDW), Forward Collision Warning (FCW), Adaptive Cruise Control (ACC), Automatic Braking System (ABS) and Electronic Stability Control (ESC). These technologies were targeted especially at the large commercial vehicles (CVs) travelling at highway speeds that require longer stopping distances in any safety-critical incident. The NTSB also endorsed additional technologies to aid CV operators, including tire pressure monitoring systems (TPMS), speed limiters and proximity warning systems. Some of these technologies are discussed briefly below.

5.5.2.1 Lane departure warning systems (LDWS)

Lane departure warning systems (LDWS) are technologies that alert drivers when their vehicle is departing their current lane of travel in the absence of a turn signal. These systems are primarily used on highways and other well-marked roadways; if there are no lane markings the system is inoperable. SAE-J3045_201507 provides a recommended practice for the test procedure for large truck and bus lane departure warning systems (Truck and Bus Lane Departure Warning Systems Test Procedure, 2015). The following sections will provide brief summaries of LDW systems manufactured by a two different. The summaries are a combination of material from the web and from interviews with the companies about their products.

5.5.2.1.1 Bendix® AutoVue® LDWS

Bendix's® AutoVue® LDWS helps combat lane drift due to fatigue, distractions, and bad weather. The system is configured to each vehicle's unique specifications. AutoVue® works both day and night, and in most weather conditions where visibility is limited.

A camera mounted in the windshield detects when the vehicle drifts across a lane marking without using a turn signal and automatically emits a distinctive warning, alerting the driver to make a correction. Warnings can be auditory, haptic, or both. The auditory alert is a buzzer, the volume of which can be adjusted by the driver. The haptic "rumble strip" alert is generated by a motor, which fits into the driver's seat and vibrates when triggered. The driver cannot adjust the haptic feedback levels.

Bendix® noted that some companies prefer to order haptic alerts only because they do long-distance tandem driving. The seat vibration will not wake up the sleeping driver but the auditory alarm will. The driver can turn the system off, but only for a short period of time.

The data generated from the camera are reported back to the fleet via a system called SafetyDirect®. SafetyDirect® is a web-based portal that displays safety information. The portal provides fleet management with the ability to develop targeted training programs to address safety critical issues (see more details below).

We were not able to obtain information on the cost of this technology or degree of market penetration.

5.5.2.1.2 Meritor WABCO OnLane™ LDWS with SafeTraK technology by Takata

Meritor WABCO's OnLane™ LDWS with SafeTraK technology by Takata helps the vehicle avoid unintentional lane drifting by alerting the driver to take a corrective action to prevent potential collisions or run-off-road accidents. The system utilizes a camera mounted near the top center of the vehicle windshield to monitor and calculate the vehicle's position within the lane. When OnLane™ detects that the vehicle is crossing lane markings without the turn signal being activated, the system sounds an audible warning.

The Driver Alertness Warning (DAW) feature detects erratic driving behavior within a lane or unintentionally departing the lane and provides an audible warning sound. If the vehicle is weaving within its lane, the DAW will sound as well as broadcasting the data to the carrier via telematics. The system will only work in highway conditions; the vehicle has to be traveling over 42 mph. The manufacturer told us that the DAW could be haptic or audible. Drivers report some false alarms. Drivers can turn off the technology, but only for about 15 minutes at a time, after which the system reactivates automatically.

OnLane™ includes SmartDrive analytics for driver monitoring (see above). The system costs approximately $800.00 per unit. According to the manufacturer, this technology has penetrated the market less than basic stability control systems. Meritor WABCO predicted that about 10-15% of the OEM tractor market was using LDWS across all manufacturers.

5.5.2.2 Bundled Systems

Adaptive cruise control (ACC) is a system for road vehicles that automatically adjusts the vehicle speed to maintain a safe distance between one vehicle and the vehicle ahead of it (Howard, 2013). A forward collision mitigation (FCM) system detects how far and fast the vehicle ahead is moving, and automatically applies the brakes if the driver does not. In this way, an FCM system works to reduce the chance of crashes and reduces the severity of collisions when they do occur. FCM should not be confused with Forward Collision Warning (FCW). A mitigation system will both warn the driver and slow the vehicle, whereas a warning system will only warn the driver (AAA, n.d.). The following section provides summaries of some bundled collision mitigation products.

5.5.2.2.1 Meritor-WABCO OnGuardACTIVE™

Meritor WABCO's OnGuardACTIVE™ combines a collision mitigation system with an adaptive cruise control (ACC). It measures the vehicle's position in relation to other vehicles, maintaining a 3.6-second interval between the equipped vehicle and the vehicle ahead of it.

The system registers vehicles by one of three classifications:

- Moving – A vehicle currently and continuously in motion in the same direction
- Stopped – A vehicle the radar has registered as moving but is now stopped (e.g., traffic lights)
- Stationary – A vehicle the radar is picking up but has never seen move (e.g., disabled cars)

The system will warn the driver when a possible collision is evident by providing audible, visual and haptic warnings. The visual warning is a discrete visual display that shows following distance. The audio warning is a beep emitted from the dashboard if the driver is going faster than 15 mph and there is an object within a 1.5-second collision zone. The haptic warning is a short, noticeable brake pulse. If the speed differential between the two vehicles indicates an impending collision, the driver will get a visual/auditory warning, then a haptic warning. Then, the brakes will be applies to the power unit and even the trailer in some scenarios. It can apply up to 50% of the vehicle's braking power to help avoid or mitigate a collision in all three categories (above).

The system is always turned on when the vehicle is traveling above 15 mph, even when the cruise control is not set. The driver cannot turn off the system. The adaptive cruise control maintains a set speed in cruise control mode when the lane ahead is clear and automatically adjusts speed to maintain a predetermined following distance when a vehicle ahead is detected. If the ACC is set at 60 mph and the vehicle ahead is at traveling at 55 mph, the system will apply the engine brakes and reset the speed based on the lead vehicle's speed. If the lead vehicle then speeds up or turns out of the traveling lane, the vehicle will resume travel at 60 mph.

This technology costs about $2500.00 per unit. We do not have data on market penetration. Meritor WABCO suggests that this technology helps mitigate driver fatigue on the roadway.

5.5.2.2.2 Bendix® Wingman® Advanced™ and Wingman® Fusion™

Wingman® Advanced™ combines ACC with braking collision mitigation technology (the old Bendix® Wingman® ACB) and the Bendix® ESP® electronic stability control system. In addition, the system can provide data to the fleet.

The Wingman® Fusion™ combines a variety of technologies including Bendix® ESP® Electronic Stability Program full-stability system, Bendix® Wingman® Advanced™ – A Collision Mitigation Technology, and AutoVue® Lane Departure Warning System from Bendix CVS. Wingman Fusion gathers input from radar, video, and the brake system.

We were not able to obtain information on the cost of this technology or degree of market penetration.

5.6 Blind Spot Protection Systems

Blind spot monitoring systems alert drivers when another vehicle is traveling in their blind spot, generally on the sides or in the rear of the vehicle. An example of this technology is described below.

5.6.1 Delphi RSDS

Delphi's Rear and Side Detection System (RSDS) alerts drivers of approaching vehicles when changing lanes or making turns (Delphi Rear and Side Detection System, n.d.). By providing an alert when a vehicle has entered a blind spot to the rear or side of the vehicle, RSDS enables drivers to react to obstacles that may be difficult to see in their mirrors. The vehicle manufacturer determines the alerts, which can be auditory chimes or visual indicators shown on the side mirrors. When the vehicles turn signals are in use, the audible alerts can be deactivated.

RSDS combines a variety of features in addition to blind spot detection. For example, the system provides lane change merge assist, which helps to mitigate unsafe lane changes by monitoring other vehicles that are passing in adjacent lanes. Rear cross traffic alerting detects objects on the sides of the vehicle and detects approaching vehicles when backing out of parking spaces. Finally, the rear pre-crash sensing feature detects potential rear-end collisions, working with other available features on the vehicle to help avoid the collision.

We were not able to obtain information on the cost of this technology or degree of market penetration.

5.7 Effectiveness of Advanced Safety Technologies in Preventing Tank Vehicle Rollovers

Advanced safety technologies for heavy commercial motor vehicles have the potential to reduce the number and severity of crashes. These technologies can accomplish a reduction in crashes by alerting the CMV driver to hazardous situations and by intervening directly to alter the speed or direction of the vehicle. In this section, we discuss what effect safety technology can be expected to have on the incidence of tank truck rollovers, including hazmat-transporting vehicles.

5.7.1 Rollover Characteristics

Our analysis of a sample of hazmat tank vehicle rollovers occurring in the 2011-2014 timeframe (refer back to 4.5.3 for more details of results), along with related data, yielded a number of observations regarding their characteristics:

- 77% of rollovers occurred on straight roads; only 20% occurred while the vehicle was negotiating a curve.
- 66% of rollovers involved driver error. Of these, 50% were performance errors, most often poor directional control or overcompensation.
- 19% of rollovers were caused by a driver in another vehicle.

In the sample of rollover accidents we analyzed, 94% of the tank vehicles that rolled did not report any form of advanced safety technologies on board. Taken on its own, this statistic could be interpreted to mean that if these safety technologies had been installed, rollover could have been prevented. However, when taking into account our data concerning rollover contributing factors, advanced safety technology capabilities and advanced safety technology market penetration, this conclusion is not well supported.

We discuss the potential impact of the various technologies on rollover accidents in light of these considerations below.

5.7.2 Stability Control Systems

We are not able to state definitively whether ESC will make noticeable impact in the incidence of tank truck rollovers. However, while systematic data are sparse, carrier experience, reported anecdotally, has been positive.

Broadly speaking, ESC is intended to prevent rollovers that occur on curved roadways, including entrance and exit ramps, when excessive speed is a factor. In NHTSA's recently issued regulation requiring ESC technology on new tractors manufactured after August 1, 2019 (Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles, 2015), the agency states:

> In 2018, we expect that, without this rule, about 34 percent of new truck tractors and 80 percent of new buses affected by this final rule would be equipped with ESC systems. We believe that, by requiring that ESC systems be installed on the rest of truck tractors and large buses, this final rule will prevent 40 to 56 percent of untripped rollover crashes and 14 percent of loss-of-control crashes. As a result, we expect that this final rule will prevent 1,424 to 1,759 crashes, 505 to 649 injuries, and 40 to 49 fatalities at $0.1 to $0.6 million net cost per equivalent life saved, while generating positive net benefits.

However, the studies cited by NHTSA in support of this Final Rule were conducted on conventional tractor-trailers, not tank vehicles.

The scope of the current study was too limited to enable us to fully investigate the effectiveness of this technology through discussion with the manufacturers. Meritor WABCO informed us that it has tested its technology on closed courses with tank vehicles to demonstrate effectiveness; this information is promising, but we have not had an opportunity to review the data.

The few carriers we spoke to, all of whom implemented RSC and ESC years ago, were unequivocal in their belief that the technology has dramatically reduced rollovers. The following anecdotal examples are paraphrased from our discussions with carriers:

- Since they were installed around 2006-2007, rollover devices have "drastically reduced" our rolls unless there was soft soil. They have proven their worth.
- We have not had a rollover on a truck equipped with both RSC and ESC since we installed them in 2006. We have had rollovers (on trucks not equipped with these technologies), and we are working toward having the equipment on the entire fleet.
- Stability control systems slow the driver before the tipping point. We also have collision avoidance, blind spot, LDW, etc. Our last rollover was in 2013. Before that – 2010. We attribute (this safety record) it to the combination of stability control systems and the critical event reporting systems to manage those types of incidents.

While these reports from these three carriers are highly positive, there is an element of selection bias on our part in effect here. Our primary reason for selecting these particular companies to contact was that they are known for their outstanding driver training programs. They select exceptionally suitable driver candidates, train them in the specifics of safe tanker operation, and monitor their performance for the purpose of corrective retraining—all of which suggests that their drivers are surrounded and influenced by a strong safety culture. Because driver performance errors are a major contributor to rollovers, we cannot solely attribute the positive experience of these companies to the effects of the safety technology.

The fact that this technology is mandated on all tractors manufactured after August 1, 2019, means that with time the technology will be almost universally adopted. The rate of adoption will be dependent upon the carrier's decision that it should, or must, replace an existing power unit. The current marginal cost for ESC ranges between $1100 and $2500 per tractor, so smaller carriers may be slower to adopt it.

As noted above, only about 20% of the rollovers in the current dataset occurred on curves (curved roads or entrance/exit ramps). Consequently, even with universal adoption of ESC and universal effectiveness, this particular technology is not a panacea.

We suggest that advanced safety technologies other than ESC may be required to address the contributing factors in the remaining 80% of rollovers.

5.7.3 Other Advanced Safety Technologies

A challenge in accurately identifying the human factors contributing to rollovers is the possibility that the information the driver provides the officer at the scene may not be entirely factual – particularly when fatigue and distraction are the true contributors. As we reviewed the rollover cases in this study, we often felt that a right- or left-lane-departure rollover that occurred on a stretch of straight road at normal speed, and was either a straight run-off or the result of sudden overcorrection, could be due to either or both of those factors. However, without the officer at the scene explicitly reporting the involvement (or noninvolvement) of fatigue and distraction, we were unable to confirm this hypothesis.

Focusing on the observable behaviors of poor directional control and overcorrection does suggest that lane departure warning systems, especially those with enhancements that alert the driver to the fact that the vehicle is weaving within-lane, could make a substantial difference of reducing rollover incidence by 15% to 20%.

In the case of the 19% rollovers in which another vehicle was the contributing factor, blind-spot detection systems and forward collision mitigation systems could also play a valuable part in rollover reduction. Again, the marginal cost of such systems will limit their rate of adoption.

5.7.4 Beyond CMV Advanced Safety Technologies

The new mandate for electronic recording devices to manage Hours-of-Service reporting may in its own right help to reduce the rate of rollovers that result from driver fatigue due to HOS violations.

The increasing market penetration of advanced safety technologies in the low- to mid-priced automotive market may also improve the conduct of those vehicles in relation to CMVs. The safety impact of driverless car technologies around CMVs was outside the scope of the current study.

6. Advanced Training Technologies

This section provides information about the relevant progress in the areas of computer-based and simulation-based training for commercial tank drivers. The information in this section serves as an update to a corresponding section in the preceding 2007 report. Therefore, only research published after 2007 is included here.

6.1 Computer-Based Training

Computer-based training (CBT) is “any course of instruction whose primary means of delivery is a computer” (Rouse, 2011). Research on the prevalence of CBT in professional driver training is limited, though it is believed to be increasing as both the availability and capabilities of computers increase.

6.1.1 Connectivity

The average Internet connection speed has increased steadily since 2007. Akamai (2015) reported that the average connection speed has almost tripled, from 3820 kbps in 2007 to 11,127 kbps in 2014. Faster Internet connections facilitate the use of CBT features such as games, video files and real-time visual communication during training.

The number of people in the United States with access to the Internet has also increased over the last several years. There were 22% more Internet users in 2014 than there were in 2007 (Internet Live Stats, 2015). An increase in Internet users means that online training content training is more accessible. As Internet access increases, web-based training can be a more effective means of delivering training.

The growth in Internet users is likely, in part, a product of the increasing portability and affordability of devices that can access the web—19% of U.S. adults use a smartphone data plan for Internet access (Smith, 2015). At the time of the 2007 report, tablets and smartphones had not been introduced; recent surveys indicate that 42% of American adults own a tablet (Zickuhr & Rainie, 2014) and 64% own a smartphone (Smith, 2015). Ownership of these devices will likely continue to rise as their prices continue to drop (Richter, 2014). The pervasive use of portable electronic devices that can access the web illustrates the relevance and potential of web-based computer training, as well as the need for CBT to be compatible with a variety of devices.

6.1.2 Advances in CBT

The CBT offered to hazmat/tanker drivers has progressed since 2007, taking advantage of the trends described above in the Connectivity Section. Research on the prevalence of CBT in professional driver training is limited; anecdotally, it appears to be increasingly common as both the availability and capabilities of computers increase.

Training providers like JJ Keller are offering tablet-compatible programs that incorporate video streaming, interactive games, and collaborative platforms to trainees. Compared to training in 2007, the training content available now appears to be more comprehensive and customizable. Providers are offering a-la-carte content in addition to a full, specialized on-line curriculum. The a-la-carte on-demand videos are available for a wide variety of commercial driving topics, including a host of Hazmat/Tank specific videos. This feature allows trainees to focus of topics that are most relevant to their training needs.

Post- 2007 research in CBT has focused on the efficacy of CBT games, suggesting that interest in using computer-based games as training tools has increased. The concept of “serious games” refers to the use of interactive digital technologies for training and education (Raybourn, 2008). A 2011 meta-analysis examined the effect of training games on knowledge levels. Results indicated that individuals who were trained using a game retained 9% more information, learned 11% more factual knowledge, and 14% more skill-based knowledge than those in the comparison group (Sitzman, 2011)

Progress has also been made in developing customized, “smart” game-based learning environments. Niehaus & Riedl (2009) developed a method for adapting a game scenario in order to achieve an individual’s specific objectives. The authors suggest the ability to customize scenarios may increase the efficacy of computer-based learning and improve learner engagement.

6.2 Simulation

As simulation technology advances, the use of simulators as instructional tools has become increasingly popular. A study by Morgan et al. (2011) spoke to the user reception and cost of simulator use in training. Results indicated that drivers had a positive opinion about simulator-based training, and that simulation is more cost effective than conventional behind the wheel training. The authors also point out that training costs are expected to continue to decrease as cost of simulators decrease.

6.2.1 Simulator Fidelity

Simulator fidelity has been a popular area of study in the years following the 2007 report. Simulator fidelity refers to the amount of realism in the simulation. A literature review by Goode, Simon, and Lennon (2013) outlines a study conducted by Allen et al (2007) testing the effect of simulator fidelity on crash rates. Three levels of simulator fidelity were used to train participants: a single monitor simulation, a three-monitor simulation, and a highly realistic vehicle simulation. Accident data was obtained two years after the study. Results showed that as simulator fidelity increased, crash rates decreased; participants that were trained using the highest fidelity simulator had the lowest crash rates.

Research by Phillips and Morton (2015) also focused on simulator fidelity, comparing the physical and behavioral fidelity of four simulators that represented a range of fidelity and cost. Simulators with high physical fidelity –motion and higher degrees of freedom (DOF) —demonstrated high behavioral fidelity. High fidelity simulators were also likely to provide good estimates of mean speeds in typical engineering applications such as roundabouts and roadway treatments designed to moderate drivers' speed. A detailed analysis of both physical and behavioral fidelity suggests the need to carefully assess the match between simulator features and the properties of the roadway design.

Another study by Freeman et al. (2015) looked at the use of a fixed-base simulator as a training tool for handling situations where a vehicle runs off the road. This study validated the simulator's ability to prepare drivers to handle dangerous run off the road events. In addition to its contributions to supporting simulator fidelity, this study also addresses a need identified by the HMCRP Report OO7 (Pape, Murray, Abkowitz, & Fleming, 2012) where drivers lamented that training often addresses situation avoidance, rather than action, if a critical situation suddenly arises.

While plenty of research points to the benefits of high fidelity simulation, it is noteworthy that low-fidelity simulation also has advantages, and is still superior to training without any simulator component. A case study reported by Dahlstroma, Dekkera, van Winsen, & Nyce, (2009) points out that high fidelity simulation is prohibitive in terms of both cost and availability. The authors contend that low fidelity simulation is an effective training resource for developing operators that are resilient to unexpected events.

6.2.2 Simulators and Driver Performance

The effect of simulator training on driver performance was another popular area of study in recent years. The literature review by Goode, Simon, and Lennon (2013) discussed three research efforts in this area. Studies by Diete (2008) and Pradhan et al (2009) used eye trackers to measure the gaze patterns of drivers trained with simulation and non-trained drivers. Trained drivers were more likely to gaze at areas that contain information about hazards.

Morgan et al (2011) tested driver performance under three types of commercial motor vehicle training: CDL-test focused training, behind the wheel training, and simulation training. When tested in a simulator, drivers that received simulation or behind-the-wheel training did better than drivers that receive CDL-test focused training when tested.

6.2.3 Simulator Manufacturers

The 2007 report identified three companies that manufacture and sell commercial truck and bus training simulators in the United States: Doron, FAAC and L-3. The following sections outline the upgrades these three companies have made to their simulators since 2007, as reported by company representatives. Two additional simulation companies are also discussed below: Virage, a Canadian company that entered the US market in 2010, and AplusB Software, a company that recently released scenarios designed to prevent cargo tank truck rollovers. In general, these five companies reported upgrades such as better graphics, higher resolution screens, additional motion for increased realism, interactive programs afforded by apps on portable electronic devices, and customizable packages for customers.

Some of the companies below report the capability to simulate a liquid weight shift (e.g., slosh and surge). However, conversations with these companies indicated that their available simulation software might not use robust probabilistic data that can fully emulate the behavior of liquid in a cylindrical container during a given scenario.

6.2.3.1 Doron Precision Systems

Doron reports that they have made many changes to their truck driving simulators since 2007, both in technology and curriculum. Interactive computer generated imagery with high-resolution graphics has replaced film based training. Hundreds of driving scenarios with varying traffic densities are available, from light to very heavy. Intrusion of another vehicle into the immediate path of the training vehicle can also be simulated.

Doron simulation training now includes drivable vehicles with realistic vehicle dynamics to increase realism, making simulator operation feel more like that of an actual vehicle. An optional 3 DOF motion base provides additional realism to Doron simulators. The capability for 3 DOF motion lends itself well to vehicle dynamics that can simulate weight shift of liquid materials while driving. When simulated liquid weight shift occurs, the driver receives feedback through both motion base movement and visual presentation.

6.2.3.2 FAAC

FAAC indicated their heavy vehicle training has seen improvements in multiple areas since 2007. The After Action Scenario Review (AASR) features resynchronized live video and audio playback, enabling real-time instructor and classroom review opportunities. A new training environment, Safety City, is now in use. This environment uses the latest in graphics technology to deliver a vivid training environment. Simulators are now outfitted with higher resolution displays and more realistic motion. The company has also made use of tablets, integrating an app that allows the instructor to remote control the simulated scenario. Lastly, a new advanced scoring system keeps a record of training performance, allowing the instructor to forecast future performance and adjust the training accordingly for each individual.

6.2.3.3 L-3

L-3 has made extensive upgrades to their main truck driving simulator line since 2007, including their tank truck simulation. Motion fidelity has increased. L-3 offers a vocational specific simulation through their sensory package, which simulates the unique visual and surface driving conditions faced during specific job functions (e.g., conditions consistent with snowplow driving). New physics have also been added to simulate either liquid or solid cargo. A new mobile training fleet has also been deployed as a showcase or a means of temporary simulator use. In addition to these simulation changes, L-3 has noted a shift in their market since 2007. Instead of just the simulation platform, customers are requesting comprehensive packages that include a simulator, curriculum, and e-learning tools.

6.2.3.4 Virage

Virage has been providing truck simulators to public truck driving schools, private schools, and fleets in the U.S. since 2010. Their simulators provide realistic simulation of the non-synchronized truck transmission, large visual displays and motion systems. They have a library of training scenarios meant to address a variety of skills, from simple skills for new drivers to complex skills for more advanced training. Most Virage simulators have motion built-in. Their specialized tank-truck simulators offer a rollover prevention training program and the capability to simulate the amplified lateral force that occurs when a tank truck's center of gravity shifts. While this simulation does not claim to model the physics of slosh and surge in the tank, it does give the trainee an awareness of the slosh/surge phenomenon.

6.2.3.5 AplusB Software

AplusB produces the SimuRide Professional Driving Simulator. This simulator provides haptic feedback to the driver, applying resistance to the steering wheel while turning and producing tremors when the vehicle hits a curb or shoulder. Simulated sound recreates the sounds of road conditions and the engine based on speed. In 2015, AplusB introduced a special vehicle and training scenario to address the issue of cargo tank rollovers. This scenario uses speed, tank fill percentage and turn radius as variables that contribute to rollovers. The company's website contends that more than 78% of tank rollovers involve driver error, explaining why they decided to develop this feature to teach drivers about the factors associated with rollovers.

7. Training Regulations, Gaps, and Recommendations

Operating a hazmat tank vehicle safely requires specialized knowledge and skills beyond those needed to operate a basic semitrailer. In a tank vehicle, liquid nature of the cargo allows for very little room for error in handling. To operate safely, a tank vehicle driver needs to be able to accurately anticipate how the tanker will behave in a wide variety of situations. These range from commonplace situations such as stopping, turning, and travelling on curves, to less frequent, higher risk, situations such as skids and avoidance maneuvers. All of these situations require a different approach to driving the tank vehicle. The specific behavior of the tank also depends on the properties of the liquid cargo; the extent to which it will slosh and surge under various conditions will depend on its viscosity as well as on the extent to which the tank is filled.

The focus of this study is on the human factors that contribute to rollover incidents involving tank trucks transporting hazardous materials, and thus on the drivers operating those vehicles. The behavior and decisions by a driver in the moments preceding a rollover are reflective of training and experience, as well as hiring factors (such as prior safety record) that the carrier considered before putting that particular driver behind the wheel.

In this section, we describe the relationship between the training regulations promulgated by FMCSA and those by PHMSA, which share responsibility for ensuring the safe performance of hazmat tank truck drivers. In addition to these federal agencies, other relevant organizations in the regulatory domain are the states and the American Association of Motor Vehicle Administrators (AAMVA), which together implement CDL testing and CMV enforcement under Federal rules. Other important stakeholders include hazmat employers and hazmat employees—specifically, drivers.

Section 7.1 presents the driver training regulations for FMCSA and PHMSA, discusses their relationship, and describes the role of the states in preparing and testing CMV CDL drivers. In Section 7.2 we discuss the attributes and business factors that hazmat tank carriers are likely to consider when taking on a new driver. In Section 7.3 we present information on how, in the context of these regulations, drivers are trained to operate a CMV in general and hazmat tank trucks in particular. The parties involved in training delivery are typically training schools, carriers, and driver candidates. Finally, in Section 7.4 we identify gaps in the training regulations and their implementation; discuss those gaps from a human factors perspective; and present recommendations for regulatory changes to address them.

7.1 Federal Training Regulations and State Implementation

7.1.1 Overview of Cross-Agency Regulatory Framework

Effective training for all individuals with a responsibility for handling hazardous materials in transportation, including CMV drivers holding a CDL, is essential for public safety. The statutory responsibility for regulating hazmat driver training and operational safety is shared between FMCSA and PHMSA. Under their regulations, before an individual can legally operate a CMV to transport hazmat in a tank vehicle for an employer[4], he/she must first learn how to drive a CMV, acquire specialized knowledge regarding tank vehicle operation and the transport of hazmat, and receive training from the employer on proper handling and documentation of hazardous materials.

FMCSA regulations cover basic commercial motor carrier driver knowledge and skills needed in order to acquire the required CDL. They also cover the unique requirements for the specialized operating knowledge needed for tank vehicle operation and hazmat transport, as indicated by acquisition of special Tank Vehicle and Hazardous Materials endorsements. FMCSA delegates the implementation and management of the CDL system, which includes knowledge and skills testing, issuance of learner's permits (CLPs) and licenses, and maintenance of records, to the states. The states' oversight of the model manual specifying information needed for the CDL and endorsements is prescribed in the FMCSA regulations (Test Manuals, 2016).

PHMSA regulations cover the technical and operational training of all hazmat employees, as well as additional requirements specific to the training of CMV drivers in the safe handling and transport of hazardous materials on the nation's roads. PHMSA has assigned to the hazmat employer the responsibility for the systematic training of all individuals (i.e., including but not limited to drivers) who handle hazmat in transportation (Hazardous Materials Training, 2016). The PHMSA regulations explicitly acknowledge the FMCSA training requirements by reference. Thus, the regulations of the two agencies are written to dovetail in support of their related missions. This cross-agency regulatory and implementation framework is detailed below.

7.1.2 FMCSA's Regulation of Hazmat Tank Vehicle Driver Training

The primary mission of FMCSA is to reduce crashes, injuries and fatalities involving commercial vehicles. The agency outlines the rules for safe operations on the nation's roads in 49 CFR, Parts 350 through 399. The FMCSA regulations specify what constitutes safe commercial vehicle maintenance, operation, and driving behavior; assign responsibility for ensuring and enforcing safety; and establish penalties for noncompliance.

FMCSA does not have direct regulatory authority over training entities. Rather, the FMCSA CDL regulations describe what the beginning driver needs to know and do in order to operate a commercial motor vehicle safely—i.e., the knowledge and skills that are the intended *outcomes of training*. These training outcomes reflect an informal consensus established between industry and government over a period of two decades. At present, FMCSA does not require formal training for the CDL; a motor carrier driver may qualify "by reason of experience, training, or both" (General Qualifications of Drivers, 1998).

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[4] The employer may be the driver him/herself, as an independent owner-operator.

Any driver (regardless of the amount or type of training) who has taken and passed CDL written knowledge and behind-the-wheel skills tests that meet the Federal requirements is qualified to operate a CMV (Commercial Driver's License, 2016).

FMCSA also has legal responsibility for setting the formal training standards to achieve these outcomes. However, the process of setting formal training standards, and what they should be, has been somewhat unsuccessful until 2015. [5]

FMCSA issued a Final Rule in December 2016 (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; Final Rule, 2016). This Final Rule is based on the authority of the Motor Carrier Act of 1935, the Motor Carrier Safety Act of 1984, and the Commercial Motor Vehicle Safety Act of 1986 (CMVSA). It also implements Section 32304 of the Moving Ahead for Progress in the 21st Century Act (MAP–21), which requires the establishment of a set of minimum driver training standards pertaining to certain individuals required to hold a CDL. In addition, the Final Rule responds to the March 10 (2015), order of the U.S. Court of Appeals for the District of Columbia Circuit (DC Circuit) that FMCSA fulfill the MAP-21 mandate no later than September 30, 2016.

Under the negotiated rulemaking process, in late 2014 FMCSA established the Entry-Level Driver Training Advisory Committee (ELDTAC), comprising 25 industry stakeholders and FMCSA (Minimum Training Requirements for Entry-Level Driver Commercial Motor Vehicle Operators; Establishment of a Negotiated Rulemaking Committee, 2014). The ELDAC was convened in early 2015 (Minimum Training Requirements for Entry-Level Drivers of Commercial Motor Vehicles: Negotiated Rulemaking Committee Membership and First Meeting, 2015), and rendered its consensus report in June 2015. The training standards set forth in the Final Rule reflect these recommendations [6].

The Final Rule sets forth new training standards for new Class A and Class B CDLs; for the upgrading of the CDL to a higher class (e.g., from a Class B CDL to a Class A CDL); for the Hazardous Materials, Passenger Vehicle, and School Bus endorsements; and for ‘‘refresher’’ training (for CDL holders who have been disqualified from operating a CMV). Details of the Final Rule pertinent to this study are discussed below in 7.1.2.4; their regulatory impact and human factors implications are addressed in 7.4.

When this report was prepared the new Final Rule had recently been issued, but it is not expected to go into effect until sometime in May 2017. The regulations and requirements that are described immediately below are those in place in the December 2016 Final Rule, but may be subject to change following federal review.

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[5] This history is detailed in the FR notice of proposed rulemaking, 81 FR § 11944, starting on pp 11950 through 11954.

[6] Under the rules of procedure adopted by the ELDTAC in its first meeting, “consensus” is defined as “no more than three negative votes” with abstention not to be construed as a negative vote (Consensus Report, June 15, 2015, p. 5).

7.1.2.1 CDL Requirements

The regulations with respect to CMV driver training address both the knowledge and skills required for operation of any commercial motor vehicle and as well as those required for specialized vehicles (Commercial Driver's License Standards; Requirements and Penalties, 2016). With only a few limited exceptions, any individual who operates a CMV in interstate, foreign, or intrastate commerce must have a CDL (Applicability, 2016). FMCSA regulations specify the knowledge and skills that all CMV drivers must demonstrate in order to obtain first a Commercial Learner's Permit (CLP) and subsequently a CDL (Commercial Driver's License Standards; Requirements and Penalties, 2016). In addition, the regulations detail the knowledge and skills (if applicable) required to obtain each of the endorsements that permit drivers to operate specialized motor vehicles.

The basic knowledge and skills that a CMV driver needs to obtain a CDL depend on the vehicle to be operated. FMCSA divides commercial motor vehicles into three for the purpose of licensure and training: A, B, and C classes (Commercial and Motor Vehicle Groups, 2016). Class A consists of tractor-trailers with a GVWR of >26,000 lb. Class B consists of straight trucks with a GVWR of >26,000 lb. Class C consists of small commercial vehicles that do not belong in either A or B but that either are designed to transport 16 or more passengers including the driver, or are used in the transportation of hazardous materials. FMCSA permits a driver who has passed the CDL knowledge and skills tests for a combination vehicle (Class A) to operate a heavy straight vehicle (Class B) or a small vehicle (Class C), provided that he/she possesses the requisite endorsement(s). By the same logic, a driver who has passed the knowledge and skills tests for a heavy straight vehicle (Class B) is permitted to operate any small vehicle (Class C), provided that he/she possesses the requisite endorsement(s).

The CDL is awarded if the applicant successfully demonstrates the required knowledge and skills through testing; the knowledge test is written, but the skills test is behind the wheel. Under 49 CFR § 383.113 (Required Skills, 2016), all drivers seeking a CDL, regardless of vehicle group, must have knowledge and skills in a wide range of areas (See Appendix E for the full list of topics.) These areas encompass not only the basic handling and operation of the vehicle, but also the FMCSA safety regulations (FMCSRs) specified in 49 CFR Parts 350 through 397. These include driver qualifications and disqualification, alcohol and drug use, safe driving of CMVs, hours-of-service regulations, driver and carrier responsibilities regarding vehicle maintenance and inspection, and transport of hazardous materials.

The areas of driver knowledge required by FMCSA for the CDL include several areas of particular relevance to the rollover occurrence and prevention:

- Visual search (including seeing ahead, to the sides, and to the rear, and using mirrors)
- Speed management (including speed and the shape of the road)
- Night driving factors
- Hazard perception (covering road characteristics and road user activities)
- Emergency maneuvers (e.g., how and when to perform evasive steering and off-road recovery)
- The relationship of cargo to vehicle control (for example, weight distribution)
- Hazardous materials (e.g., which hazardous materials require a hazmat endorsement for

transport, and need for specialized training in order to obtain the endorsement)
- Fatigue and awareness (what to do when driving to avoid fatigue, when becoming sleeping, and when becoming ill)

Actual implementation of the testing and licensing system is assigned to the states, with funding and oversight from FMCSA, by the Commercial Motor Vehicle Safety Act of 1986 (Requirement for State Participation, 2015). The regulations implementing the law appear in 49 CFR Part 384 (State Compliance with Commercial Driver's License Program, 2016).

7.1.2.2 The Tank Vehicle and Hazardous Materials Endorsements

In order to lawfully operate certain types of vehicles, a CDL driver must possess an endorsement for each type by passing an additional specialized test (Endorsements, 2016). Drivers who want to be employed as a tank vehicle operator must acquire the Tank Vehicle endorsement. Those who want to operate hazmat tank vehicles must also acquire the Hazardous Materials endorsement.[7] The required topics are listed in Figure 5 and 6 [(Requirements for Tank Vehicle Endorsement, 2016); (Requirements for hazardous materials endorsement, 2016)].

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[7] The driver's CDL shows both the vehicle class (A, B, or C) and which endorsement(s) the driver carries. Hazmat is indicated by H, and tank vehicle by N; if the driver has both endorsements, this is represented as an X.

Tank Endorsement

- Causes, prevention, and effects of cargo surge on tank vehicle handling in relation to stopping distance
- Knowledge of outage requirements for specific liquids when hauling in bulk
- How to check the tank's body, valves, pipes, connections, hoses, covers, and vents for leaks and proper closure
- How much liquid to load to stay within legal weight limits
- High center of gravity and resulting vehicle vulnerability to rollover, especially on curves
- When operating a DOT-specification tank vehicle, the retest and marking requirements
- Effects of road grade and curvature on tank vehicle handling with filled, half-filled, and empty tanks
- Knowledge of required vehicle-specific emergency equipment and proper use of emergency equipment and systems
- Differences in tank vehicle type and construction
- Differences in cargo surge for liquids of varying product densities
- Proper braking procedures for the tank vehicle when it is empty, full, and partially full
- Differences in handling of baffled/ compartmented tank interiors vs. non-baffled motor vehicles

Figure 5. FMCSA Required Knowledge Areas for CDL Tank Endorsement.

Hazmat Endorsement

Hazmat Regulations
- Hazmat table
- Shipping paper requirements
- Marking
- Placarding requirements
- Labeling
- Hazmat packaging
- Hazmat definitions and preparation
- Other regulated material (e.g., ORM-D)
- Reporting hazmat accidents
- Tunnels and railroad crossings

Hazmat Handling
- Forbidden materials and packaging
- Loading and unloading materials
- Cargo segregation
- Passenger carrying buses and hazmat
- Attendance of motor vehicles
- Parking
- Routes
- Cargo tanks
- "Safe Havens"
- Use of equipment to protect the public
- Operation of emergency equipment
- Use of equipment to protect the public

Operation of emergency equipment
- Use of equipment to protect the public
- Special precautions for equipment to be used in fires
- Special precautions for use of emergency equipment when loading or unloading a hazmat laden motor vehicle
- Use of emergency equipment for tank vehicles

Emergency Response procedures
- Special care and precautions for different types of accidents
- Special precautions for driving near a fire and carrying hazmat, and smoking, and carrying hazardous materials
- Emergency procedures
- Existence of special requirements for transporting Class 1.1 and 1.3 explosives

Figure 6. FMCSA Required Knowledge Areas for CDL Hazmat Endorsement.

7.1.2.3 The CLP and Hazmat Tanker Drivers

In May 2011, FMCSA issued a final rule that established new minimum Federal standards for states to issue the CLP (Commercial Driver's License Testing and Commercial Learner's Permit Standards, 2011).

To obtain a CLP, the trainee must first pass the CDL knowledge test. In addition, if (s)he is seeking the N endorsement, that knowledge test must also be taken at that time. The trainee may then only operate an *empty* tank vehicle. The CLP regulation also prohibits the pre-CDL trainee from operating any tank vehicle which previously contained hazardous materials but that has not been purged of any residue. In this final rule (p. 26862), FMCSA explained that "An N endorsement on the CLP with an ''empty'' restriction balances safety concerns with industry needs to train drivers on the type of vehicles they will eventually be driving, but does not allow them to train under cargo-laden conditions until they have learned the basics of operating the vehicle."

7.1.2.4 The Final Rule for Entry-Level Driver Training

Currently, FMCSA regulations list the 20 areas of knowledge (Required Knowledge, 2011) and the skills (Required Skills, 2011) that the CDL applicant must satisfy through successful written and behind-the-wheel test performance in order to obtain the CDL. The assumption underlying these regulations is that passing those tests is satisfactory evidence that the applicant has mastered the required knowledge and skills. The regulations covering the requirements for the various endorsements[8] are based on the same assumption. Training requirements associated with achieving mastery are not specified. The new Final Rule sets forth knowledge and skills training standards for new Class A and Class B CDLs; for the upgrading of the CDL to a higher class (e.g., from a Class B CDL to a Class A CDL); for the Hazardous Materials, Passenger Vehicle, and School Bus endorsements; and for ''refresher'' training (for CDL holders who have been disqualified from operating a CMV).

The Final Rule primarily expands 49 CFR Part 380 (Special Training Requirements, 2016). Any individual wishing to obtain a Class A or B CDL will be required to successfully complete driver training from a provider listed on the newly established Training Provider Registry. That driver training, to be comprised of theory instruction (knowledge) and behind-the wheel range and public road training (skills), must follow the CDL curriculum set forth in 380 Appendix A and B, respectively. The final rule will apply to persons who drive, or intend to drive, CMVs in either interstate or intrastate commerce. There is no required minimum number of instruction hours for theory training, but the training provider must cover all the topics in the curriculum. There is no required minimum number of hours for behind-the-wheel training, but the training provider must ensure that the trainee demonstrate proficiency in performing all required behind-the-wheel skills.

The Final Rule will also result in the creation of 49 CFR 380 Appendix E, which would specify a training curriculum that provides the knowledge required to obtain the H endorsement.[9] As is true for CDL

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[8] For details of the regulations covering each of the endorsements:
49 CFR §383.115 (Requirements for Double/Triple Trailer Endorsements, 2016)
49 CFR §383.117 (Requirements for Passenger Endorsements, 2016)
49 CFR §383.119 (Requirements for Tank Vehicle Endorsement, 2016)
49 CFR §383.121 (Requirements for Hazardous Materials Endorsement, 2016)
49 CFR §383.123 (Requirements for a School Bus Endorsement, 2016)

[9] The Final Rule further specifies training curricula for individuals seeking the Passenger and School Bus endorsements in Appendixes C and D, but the details of these are outside the scope of this study.

theory training, there is no required minimum number of instruction hours, but the training provider must cover all the topics in the curriculum (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; Final Rule, 2016). The Final Rule adds a requirement to the H endorsement in relation to driving tank vehicles: driver trainees must learn rollover prevention methods, including vehicle design and performance considerations, load effects, highway factors, and driver factors.

To create the rule, FMCSA made editorial changes to certain units in the H endorsement curriculum recommended by the ELDTAC. It changed the name of the ''Cargo Tank'' unit to ''Bulk Packages'' and edited the ''Loading and Unloading HM'' unit to more accurately reflect the range of transportation containers addressed in current regulations (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; NPRM, 2016) (p. 11954). FMCSA intends to provide additional post-rule guidance concerning available resources that may be used to supplement the required curricula (p. 11958). These sources, which were identified by the ELDTAC, include:

- The North American Fatigue Management Program (NAFMP)[10]
- Pipeline and Hazardous Materials Safety Administration (PHMSA) basic hazmat awareness[11]
- Training for commercial drivers of cargo tank motor vehicles transporting hazmat that was created jointly by FMCSA, PHMSA, and industry partners, and includes the well-received video (Cargo Tank Rollover Prevention Training Video, 2015).[12]

7.1.3 PHMSA's Regulation of Hazmat Tank Vehicle Driver Training

The primary mission of PHMSA is to protect people and the environment from the risks of hazardous materials transportation. Under federal regulations, *hazardous material* is a substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and has designated as hazardous under Section 5103 of Federal hazardous materials transportation law (General regulatory authority, 2015). The term includes hazardous substances, hazardous wastes, marine pollutants, elevated temperature materials, materials designated as hazardous in the Hazardous Materials Table (Purpose and use of hazardous materials table, 2016), and materials that meet the defining criteria for hazard classes and divisions (Hazardous Materials Program Definitions and General Procedures, 2016). Such materials require special handling in order to be transported in a safe manner.

PHMSA sets rules for hazardous materials training in two parts. The first part comprises rules applicable to all individuals with responsibility for handling hazmat in transportation via all transportation modes (Hazardous Materials Training, 2016). The second part presents additional rules specific to those using highways to transport hazmat, i.e., carriers and drivers (Carriage by Public Highway, 2016). Below we will focus on the training regulations for CMV carriers and drivers.

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[10] For details, see: http://www.namfmp.org.en/

[11] For details, see: http://www.phmsa.dot.gov/hazmat/outreach-training

[12] Video available at: http://www.fmcsa.dot.gov/rolloverprevention

Part 177 sets the requirements for highway transportation of hazmat by private, common, or contract motor vehicle carriers (Purpose and scope of this part and responsibility for compliance and training, 1996). These requirements assign compliance and training responsibilities to the carrier (including connecting carriers). In this context, a carrier *employer* is any person who engages in a business affecting interstate commerce,[13] owns or leases a CMV for that business, or assigns employees to operate it. Similarly, an *employee* is any individual who is employed by a hazmat employer and, in the course of his/her employment, directly affects commercial motor vehicle safety; this includes drivers, mechanics, and dispatchers (Commercial Driver's License Standards; Requirements and Penalties, 2016).

Part 177 states that the CMV carrier is responsible for assuring that each employee involved in the transportation of hazmat is trained, both as required in Part 172 subpart H and in Part 177. The regulation bars the carrier from transporting hazmat unless this requirement is met (Purpose and scope of this part and responsibility for compliance and training, 1996). If an investigation is conducted, FMCSA Safety Investigators may request documentation from motor carriers, including evidence of hazmat training. PHMSA Training Requirements for All Hazmat CMV Drivers

7.1.3.1 PHMSA Requirements for All Hazmat CMV Drivers

The PHMSA regulations (Driver Training, 2015) require hazmat CMV carriers and CMV drivers to comply with the FMCSA CMV CDL driver testing and licensure regulations (Commercial Driver's License Standards; Requirements and Penalties, 2016) and the FMCSA CMV operational safety regulations (49 CFR Parts 390 through 397), to the extent that those regulations apply (Compliance with Federal Motor Carrier Safety Regulations, 2013). That means that the driver must meet three requirements. First, they must have received training in the knowledge (and skills necessary to operate a CMV (i.e., both safe handling and operation the FMCSRs). Second, they must have obtained a commercial driver’s license by passing the (written) knowledge and (behind-the-wheel) skills tests in their state of residence. Third, they must pass the hazardous materials and, if applicable, the tank vehicle endorsement written tests. In addition, the PHMSA regulations call out specific 49 CFR 392 regulations: Hazmat drivers must comply with the FMCSA safe clearance requirements for highway-rail grade crossings (Highway-rail crossings; safe clearance, 2013), and may not “engage in, allow, or require” texting (Prohibition against texting, 2011) or using a hand-held mobile telephone (Using a hand-held mobile telephone, 2011) while driving.

7.1.3.2 PHMSA Training Requirements for Hazmat Tank Vehicle Drivers

PHMSA has special training requirements for drivers transporting hazmat in cargo tanks and portable tanks with a capacity of 1,000 gallons or more. 49 CFR 177.816(b) specifies that training must cover special tank vehicle handling characteristics (Driver Training, 2015), including:

- Operation of the tank’s emergency control features
- High center of gravity, fluid load subject to surge, effects of surge on braking, characteristic

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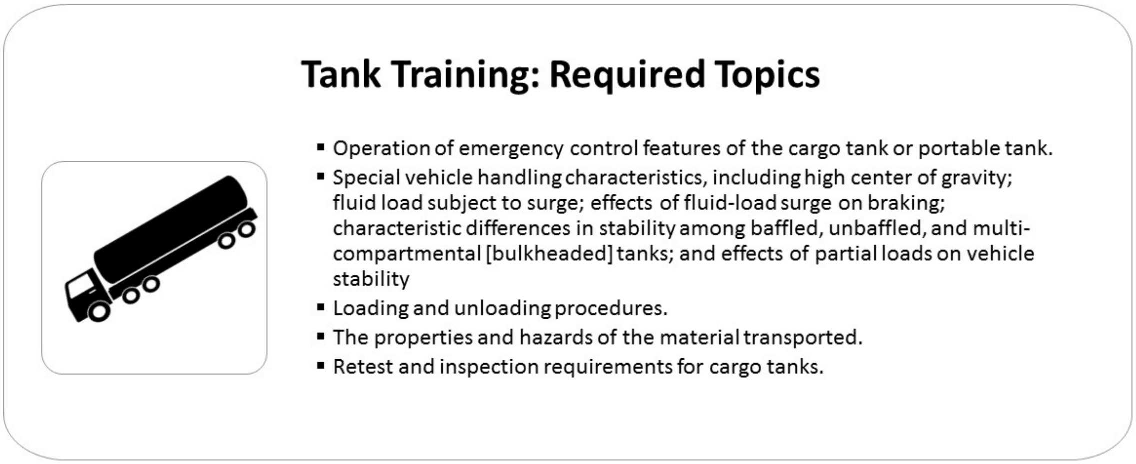
[13] This definition explicitly excludes Federal, State, and local government employees.

differences in stability among baffled, unbaffled, and multi-compartmental tanks, and effects of partial loads on vehicle stability

- Loading and unloading procedures
- Properties and hazards of the transported material
- Re-test and inspection requirements for cargo tanks.

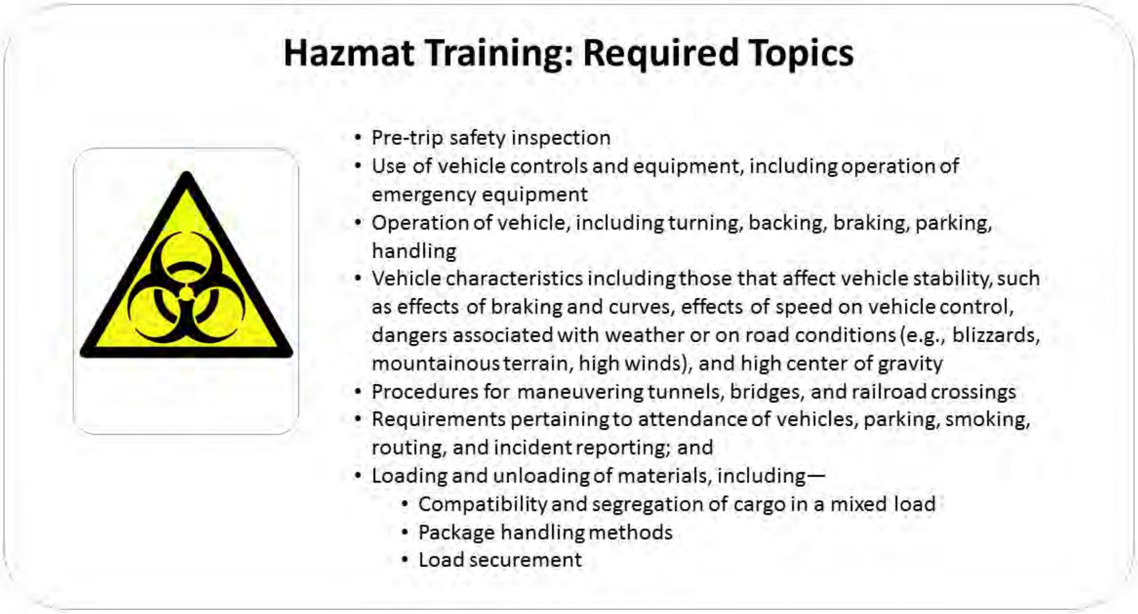
PHMSA has required specialized hazmat driver training topics, including those for drivers operating tank vehicles, shown in Figure 7 and Figure 8.



Tank Training: Required Topics

- Operation of emergency control features of the cargo tank or portable tank.
- Special vehicle handling characteristics, including high center of gravity; fluid load subject to surge; effects of fluid-load surge on braking; characteristic differences in stability among baffled, unbaffled, and multi-compartmental [bulkheaded] tanks; and effects of partial loads on vehicle stability
- Loading and unloading procedures.
- The properties and hazards of the material transported.
- Retest and inspection requirements for cargo tanks.

Figure 7. Summary of PHMSA Tank Vehicle Driver Training Requirements.



Hazmat Training: Required Topics

- Pre-trip safety inspection
- Use of vehicle controls and equipment, including operation of emergency equipment
- Operation of vehicle, including turning, backing, braking, parking, handling
- Vehicle characteristics including those that affect vehicle stability, such as effects of braking and curves, effects of speed on vehicle control, dangers associated with weather or on road conditions (e.g., blizzards, mountainous terrain, high winds), and high center of gravity
- Procedures for maneuvering tunnels, bridges, and railroad crossings
- Requirements pertaining to attendance of vehicles, parking, smoking, routing, and incident reporting; and
- Loading and unloading of materials, including—
  - Compatibility and segregation of cargo in a mixed load
  - Package handling methods
  - Load securement

Figure 8. Summary of PHMSA Hazmat Driver Training Requirements.

All of the above required training may be satisfied by compliance with “the current requirements for a CDL with a tank vehicle **or** hazmat endorsement” (Driver Training, 2015).

7.1.3.3 PHSMA Recordkeeping Requirements

Recordkeeping of training is an essential employer responsibility. The employer must create and retain a record of each hazmat employee's training, inclusive of the preceding 3 years. This record must contain the employee's name; the most recent training completion date; a description, copy, or location of the training materials; the name and address of the person providing the training; and certification that the hazmat employee has been trained and tested as required by this subpart. The employer must retain the training record for as long as the hazmat employee is with that employer and for 90 days thereafter (Training requirements, 2015).

7.1.4 The Role of the States in Implementation of Training and Licensure Regulations[14]

FMCSA regulates state implementation of CDL requirements by setting standards for the information provided to CLP and CDL applicants, for the states' establishment and management of the CDL Program, and for the testing of applicants. The state also has responsibility for the quality of both state employee and third-party CDL examiners. FMCSA regulations describe the methodology and standards for content, administration, and scoring of the CDL knowledge and skills tests and the additional tests required for special endorsements. In doing so, FMCSA seeks to assure comparability of the state CDL programs while providing the states with sufficient flexibility to accommodate local policies. [15]

State maintenance of the licensure process, according to the prescribed standards, involves several responsibilities. States must assure that applicants have been provided with information on the licensure system and the knowledge and skills they will need to acquire in order to obtain the CDL and special endorsements. States must assure that the applicants meet FMCSA's eligibility criteria. States must assure that tests are fairly administered and scored. Finally, states must assure accurate test outcomes and prevent fraud through the process of properly screening, training, and supervising all individuals associated with the testing and recordkeeping. These individuals include but are not limited to the test examiners.

Founded in 1933, the AAMVA represents the state and provincial officials in the United States and Canada who administer and enforce motor vehicle laws. Because all states are represented in AAMVA, this organization provides the structure needed to produce model documentation to enable state

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[14] This discussion does not address the Motor Carrier Safety Assistance Program (MCSAP) or state roadside enforcement and inspection.

[15] In the early 1970's the CDL Program (49 CFR parts 383 and 384) did not exist. Thus, there were no federal restrictions that prevented a driver from operating a vehicle ≥26,000 lb. without demonstrating minimum knowledge and skills. In states that did have a classified licensing system, the driver candidate was not skills-tested in a representative commercial vehicle. As a result, many drivers were operating large commercial motor vehicles that they may not have been qualified to drive. Additionally, because there was no tracking of existing licenses, there was no systematic method for preventing drivers from obtaining multiple licenses from multiple states. With passage of the Commercial Motor Vehicle Safety Act of 1986 (CMVSA), and subsequent implementation of the CDL Program and its supporting information system (CDLIS), these issues were addressed.

compliance with the FMCSA regulations. AAMVA's programs encourage uniformity and reciprocity among the states and provinces. It is a tax-exempt, nonprofit organization developing model programs in motor vehicle administration, law enforcement and highway safety. The association also serves as an information clearinghouse in these areas, and acts as the international spokesperson for these interests (American Association of Motor Vehicle Administration, n.d.). The CDL Program is a nationwide effort to ensure that only qualified commercial drivers receive and maintain CDLs and to remove unsafe and unqualified drivers from our highways (Administration, American Association of Motor Vehicle, n.d.). AAMVA has prepared and periodically updates the CDL Test System's Model Commercial Driver Manual, Model CDL Examiner's Manual, Test Item Summary Forms, and Requirements Document for use in Developing Computer-Generated Multiple-Choice CDL Knowledge Tests.

FMCSA reviews and approves the originals and revisions of each of these documents and provides them to all State Driver Licensing Agencies. At the time this report was written, the above documents are dated 2005, with revisions approved by FMCSA in July 2010.

FMCSA requires (Test Manuals, 2016) that the state must provide each CLP or CDL applicant with an FMCSA-pre-approved driver information manual comparable to the most recently approved AAMVA *CDL Test System Model Commercial Driver Manual* (American Association of Motor Vehicle Administrators, 2010).

The sections of the model manual most relevant to the training of hazmat tank truck drivers are:

- *Section 1: Introduction* covers commercial driver license tests, driver disqualifications, and other safety rules.
- *Section 2: Driving Safely* contains most of the essential knowledge and safe driving information that all commercial drivers should know (45 pages).[16]
- *Section 3: Transporting Cargo Safely* addresses the additional essential knowledge and skills associated with inspecting cargo, cargo weight and balance, securing cargo, and cargo needing special attention (including dry bulk, but not liquid) (3 pages).
- *Section 5: Air Brakes* covers air brake system parts, dual air brake systems, inspection, and use (10 pages).
- *Section 6: Combination Vehicles* provides the minimum information needed to pass the tests for combination vehicles (tractor-trailer, doubles, triples, straight truck with trailer); drivers seeking the endorsement for doubles and triples must also study Section 7, below. 6.1, Driving Combination Vehicles Safely, talks about avoiding rollovers, the "crack the whip" effect, and jack-knifes, but only with regard to box trailers (11 pages).
- *Section 8: Tank Vehicles* covers checking for leaks; driving safely by taking high center of gravity

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[16] The Section 2 topics are vehicle inspection, basic vehicle control, shifting gears, visual search and using mirrors, communicating with other drivers and pedestrians, managing space between and among vehicles, speed control under various conditions, recognizing and anticipating hazards, districted driving, aggressive drivers and road rage, night driving, driving under foggy, wintry, and hot weather conditions, railroad-highway crossings, mountain driving, driving emergencies, antilock braking systems, skid control and recovery, accident procedures, fires, defensive driving, use of alcohol and drugs, staying alert and fit to drive, and hazardous materials rules.

and the danger of surge into account; baffled vs. unbaffled tanks; loading and maintaining an outage; braking; handling curves; stopping distance; and avoiding skids and jackknifes (3 pages).
- *Section 9: Hazardous Materials* extensively covers the regulations and their intent; bulk tank and bulk packaging loading, unloading, and marking; driver responsibilities; driving and parking rules; communications rules; and handling of various emergencies (21 pages).
- *Section 11: Pre-Trip Vehicle Inspection Test* provides a detailed list and instructions for all aspects of internal and external vehicle inspection (8 pages).
- *Section 12: Basic Vehicle Control Skills Test* describes (with diagrams) the exercises on which the driver may be tested, and explains scoring (5 pages).
- *Section 13: On Road Driving Test* describes where the driver will be tested (e.g., intersections) and the behaviors the examiner will watch for in each instance (3 pages).

All of the states have manuals that are adaptations of the AAMVA model manual. A Volpe comparison of the manuals issued by California (State of California Department of Motor Vehicles, 2014-2015), Illinois (Illinois Office of the Secretary of State), Massachusetts (Massachusetts Department of Transportation Registry of Motor Vehicles), Pennsylvania (Commonwealth of Pennsylvania Department of Transportation, 2014), and Washington state (Washington Department of Licensing, 2014) found essential comparability of the contents. [17] The state may include any additional state-specific information related to the CDL testing and licensing process. Section 1 in the four manuals showed the greatest content variation, reflecting local policy priorities and state-specific regulations.

7.1.4.1 CDL Knowledge Tests

State-administered CDL tests must be able to establish that each applicant has the required knowledge and skills for the license or endorsement he/she is seeking (Test Methods, 2016). AAMVA maintains a database of questions, from which the state generates an instrument for the applicant. The state method of generating the pool of questions must be comparable to the requirements outlined in AAMVA's *CDL Test System Test Item Summary Forms.* Among the requirements is that each test must contain a set number of questions with a prescribed number of questions from each of the knowledge areas. Algorithms within the AAMVA system enable the state to satisfy these requirements automatically when generating a test form for the CDL applicant. The state must use a different version of the test when an applicant retakes a previously failed test.

The knowledge test, which comprises 25 questions drawn separately for each applicant from a database, may be administered in written form, verbally, or in automated format and can be administered in a foreign language, provided no interpreter is used in administering the test. The driver applicant must correctly answer at least 80 percent of the questions on the general knowledge or endorsement test.

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[17] These state manuals did vary in their treatment of information needed for the School Bus endorsement. The AAMVA Model Manual notes: "Because state and local laws and regulations regulate so much of school transportation and school bus operations, many of the procedures in this section may differ from state to state" (p. 10).

7.1.4.2 CDL Skills Tests

The state skills tests must be based solely on the content of the driver and examiner manuals. Test administration and scoring must be standardized as described in the examiner manual. The skills tests must take place in a representative vehicle to meet the skills requirements of 49 CFR § 383.111 (Required Knowledge, 2011). Part of the skills tests must take place in on-street conditions. The language of communication during the skills test must be English. Applicants must be able to understand and respond to the skills test examiner in English. The skills test must be administered and successfully completed in the following order: Pre-trip inspection, basic vehicle control skills, on road skills.

To achieve a passing score on each segment of the skills test, the driver applicant must demonstrate that he/she can successfully perform all of the skills and attain the scores listed in the examiner manual for the type of vehicle being used in the test. A driver applicant who does not obey traffic laws, causes an accident during the test, or commits any other offense listed as a reason for automatic failure in the standards contained in the driver and examiner manuals must automatically fail the test (Passing knowledge and skills test, 2016).

7.1.4.3 Endorsement Tests

In compliance with 49 CFR § 383.93(c) (Endorsements, 2016) and 49 CFR § 384.202 (Test standards, 2016), obtaining either the Tank Vehicle or Hazardous Materials endorsement requires that the driver pass only a written knowledge test; there is no behind-the-wheel skills test. [18] The driver should be able to respond correctly to questions addressing any of the required knowledge areas. The test for each of these endorsements comprises 10 questions, drawn from a larger question pool.

7.2 Hazmat Tank Carrier Hiring Practices

PHMSA holds the hazmat carrier responsible for assuring that each CDL hazmat driver they employ has the appropriate knowledge, skills, and capability to operate a tank truck safely. Most carriers want to be careful whom they hire for reasons that are not limited to compliance. The costs of a reportable accident involving a hazmat-carrying vehicle are substantial in terms of possible injury or death, lost property, cleanup, and higher insurance premiums.

The motor carrier industry sometimes struggles to find safe driver candidates. Further, hazmat tank carriers as a whole also struggle, perhaps to an even greater degree, because of their need to find and retain the safest drivers. However, there is very little information generally available on the factors that these carriers actually consider when hiring and training drivers. While tank trucking associations can offer some valuable insights, the tank truck industry resembles the larger heavy-vehicle carrier industry in that the largest proportion of carriers are small, and tend not to belong to these groups.

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[18] Only the endorsements involving the transport of passengers require both a written knowledge test and a behind-the-wheel skills test.

One recent study on the subject sought to obtain information on the range of driver hiring practices among hazmat employers through interviews with a variety of sources, including small and large carriers, private and for-hire fleets, senior executives and drivers, domestic and foreign operations, industry associations, and federal regulatory agencies (Pape, Murray, Abkowitz, & Fleming, 2012). The researchers found that the carriers they examined do not consider hazmat tank truck driving to be an entry-level position. Driving experience requirements vary among carriers, with more specialized carriers typically requiring prior tank truck experience.

The researchers also found that carriers are creative and thorough when screening applicants, including checking social media, pulling personal driving records (in addition to professional), using advanced drug testing methods, and administering competence tests. Lastly, the researchers outlined some characteristics that carriers would use to disqualify an applicant—for example, prior DUI convictions, although some carriers said they might consider the amount of time elapsed since the conviction. The researcher also reported that carriers cited aggressive or reckless driving, a history of speeding, felonies, or an undisciplined lifestyle as potential deal breakers.

Operating a tanker and performing pre-trip inspections are physically demanding. At least one carrier that we spoke to reported that they test physical capabilities of drivers to make sure they can endure the physical demands of tank operation. This testing goes beyond the DOT physical to screen drivers who may be injury prone and those who have balance or dexterity issues.

Our discussions with a very limited number of carriers found that all of them are continuously searching for experienced drivers with excellent safety records, but these are hard to find; driver openings chronically exceed the number of ideal candidates. Consequently, some of our industry contacts are willing to take on drivers who are fresh out of CDL school. Those companies managed the risk of doing so in three ways:

First, by being highly selective about the schools from which they will take candidate. They vet the driving schools beforehand on criteria such as how they teach and the number of hours trainees get behind the wheel. They avoid schools that just give the trainee sufficient miles to get the license.

Second, by having in-house finishing programs. These programs allow carriers to ensure that trainees gain instruction and experience in areas that they did not receive through CDL school alone, in order to ensure that new employees meet the safety standards held by the carrier.

Third, by looking for a particular set of cognitive and personality attributes. Having a clean personal driving record is an obvious prerequisite. An attractive candidate also has to be able to grasp certain aspects of physics, i.e., how valves and components are involved in loading and unloading. A professional demeanor and good emotional regulation are important to these carriers. One carrier we spoke with uses a personality index when hiring. It is not just a screening device for this company; it is used to find out about the individual, and the information is used to teach managers how do deal with people who think in different ways.

Those companies that require driver candidates to have experience may be willing to take those with a solid safety record of hauling regular freight, but others may also want to see a year or more of experience behind the wheel of a tanker. This was consistent with the findings of the study cited above (Pape, Murray, Abkowitz, & Fleming, 2012). One carrier commented that the military is an excellent source of candidates for them. Another looks with particular favor on applicants who have gone through Smith System® collision avoidance driver training [19].

The Safety Managers we engaged at the association conference via teleconference reported that, with some exceptions, none of their employers hires novice CDL drivers. They noted that all CDL drivers know that different tank configurations behave differently, and the fluid dynamics that a driver has to consider pose new and significant challenges. These challenges reportedly deter many CDL drivers from entering the tank industry. When an experienced CDL driver does make the switch to tanks, the safety managers said that carriers typically use *finishing training* to educate the driver—placing him/her with a highly experienced tank driver. Experienced tank driver trainers typically have millions of accident free miles; this extensive experience makes them uniquely positioned to teach the key difference between box trucks and tanks. Note, all of these safety managers reported working for carriers with a fleet size of over 100.

7.3 How Hazmat Tank Drivers are Trained

This section describes the basic path to becoming a CDL driver, and how and why the hazmat driver and hazmat tank driver paths differ from the generic model.

7.3.1 Generic CMV CDL Training in Practice

The training of the generic CMV CDL driver can be thought of as potentially having three segments over time:

1. **Pre-CDL.** Training covers the basic knowledge and skills required under FMCSA regulations to obtain a CDL and legally operate a CMV.
2. **Post-CDL (a.k.a. Finishing Training):** The employer may give new CDL drivers additional behind-the-wheel training to gain experience in dealing with both common and less frequently occurring driving conditions. New hires, regardless of experience, may undergo orientation to company policies and safety culture. Both of these are at the discretion of the employer.
3. **Recurring in-service and/or remedial training.** Provision of such training, as well as content and timing, is at the discretion of the employer.

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[19] For details, see https://www.drivedifferent.com/

7.3.1.1 Pre-CDL

The manner in which drivers receive training prior to obtaining their CDL appears to be highly variable. Pre-CDL drivers have not been systematically studied; therefore our characterization of pre-CDL training presented here is based primarily on conversations with drivers, carriers, and representatives from training programs. There are several ways for individuals who want to become CMV CDL truck drivers of any type obtain training. Most drivers appear to train through formal programs offered by proprietary schools and community colleges; some drivers receive informal training from friends or family; a smaller number of drivers do both (Bartinique & McInnis, 2015). [20] Data have not been collected to estimate the total number of trainees per year or the breakdown across training sectors.

It is not well documented how pre-CDL drivers seeking a formal program today are actually trained. The topics and, to some extent, content are specified in FMCSA's knowledge and skills requirements for the CDL. However, due to an absence of either government or industry mandatory training standards, there has been no uniform approach to pre-CDL driver training,

Current pre-CDL training programs range in length from several hundred hours to less than a week. The reason for the large range in duration of training programs is that such programs vary widely in content. The training methods used; the amount of time spent on specific topics; the proportion of time trainees spend in assigned independent study, in the classroom, and hands-on behind the wheel; and the ways in which schools measure whether the trainee has learned the material are highly variable. Furthermore, a large proportion of new CDL holders appear to leave the industry within the first year. These factors may all affect the trainees' ability to operate a CMV safely, but large-scale, rigorous studies have not been performed to investigate this relationship.

7.3.1.2 Post-CDL (Finishing) Training

Based on our discussions with members of the industry, it is generally acknowledged that novice CDL drivers require some form of post-CDL training. The training necessary to obtain a CDL is insufficient to prepare an inexperienced driver to safely operate a Class A motor vehicle alone. The Professional Truck Driver Institute suggests that an "entry-level" driver is one who has the knowledge to operate a CMV but still needs professional supervision and behind the wheel experience (i.e., loading tankers, load securement, etc.) before they can drive a CMV solo (Professional Truck Driver Institute, 2011). This carrier-provided, behind-the-wheel supervised experience is referred to as finishing training.

Finishing training in the operation of a tractor-trailer is not an FMCSA regulatory requirement. Some carriers provide the opportunity for the novice CMV CDL driver to operate a rig for some period of days or weeks with an experienced mentor. While the trainee drivers, a more experienced driver-trainer rides

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[20] This stands in contrast to training options available 30 years ago and more, when fewer than a quarter of aspiring drivers went through a formal school training program or were trained by their company and/or in the military. Over half got their training informally from family or friends, or through experience on the farm; the remainder learned through a mix of informal and formal options (Bartinique & McInnis, 2015).

along in the jump seat to observe, discuss what the trainee is encountering and how s/he thinks it should be handled, and give feedback. Formal studies have not been conducted on finishing training, so we lack data on the percentage of carriers who actually provide it, the relation of carrier size to investment in finishing, the length of the training, and other important characteristics. No studies have systematically evaluated the effect of finishing training on driver safety performance, carrier ability to retain drivers, or other considerations.

Apart from the mentor/trainee pairing described above, some carriers pair a novice with a second driver in a team driving arrangement. The other driver may or may not be considerably more experienced than the new hire. The degree of the other driver's experience may be somewhat irrelevant, however, because in the team environment, one driver is resting while the other is behind the wheel; consequently, the novice may be operating the rig when the trainer is asleep in the bunk.

7.3.1.3 Recurrent and/or Remedial Training

Carriers may provide drivers with periodic retraining, and/or remedial training. Provisions of such training varies between carriers, depending on factors such as the carrier's size or safety culture. The decision to provide either form of training is reflective of the carrier's safety culture and resources; even small companies may make a commitment to this, allocating resources as a priority. Recurrent training seems to be an important part of maintaining safe, high performing drivers. One carrier even reported producing its own training videos, some of which cover rollovers and tank safety.

7.3.2 Training the Hazmat Tank Driver in Practice

The training path of the hazmat tank driver can be more complicated than the typical CDL training path outlined above. While other CDL drivers only require training in tank vehicle operation, hazmat tank drivers require the additional component of hazmat training.

7.3.2.1 Training to Transport Hazmat

In order to train a driver to safely transport hazmat, the driver must master additional knowledge and skill at each stage of the training process:

1. **Pre-CDL:** In addition to the knowledge in relation to hazmat required for the CDL, training in this segment (typically) covers the required knowledge for the hazmat endorsement. [21]
2. **Post-CDL**: Under PHMSA regulations, the employer **must** provide every new driver, regardless of his/her past experience, with training as a hazmat employee and as a hazmat driver in the safe handling of, and communications regarding, the specific hazmat the carrier transports. Regulations specify the content and timeframe for initial training, as well as recordkeeping requirements. Every time a hazmat driver changes jobs, s/he should receive training from the

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[21] Many pre-CDL trainees obtain this endorsement, but it can be acquired at any time after the CDL.

new employer. Furthermore, regulations specify that training should recur every three years.

Anecdotally, the situation is unambiguous: All training is required and explicitly detailed in each timeframe. Not all carriers are in compliance with these requirements, but the requirements do exist.

7.3.2.2 Training for Tank Vehicle Operation

Training for tank vehicle drivers is quite different from that of conventional freight drivers. This includes tank vehicles drivers that transport non-bulk liquid hazmat.

1. **Pre-CDL:** Virtually all individuals seeking a CDL are required to obtain a CLP by passing the CDL knowledge test before they may undergo behind-the-wheel training and take the CDL skills test. As noted above, a pre-CDL trainee who wants to operate a tank vehicle once s/he has the CDL must also pass the Tank Vehicle endorsement knowledge test to obtain a CLP.

   The trainee may then only operate an *empty* tank vehicle during behind-the-wheel training. FMCSA's reasoning was that this "empty restriction" balances safety concerns with industry needs to train drivers on the type of vehicles they will eventually be driving, but does not allow them to train under cargo-laden conditions until they have learned the basics of operating the vehicle (Commercial Driver's License Testing and Commercial Learner's Permit Standards, 2011). Our research suggests that few training schools actually give trainees behind-the-wheel experience in a tank vehicle, empty or otherwise. Additionally, although the applicant intends to operate a tank vehicle once employed, the regulations for the skills test only require that the driver be tested on a representative vehicle from the same group (Commercial and Motor Vehicle Groups, 2016). Theoretically, the driver candidate could be tested on a conventional truck rather than a tank truck if they are both in the same class.

   One of the training schools we spoke with had access to a tank vehicle, a rarity among schools as reported by Safety Mangers, Training Associations, and the schools themselves. This school had two tank trucks in their fleet that they used to train students interested in working for a tank carrier, but all students have the opportunity to drive the tanks. The school reported that they fill the tank partially with water and allow the students to operate it on a large driving range. In earlier years, instructors would take students out on the road with the tanks; this practice stopped due to state rules prohibiting drivers from pulling cargo in a tank until they have passed a skills test. Such restrictions about behind the wheel training have led the school to consider purchasing a simulator. The interviewee from this school noted that, while behind the wheel experience in a tank and simulation help, being a safe driver is the most important characteristic of a tank driver.

   A second training school did not have a tank truck in their training fleet. The school reported that their curriculum covered all of the information required to pass the N and H endorsements, however most of their drivers do not go on to the tank industry. One of the primary reasons for this was geographic location: the school indicated that tank carriers seem to be somewhat collocated. Therefore, schools will invest in tanks when students and tank carriers demand more extensive tank training. For financial reasons, this school also did not own a simulator; the school reported that three box trucks could be purchased for the price of one simulator.

2. **Post-CDL:** If the newly hired driver does not have tanker driving experience, the employer **may** provide hands-on training to operate a tank vehicle. However, there is no regulatory requirement for it. Doing so is entirely discretionary; therefore, it becomes a business decision. As noted above, some hazmat tank carriers do hire freshly minted CDL; in that event, this would be finishing training. The fact that many new hires may have over-the-road experience, but not in a tank vehicle, means that hands-on tank vehicle training in this segment cannot be thought of as “finishing” in the conventional, immediately-post-CDL sense. New hires, regardless of experience, may undergo orientation to company policies and safety culture.

3. **Recurring in-service and/or remedial training:** Again, whether to offer this, the content, and timing are discretionary business decisions because there are no regulatory requirements for them.

7.3.2.3 Post-CDL Carrier Training Policies and Practices

Carriers may tie their training policies directly to their hiring policies. In the sample of carriers we interviewed, all new hires undergo several days of training in the company’s policies and safety culture, regardless of their level of experience.

One of the key factors in training a driver safely drive a tank truck is giving them the feel for how differently a tank truck behaves because of surge and slosh. For carriers willing to hire drivers without tanker experience, whether experienced or newly licensed, the first step in training is introducing how a tank truck handles. However, the way carriers provide this experience varies between carriers. One carrier we spoke with starts the recruit off on a simulator to get the feel of a tank truck. Another carrier has the new hire ride along while an experienced driver trainer takes the loaded vehicle through a variety of conditions and talks with the trainee about what vehicle behavior can be expected. After this introduction to tank vehicle handling, the trainee may start hands on training by operating a tank vehicle in the yard for basic maneuvers. Following this introduction, the next step in training is pairing the recruit with a seasoned hazmat tank driver in the jump seat for over-the-road experience. The trainee gets coaching from an expert under a variety of driving conditions to understand how driving a tanker is different from driving a conventional semi.

Training may also cover rollover prevention training. Three of the companies we spoke with had been involved in the creation of the PHMSA/FMCSA Rollover Prevention Training Video and use it for both initial and recurrent training. One carrier was unfamiliar with it, but once directed to it, told us that it was excellent and would be incorporated into company training activity.

Training in the management side of the job is also essential, including skills like how to look at the work assignment, how to use any telematics or communications systems, and how to log hours of operation. Just as important is exposing the novice to the lifestyle and providing coaching in the skills needed to cope with it: time management, including where and when to take breaks; where to stop for fuel; where to eat; staying in touch with family; and getting adequate rest.

It is not surprising that these carriers all engage in recurrent and remedial training. With regard to recurrent training, one carrier talked about working with drivers on fatigue:

> The most important thing about fatigue is knowing the symptoms of fatigue and recognizing them. If you can’t remember the last exit you passed, or what highway you’re on, you need to know you’re fatigued. Get fresh air in the cab, always have water in the cab, apple or apple slices – more refreshing than coffee. Get your eyes moving to get your brain active. But don’t think you’re wide-awake. As soon as possible, find a safe place to pull over and sleep.

This carrier also talked about the importance of involving the driver’s entire family in ensuring that the driver is able to sleep during the hours off-duty, and making the driver aware of the situational factors that prevent quality sleep (for example, going to bed with the TV on, or letting children climb into the bed).

Training may also involve the advanced safety technologies present in the truck. The same carrier that likes to hire drivers who have already had Smith System® collision avoidance training provides Smith System® training for those new hires who have not. These carriers build in a human factors perspective:

> We have safety people who do ride-alongs with the guys. We index a number of behaviors– speed index, customer complaints, near misses. If these become an issue we’ll call him in and ask what’s going on. One guy was having a problem at home. You can’t discount what happens when he’s NOT at work. It has so much impact on how he acts on the job.

All of these carriers employ telematics and advanced safety technologies that enable their managers to spot potentially risky driver behavior. The data are treated as an opportunity and tool for training and correction.

7.4 Regulatory Gaps, the Human Factors Perspective, and Recommendations

Our review of the shared regulatory framework leads us to conclude that there are a number of gaps, some of which are due to limitations posed by current FMCSA regulations. It would benefit the hazmat tank carrier industry (and the public) for PHMSA and FMCSA to collaborate in addressing these gaps if not already in progress.

In reviewing the relevant regulations, we have made a distinction between the state of regulated training to transport hazmat on the nation's highways and that of regulated training to operate a tank vehicle safely. The reason for this distinction is that the regulation to transport hazmat appears to us to be logically structured and well documented. In contrast, the regulation of tank vehicle training may be insufficient.

Competency regarding cargo tank rollover prevention is required by the Final Rule in order for a driver to obtain the H endorsement, but it is not required for the N endorsement (81 FR 88732, December 8, 2016, p. 11980). The Proposed Rule appears to leave the Tank Vehicle endorsement requirements (49 CFR 383.113, 2016) as currently written. Under the Final Rule, the CDL knowledge and skills and four of the six endorsements--Longer Combination Vehicles, Passenger, School Bus, and Hazardous Materials--will all have mandatory training standards and curricula. The Tank Vehicle endorsement will be without them.

The addition of tank vehicle rollover prevention training to the required curriculum for the hazmat endorsement is a significant improvement in preparing hazmat tank vehicle drivers to operate safely. While some large hazmat carriers have extensive and thoughtful finishing programs for newly hired hazmat tank drivers without tank vehicle experience, we do not know what other hazmat tank carriers do to prepare such new hires for safe operation—notably, the smaller carriers. The Small Business Administration defines a small business in the trucking industry as one with annual revenues under $25.5 million (Federal Motor Carrer Safety Administration, 2012). This roughly equals any company with a fleet size smaller than 150. The majority of carriers in our sample meet this definition of small business. In the rollovers we analyzed, two thirds of them involved tank trucks operated by carriers with a fleet size smaller than 150 vehicles (For details, see 4.5.3.4.1). While 150 vehicles larger than the FMCSA definition of a small fleet, this economic perspective is relevant. Driver training is expensive, both because of the cost of the training itself and because it involves a period of time when the new hire may not yet be hauling billable cargo. For the smaller operator, this can discourage spending money on training. Because financial concerns may dissuade the industry as a whole from providing this training, adding it to the hazmat training curriculum is completely justifiable.

However, not all tank drivers transport hazmat, and not all pre-CDL trainees seeking the Tank Vehicle (N) endorsement also pursue the Hazardous Materials (H) endorsement. Figure 9 depicts the results of pilot study of drivers that had obtained a Class A CDL within the preceding three years (Bartinique & McInnis, 2015). Of the 41 respondents, 26 held an H or N endorsement, but only 11 of the 26 (42%) had both. The vast majority of drivers holding the H endorsement also had the N endorsement, but the reverse was not true; just under half the drivers with the N endorsement also had the H endorsement.

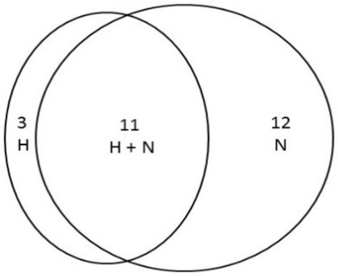

Figure 9. Distribution of H and N Endorsements in a 2015 Pilot Study. Reprinted from “A Second Look: Commercial Motor Vehicle Driver Work and Compensation Pilot Study of Methodologies for Surveying CDL CMV Drivers,” (draft) by I. Bartinique & C. McInnis (2015). FMCSA.

While these survey data are only preliminary, they suggest that as many as half of tank vehicle driver trainees will not receive the benefits of the rollover prevention training to be offered through the new hazmat endorsement curriculum.

The fact that a CDL driver who obtains only the Tank Vehicle and not the Hazmat endorsement would not receive the benefit of mandatory standards and curriculum raises concerns. Our analysis of the characteristics of tank truck rollovers indicated that the percentage of fatalities among non-hazmat rollovers in the 2011-2014 timeframe to have been significantly higher than the percentage among hazmat rollovers (see Table 26. Hazmat vs. Non-Hazmat Involvement in Injury and Fatality). Follow-up study is necessary to replicate this finding and further investigate the cause of this difference. However, with the Tank Vehicle endorsement regulations left unchanged, it appears that this population is relatively more vulnerable to rollover, absent the training, with potentially life-threatening results.

Our results also highlight the importance planning for how best to account for an aging workforce. Over the next several years, this industry sector will be facing the dual pressures of the aging out of the existing hazmat driver population, and the continuing shortage of acceptable new candidates. Our research replicate previously reported findings regarding hazmat carrier driver hiring practices indicating that the great majority of carriers prefer to hire drivers with road experience, tank experience, and a clean safety record.

This study was able to investigate a wide variety of situational factors that contribute to rollover. However, very little data was available about the characteristics of the drivers involved: their level of experience, the extent of their pre-CDL training, or other individual differences that would make them poor CMV CDL drivers in any context. Existing data sources were lacking in the details necessary to understand how these factors contribute to rollovers. Nonetheless, we argue that adequate, standardized tank driver training, including, rollover avoidance, would bring the number of non-hazmat rollovers down. Standardized training should be instituted in order to increase the number of qualified new candidates; otherwise, qualified driver candidates with non-hazmat tank experience are unlikely to be considered for hire by hazmat carriers.

7.4.1 Pre-CDL: The Tank Vehicle Endorsement and Related Relevant Topics in the AAMVA CDL Manual

7.4.1.1 The Tank Vehicle Endorsement Chapter (Section 8)

Pre-CDL trainees and CMV drivers who want to obtain the Tank Vehicle endorsement post-CDL must pass the Tank Vehicle endorsement written knowledge test in order to obtain the CLP. Those in training schools may receive some training on the subject in addition to studying the relevant section of the CDL manual; those who do not attend a training school presumably read the material on their own. Section 8 of the AAMVA Manual (American Association of Motor Vehicle Administrators, 2010) is just over two pages—extraordinarily short relative to every other section. Other sections of the manual cover some content relevant to tank vehicle operation, as per FMCSA and PHMSA regulations; the manual advises the reader to study these sections, but does not provide specific direction to key points. Furthermore, our examination of those passages found that many convey accurate information for conventional trailers, but only incomplete information in relation to tank vehicles. To the best of our knowledge, the Tank Vehicle Endorsement focuses its 10 randomly chosen questions only on the content of Section 8. Passing this written knowledge test is not in and of itself sufficient to demonstrate mastery of the content; it is easy to pass the written test after only a brief review of the Section 8 briefly content, and without demonstrating long-term retention after the test is complete. Pre-CDL trainees in particular are likely to have only acquired rote knowledge of the written material rather than its practical application to driving skills, since behind-the-wheel training in a loaded vehicle is prohibited under the CLP regulations.

7.4.1.2 Coverage of Surge and Slosh is Inadequate

The unique behavior of liquid tank cargo is a key factor in rollovers. The PHMSA tank vehicle driver training regulations specifically call out slosh, but make no mention of surge. The FMCSA Final Rule mentions neither slosh nor surge by name.

While the AAMVA manual requires an understanding of the causes, preventions, and effects of cargo surge, there is no discussion of slosh, either explicitly or implicitly. We consider this a critical omission. Several sections (Sections 2, 3, and 8) reference “high center of gravity” and resulting vehicle vulnerability to rollover, especially on curves. However, no distinction is made between the rollover risk due to center of gravity, which applies to all tractor-trailer operations, and the distinct rollover risk unique to tank vehicles caused by the liquid cargo’s sloshing. Nor does the manual describe how high center of gravity is an issue not only on curves, but also in any situation that involves abrupt actions by the driver, such as corrective steering. Drivers studying for the N endorsement are advised to study Section 6 Combination Vehicles.

In Section 6 Combination Vehicles, the AAMVA Manual presents subsection 6.1 Driving Combination Vehicles Safely, and within it, 6.1.1 Rollover Risks. The discussion gives specifics on rollover prevention, but speaks exclusively to the handling of conventional tractor-trailers. Compared to tank vehicles, conventional tractor-trailers have a lower center of gravity and do not have the problem of liquid cargo surge and slosh. This section of the manual should also discuss rollover risks for Class A tanks, and direct the reader to view the PHMSA/FMCSA Rollover Prevention Training Video.

7.4.1.3 Discussion of Cargo in AAMVA Manual Does Not Incorporate Tank Liquid Cargo Differences

AAMVA Manual Section 3 Transporting Cargo Safely, which covers basic knowledge needed by all pre-CDL trainees, has a subsection 3.4 Cargo Needing Special Attention. This subsection discusses the "special care" that dry bulk tanks require because of a high center of gravity, and the tendency of the load to shift. However, there is no parallel discussion of the special handling considerations for liquid cargo in tanks. This is not addressed and remedied in the new Final Rule's Class A CDL curriculum standards.

7.4.1.4 Disconnect: Current PHMSA Hazmat Tank Vehicle Training Requirements

PHMSA states that the required training for hazmat drivers set forth in 49 CFR 177.816 may be satisfied by compliance with "the current requirements for a CDL with a tank vehicle **or** hazmat endorsement" (Driver Training, 2015). The hazmat endorsement in the current regulation does not address special vehicle handling characteristics and the tank vehicle endorsement does not address the properties of the material transported. According to the language in the new Final Rule, the hazmat endorsement will satisfy PHMSA's requirements, but the tank vehicle endorsement still will not.

7.4.1.5 Coverage of Contributing Rollover Factors in the New Final Rule

Our review of crash reports and other supporting information leads us to conclude that poor speed management and driver fatigue are probable contributing factors to rollovers. Excessive speed is clearly identified in police accident reports. Driver fatigue is rarely explicitly identified in police accident reports, but is the most plausible cause for a rollover involving road departure on a straightaway and subsequent overcorrection, especially at night. We therefore examined the language in the new curriculum for *Speed Management*, *Hours of Service*, and *Fatigue and Wellness Awareness* (below).

7.4.1.5.1 <u>Training Curriculum for Speed Management</u>

The current AAMVA CDL Manual speaks to speed management in a few different places. In Section 2 Driving Safely: 2.6.3 Speed and Curves:

> Drivers must adjust their speed for curves in the road. If you take a curve too fast, two things can happen. The tires can lose their traction and continue straight ahead, so you skid off the road. Or, the tires may keep their traction and the vehicle rolls over. Tests have shown that trucks with a high center of gravity can roll over at the posted speed limit for a curve.
>
> Slow to a safe speed before you enter a curve. Braking in a curve is dangerous because it is easier to

lock the wheels and cause a skid. Slow down as needed. Don't ever exceed the posted speed limit for the curve. Be in a gear that will let you accelerate slightly in the curve. This will help you keep control.

In Section 6, Combination Vehicles: 6.1.2 Steer Gently

> **…** Slow down to a safe speed before going into a turn.

In Section 8, Tank Vehicle: 8.3.3 Curves

> Slow down before curves, then accelerate slightly through the curve. The posted speed for a curve may be too fast for a tank vehicle.

The new Final Rule has the following language regarding speed management training curriculum for Class A and Class B CDLs.

In UNIT A1.2.4 SPEED MANAGEMENT:

> This unit must teach driver-trainees how to manage speed effectively in response to various road, weather, and traffic conditions. The instruction must include methods for calibrating safe following distances taking into account CMV braking distances under an array of conditions including traffic, weather, and CMV weight and length.

In UNIT B1.2.4 SPEED MANAGEMENT:

> This unit must teach driver-trainees how to manage speed effectively in response to various road, weather, and traffic conditions. The instruction must include methods for calibrating safe following distances under an array of conditions including traffic, weather and CMV weight and length.

The language in these passages lacks the precision necessary for specific, actionable rules for choosing a safe speed. In particular, this is problematic for a trainee driver, whom lacks the experience necessary to judge for themselves what constitutes a safe speed.

In contrast, the carriers we spoke with offered specific guidance on this point. One said that if the posted speed on a curve is for passenger vehicles, the tank vehicle driver should run 5-10 mph slower if the tank is full; and 10-15 mph slower if pulling a partial load. Another recommended that if a curve has a posted speed of 45 mph for cars and 40 mph for trucks, the tanker should be at 35 mph.

We broached the idea of tanker-specific rollover warning signage with recommended speed for curves and ramps. Our carrier contacts liked the idea very much, one in particular because he thought it would help passenger vehicle drivers understand why the tanker ahead of them was going so slowly.

7.4.1.5.2 Training in Relation to HOS and Fatigue

We reviewed the new standards for hours of service requirements and fatigue and wellness awareness

(Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; Final Rule, 2016) (pp 88795-88799). It states:

UNIT A1.5.3 HOURS OF SERVICE REQUIREMENTS[22]:

> This unit must teach driver-trainees to understand that there are different hours-of-service (HOS) requirements applicable to different industries. The training providers must teach driver-trainees all applicable HOS regulatory requirements. The training providers must teach driver-trainees to complete a Driver's Daily Log (electronic and paper), timesheet, and logbook recap, as appropriate. The training providers must teach driver-trainees the consequences (safety, legal, and personal) of violating the HOS regulations, including the fines and penalties imposed for these types of violations.

UNIT A1.5.4 FATIGUE AND WELLNESS AWARENESS:

> This unit must teach driver-trainees about the issues and consequences of chronic and acute driver fatigue and the importance of staying alert. The training providers must teach driver-trainees wellness and basic health maintenance information that affect a driver's ability to safely operate a CMV.

UNIT B1.5.4 FATIGUE AND WELLNESS AWARENESS:

> The issues and consequences of chronic and acute driver fatigue and the importance of staying alert will be covered in this unit. The training providers must teach driver-trainees about wellness and basic health maintenance information that affect a driver's ability to safely operate a CMV.

Fatigue and Wellness should be covered before HOS, so that the point of the HOS requirements can be established; the standards do not speak to the “why” of the requirements.

The Fatigue and Wellness Awareness standard does not speak explicitly to how to maintain sleep hygiene (for example, things to do to get to sleep and stay asleep; the role of the family). FMCSA intends to recommend that trainers point trainees to the North American Fatigue Management Program, although this is not mentioned in the Final Rule (NAFMP)[23] (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; NPRM, 2016) (p. 11958)

Instructors should view the NAFMP resource in advance of covering this section so that they can emphasize why trainees should use it and trainees can involve their families. Furthermore, the existing resources are PowerPoint presentations; the resource could be improved with the addition of video

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[22] UNIT B1.5.3 uses this same language, so it is not reproduced here.

[23] For details, see http://www.nafmp.com/en/

content with live industry peers in order to make the content more salient and memorable for this audience (an example of the alternative format is the Railroader's Guide to Sleep[24]).

7.4.1.6 *Prescribing Post-CDL Tank Vehicle Driver Training is Legal but Complex*

Based on FMCSA's explanation for training pre-CDL tank vehicles only on vehicles with empty tanks, it is clearly implicit that FMCSA expects industry to train drivers post-CDL on the safe operation and handling of tank vehicles. However, data are not readily available to understand how carriers do this, or even whether they do it at all.

Industry sources told us that few hazmat carriers hire CMV drivers fresh out of CDL school to drive hazmat. The main tank carrier industry association is made of up carriers with fleets of 100 or more vehicles, and is able to speak for that membership. However, as with the box freight industry sector, the majority of hazmat tank carriers are small operations. Without an association representing these smaller carriers, we lack a central source to speak to hiring standards in this cohort.

While we do not know the details, nonetheless new CDL drivers who want to drive tanks are apparently either being hired, whether by small hazmat tank operations or perhaps more likely by non-hazmat carriers to transport water, milk, or solid non-hazmat bulk cargo. There is little information on finishing practices, if any, in this industry sector.

Given that post-CDL training of tank vehicle drivers is not regulated, and that there is neither a model nor required curriculum for employers to follow, does this have an impact on safety? We know that such drivers have rollovers, some involving fatalities or serious injuries. This population may be relatively disadvantaged in terms of safety training without a curriculum, be it model or mandatory.

The currently required Tank Vehicle endorsement requirements were created by FMCSA to represent the *outcomes* of training. However, FMCSA has not set any standards for such post-CDL training to guide carriers on what to provide or how to provide it.

MAP–21 requires DOT to regulate entry-level driver training. It charged Congress to develop training standards for the Hazardous Materials and Passenger endorsements. FMCSA extrapolated this latter charge to include the School bus endorsement (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; NPRM, 2016) (p. 11950):

> FMCSA believes that, since Congress recognized the importance of entry-level training in the operation of passenger vehicles by including the P endorsement within the scope of the MAP–21 mandate in section 31305(c), the inclusion of the S endorsement-training curriculum in the NPRM is entirely consistent with that mandate.

However, FMCSA did not follow that logic in relation to the H endorsement in order to create a training

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[24] For details, see https://www.railroadersleep.org/

curriculum for tank vehicles. It may not have done so because of the definitions of Entry-Level Driver and Entry-Level Training developed by the ELDTAC. We suggest that the unique circumstances of the lack of practical tank vehicle driver training pre-CDL create a population that are, by default, also entry-level drivers. Using the language of the ELDTAC, this group would be defined approximately as follows:

> ***Entry-Level Tank Vehicle Driver*** means 1) a person who must complete the tank vehicle endorsement requirements under 49 CFR 383.119 before receiving the CLP AND who must complete the CDL skills test requirements under 49 CFR 383.71 prior to receiving the initial CDL; **OR** 2) a person who holds a CDL, or has had a CDL reinstated, and must complete the tank vehicle requirements under 49 CFR 383.119 before obtaining a tank vehicle endorsement.

FMCSA stated that its authority to set training standards for the Hazardous Materials, Passenger, and School Bus endorsements is based primarily on 49 U.S.C. 31136(a)(1), requiring regulations to ensure that CMVs are ''operated safely,'' and secondarily on section 31136(a)(2), requiring that regulations ensure that ''the responsibilities imposed on operators of commercial motor vehicles do not impair their ability to operate the vehicles safely'' (2015). The new final rule enhances the training of entry-level drivers to further ensure that they operate CMVs safely and meet the operational responsibilities imposed on them (Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators; Final Rule, 2016).

We believe that this same argument supports the development of a curriculum for the training of CMV CDL tank vehicle drivers.

7.4.2 Recommendations

7.4.2.1 Recommendation 1 (Long-Term): Create a Tank Vehicle Endorsement Curriculum

FMCSA and PHMSA should collaborate to create a tank vehicle endorsement curriculum. Hands-on tank vehicle training, with only rare exceptions, takes place post-CDL and is delivered by individual carriers. Therefore, a challenging policy question is whether this curriculum should be mandatory for all carriers, or instead a model curriculum for voluntary use. As discussed earlier, the cost of having an in-house training program can be prohibitive for a small carrier.

Whether mandatory or voluntary, we believe that a curriculum is necessary and appropriate. It should include guidelines for the use of the PHMSA/FMCSA Rollover Prevention Training Video. We recommend that, as a first step, FMCSA and PHMSA find the means to collaborate on consultation with industry regarding the value, use, and content of a tank vehicle curriculum.

We would like to note that, because the current endorsement requires only a knowledge test, there might be imaginative, relatively low-cost solutions for carrier-led training according to such a curriculum.

This may include free software for download, self-teaching modules, and blended delivery involving downloadable materials augmented by periodic on-line sessions with a class and virtual trainer to address questions and pose situations for discussion.

7.4.2.2 Recommendation 2 (Short-Term): Revise Model CDL Manual Section 8 for Completeness and Specificity

AAMVA should revise the model CDL manual section 8 for completeness and specificity. As discussed above, the model CDL manual does not address tank vehicle considerations at a number of points where it should. At minimum, the content of the Section 8 Tank Vehicle should be updated. The manual should provide the tank vehicle endorsement trainee with material that is both directly accessible in the one section (by pulling material from other sections) and that is unambiguously relevant to tank vehicles (e.g., by editing language that is making a relevant point but only in the context of a box trailer). Recommended behaviors should be specific and, where appropriate, quantified.

7.4.2.3 Recommendation 3: Provide Curve/Ramp Rollover Prevention Signage Specific to Tankers

PHMSA and FMCSA should work with the tanker industry to research the benefits of tank-vehicle-specific rollover prevention signage. Research would be used to support the addition of a recommended speed limit for tank vehicles to be posted on curves and ramps. Furthermore, we recommend that PHMSA and FMCSA explore with industry the possibility of collaborating to determine safe tanker (vs. tractor-trailer) speeds under varying tank load conditions and curve/ramp geometries.

If the tank vehicle industry feedback supports the need for this signage, the two agencies should consider seeking assistance from rollover prevention technology manufacturers, who are likely to have expertise in this area, to determine safe tanker (vs. tractor-trailer) speeds under varying tank load conditions and curve/ramp geometries.

If both conditions are met, we recommend that FMCSA work with MUTCD on the creation of appropriate signage.

7.4.2.4 Recommendation 4: Create Advanced Safety Technology Incentives

PHMSA and FMCSA should work with the tanker industry to develop incentives for advanced safety technology adoption. These systems offer an opportunity to reduce rollovers in a variety of conditions. Lane departure warning systems in particular seem to have the most potential for mitigating tank truck rollovers as many rollovers in our dataset could be attributed to poor directional control (weaving and drifting).

Discussions with advanced safety technology manufacturers revealed that market penetration for these technologies is primarily in larger carriers, and market penetration specifically within the tank industry is uncertain. Furthermore, many systems require installation in a new vehicle and cannot be retrofitted to older power units and/or trailers. This suggests that small carriers are likely not adopting advanced safety technologies because they are cost prohibitive. We recommend that PHMSA and FMCSA work to identify incentives that would allow smaller tank carriers to invest in and adopt advanced safety technology.

7.4.2.5 Recommendation 5: Revise 49 CFR 177.816(c)

The Final Rule contains the following language (81 FR 88732, December 8, 2016, [. 88802):

> Unit E1.7 Bulk Packages
>
> This unit must teach driver-trainees the specialized requirements for transportation of cargo in bulk packages, including cargo tanks, intermediate bulk containers, bulk cylinders and portable tanks. The unit must include training in the operation of emergency control features, special vehicle handling characteristics, rollover prevention, and the properties and hazards of the HM transported. Training providers must teach driver-trainees methods specifically designed to reduce cargo tank rollovers including, but not limited to, vehicle design and performance, load effects, highway factors, and driver factors.

We recommend that PHMSA modify the language of 49 CFR 177.816(c) to read:

> The training required by this section may be satisfied by compliance with the requirements for a Commercial Driver's License (CDL) with a hazardous materials endorsement.

Given that the language in Section 380.623(c) (vii) of the NPRM is not included in the ELDT Final Rule, we further recommended that PHMSA modify 177.816(c) to read:

> The training required by this section may be satisfied by compliance with the requirements for a Commercial Driver's License (CDL) with a hazardous materials endorsement and a tank vehicle endorsement.

8. Discussion & Conclusions

8.1 Conclusions

8.1.1 Cargo Tanker Rollovers Changes Over Time

Our comparison of crash statistics from about 10 years ago to data from tanker rollovers (not hazmat specific) that occurred between 2011 and 2014, using the GES database, indicated that although the average number of cargo tank rollovers has decreased since the 2007 Battelle report, there has not been a clear overall downward trend. The number of cargo tanker rollovers, according to the GES data, seems to vary year by year. These findings suggest that although new technologies have been introduced on the market, they are either not effective at preventing rollovers for tank trucks specifically or that there has not been enough market penetration to see their impact. This result also suggests the need for additional research regarding tank truck training. Updated, effective training regulations, once implemented, could result in a consistent downward trend in the prevalence of rollovers going forward.

Our analysis yielded some unexpected results about the types of roadways where cargo tank rollovers have been occurring. The largest proportion of cargo tank rollovers occurred on a roadway that was not divided. Furthermore, the majority of cargo tank rollovers occur on a straight road (away from intersections or junctions); in fact, since the 2007 Battelle report, more rollovers occur on straight roads than on curved roads. Significantly more rollovers involved trucks traveling straight as a last pre-crash movement in our data compared to previous data. These results are of particular interest because they indicate that the problem may not be the roadway type/geometry, vehicle, or environment, but instead, that drivers are rolling over on seemingly simple straight roadways for some reason. These results might implicate distracted driving. Since 2007, smartphone usage has become more widespread. If drivers are distracted by their cell phones while in the cab, they may be inadvertently veering off the road. These results could also implicate fatigue. If drivers are dozing off when driving, their trucks may be drifting off the roadway and rolling over; or drifting off the roadway and being overcorrected due to startle.

Just under half of the cargo tank rollovers involved reported excessive speed. However, this result should be interpreted with caution. Posted speed limits are intended for light vehicles. Cautionary speed limits on curves are intended for tractor-trailers. Neither is intended for tank trucks specifically, which require a more conservative speed limit due to liquid cargo shift. The term excessive speed is ambiguous. Police officers seem to use their discretion when determining what “too fast for conditions” really means on a case-by-case basis. To address this issue, we recommend adding tank truck specific speed limit signs so that cargo tank truck drivers do not have to rely upon incorrect signage.

In our data, the majority of critical events resulting in a rollover crash were driver related, similar to the data reported in 2007. Weather, driver physical impairment, distraction, or obscured vision were rarely identified as a contributing factor; among these, fatigue was most frequent. Our analysis of contributing human factors will address these findings (below).

Finally, the average age of cargo tank truck drivers seems to be greater than it was in 2007, indicating that younger drivers are not entering the industry as much as they used to.

8.1.2 Contributing Human Factors

This research included a detailed analysis of 93 cargo tank rollovers that occurred between 2011 and 2014. We analyzed various elements associated with each rollover focusing on potential human factors contributors. Information from police accident reports (PARs), photographs, witness statements, media articles, and 5800.1 forms were the primary data sources for this analysis. Driver factors were the most frequently identified contributing factor in cargo tank rollovers. Specifically, driver performance errors comprised about half of the rollovers; a large percentage of those types of errors cab be attributed to poor directional control, followed by overcompensation. The second most frequent type of driver error was driver decision error, which in nearly all cases involved the driver going too fast for conditions. Unexpectedly, in two thirds of these cases the drivers were traveling under the posted speed limit. When comparing these data to the safety records of each driver we did not find a relationship between the distribution of driver errors and the driver's number of previous violations. These results suggest that training and safety technology should, at least in part, address unintentional lane departures and appropriate speeds for tank truck operators. These results also indicate that there does not appear to be a pattern of unsafe driving among tank truck operators in our sample; drivers had the same likelihood of rolling over despite whether or not they were involved in a previous crash.

8.1.3 Advanced Safety Technology

Advanced safety technology has become more available and sophisticated over the past decade. Prior to 2007, stability control systems and lane departure warning systems were the advanced safety technologies largely available and in use; driver monitoring technologies were in their early stages. Since then, not only have stability, lane departure warning, and driver monitoring technologies become more sophisticated, but also the range of safety technologies has greatly expanded to include collision mitigation and blind-spot protection systems. Fleet monitoring systems now provide fleets with extensive real-time data to enhance the efficiency of operations and inform training programs. While technologies have advanced since 2007, market penetration for these technologies is predominantly among larger carriers. Cost seems to be the primary factor dissuading smaller carriers from adopting these technologies. In order to encourage wider adoption of these technologies across carriers of all sizes, it may be worthwhile to explore federal incentive programs for companies that install them. The most effective technology for mitigating tank truck rollovers seems to be are lane departure systems, as many rollovers in our dataset could be attributed to poor directional control (weaving and drifting), perhaps the result of distraction or fatigue.

8.1.4 Training

8.1.4.1 Training Regulations

We analyzed the relationship between training regulations, training curricula, training technology, and advanced safety technology, noting gaps that may be compromising safety. Literature reviews, subject matter experts (SME), and stakeholder consultation were used to inform this research. We developed three main recommendations based on regulatory gaps relevant to training. First, we recommend that FMCSA and PHMSCA collaborate to develop a Tank Vehicle Endorsement Curriculum (model or mandatory TBD) that includes guidelines for the use of the PHMSA/FMCSA Rollover Prevention Training Video. Second, we recommend that *Section 8 Tank Vehicle* in the model CDL manual should be redesigned to be less ambiguous. Trainees should be provided with information relevant to tank vehicles accessible in that section rather than having to reference other sections; language that is making a relevant point but only in the context of a box trailer should be deleted from this section. Recommended behaviors should be specific and, where appropriate, quantified. Finally, we recommend that the tanker industry explore the benefits of tank-vehicle-specific rollover prevention signage with recommended speed limits for posting on curves and ramps to determine safe tanker (vs. tractor-trailer) speeds under varying tank load conditions and curve/ramp geometries.

8.1.4.2 Training Technology

Availability and usage of Computer Based Training (CBT) for CMVs has increased over the last decade as well, in part due to the growing availability and of Internet access via home computers and portable electronic devices (smartphones, etc.). Faster Internet connections facilitate the use of CBT features such as games, video files and real-time visual communication during training. Likewise, the availability and use of simulators as instructional tools has also become increasingly more popular over time. A few companies develop tank truck simulators that are on the market today, but it is unclear whether they are capable of simulating liquid weight shift using probabilistic data to accurately emulate the behavior of liquid in a cylindrical container during a given scenario.

8.2 Limitations

8.2.1 Data Availability and Quality

The purpose of this effort was not to recreate the entire statistical analysis of the 2007 report, but rather to determine if there had been any changes regarding the study's observations since then. The 2007 study benefitted from the Trucks Involved in Fatal Accidents (TIFA) database, which was discontinued in 2010. The TIFA database added useful supplemental information to the data from Fatal Accident Reports (FARs). For example, FARs provide additional vehicle data and crash environment details.

In the absence of TIFA data, our richest source of data were PARs. However, PARs are not available for every rollover incident, so the amount and quality of the available data varies between cases. Even when PARs are available, the amount of data provided in each report varies by the law enforcement officer who filed the report and by the various state requirements. Thus, the quality of each incident analysis is dependent upon the availability and quality of the PAR. Incidents with no PAR data lacked the necessary details to analyze the human factors issues associated with the event. Further, cases with PARs that lacked a narrative description and/or diagram of the incident were also difficult to analyze in terms of human factors related to rollovers.

The PARs for some cases were not accessible from PHMSA. This was a limitation since the request process for obtaining PARs varies by state. Each state has different requirements and fees associated with obtaining a past crash report. Obtaining the reports for the missing cases state by state was time consuming and oftentimes required information that we did not have available as researchers (i.e., name of person involved in the accident, name of police officer who filed the report, etc.).

To better understand the precise location of the rollover, we looked up the address of the crash on Google Maps and utilized the street view feature to locate details such as signage, roadway type, and existence of guardrails when that information was not provided on the PAR. Google Maps does not provide street view images for all roadways across the US. We were unable to see certain areas. The images provided by Google Maps may not be from the same timeframe as the rollover. For example, some images on Google were taken in 2015, yet the rollover occurred in 2011. However, we assumed it would be rare to find a roadway configuration completely changed between the time of the rollover and the time of the photo, particularly for such a small dataset.

Another limitation of the current research was the data inconsistencies between data sources. For example, fields reporting the time of day or the weather during the accident are sometimes different on the PAR, the 5800.1, MCMIS, and GES. Data inconsistencies required us to make decision rules regarding the most valid data source for each variable of interest. Ultimately, we cannot be sure which data are accurate and which data are not, so the quality of the analysis is only as good as the data used to complete it.

Finally, the type of data that were available for analysis lacked richness in relation to human factors issues. Most data collected about crashes is descriptive (i.e., weather, road type, time of day, etc.). The majority of the data available explain what happened, where it happened, and to whom it happened. There are very rarely any data available that describe why the accident occurred. In some cases, for instance, we may know that the driver reported being fatigued but we do not know why the driver was feeling tired. Did the driver violate hours of service regulations? Does the carrier have a record of hours of service violations? Is the driver suffering from a medical condition that causes fatigue? There is very limited data available about driver characteristics such driver training information or driver familiarity with the tanker, the type of cargo, or the route. Descriptive data does not allow for an in depth analysis of rollover incidents.

8.2.2 Safety Technology

It was difficult to determine the effectiveness of advanced safety technology for cargo tank trucks because most data available were for tractor-trailer trucks. Most advanced safety technology is not designed specifically for cargo tank trucks, so the impact of this technology on rollover prevention is not entirely clear. Further, because very few of our case studies reported whether or not they had advanced safety technology on their trucks during the time of the accident, and because this data is not captured in GES or MCMIS, it was impossible to look for patterns regarding the presence or absence of that technology and the characteristics of the crash, driver, etc.

8.2.3 Training

Because there is no database that provides a systematic view of the types of training provided to candidate hazmat tank truck drivers, we had to rely upon anecdotal data from industry to describe the current state of training and hiring practices. This is true for the amount, length, content, and quality of training and the type and availability of technology used by training schools and/or carriers during training.

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Appendix A

If yes, provide the Exemption, Approval, or CA number:

red hazardous materials shipment?

Form DOT F 5800.1 (01-2004)

Form DOT F 5800.1 (01-2004) e **2**

pe or Print):

Contact’s Title:

Form DOT F 5800.1 (01-2004)

Appendix B

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

Cargo Tank Motor Vehicle Rollover Study (49 CFR §171.21)

Please provide pictures related to the below sections whenever possible.

☐ Check if picture(s) attached

I. Tank Data

1. **Configuration:**
   a. Check one: ☐ Straight Truck/Bobtail ☐ Combination Tractor/Trailer
   ☐ Straight Truck/Bobtail and Trailer ☐ Other__________
   b. Check one: ☐ Circular Tank ○ ☐ Elliptical Tank ⬭
   ☐ Other__________
2. **Gross Vehicle Weight** (GVW): ______________
3. **Material of Construction** (check one and fill in type):
   ☐ Aluminum (i.e. Ally 5050, Alloy 5454): ______________________
   ☐ Steel (i.e. mild steel, stainless, high strength): __________________________

II. Tank Rollover Protection

1. Description of Rollover Protection Device(s) (i.e., Longitudinal Rails, Tombstone, Box, Roll Pipe):
   ____

III. Accident Data

1. **Rollover Direction** (check one): ☐ Roadside ☐ Curbside
2. **Degree of Rollover**(check one): ☐ 90° ☐ 180° ☐ 270°
   ☐ Greater than 270 ☐ Other
3. **Leak Location** (if applicable):_________ ______________________________________
4. **Damage** (check all that apply): ☐ Side(s) ☐ Top ☐ Front or Rear ☐ Bottom
5. **Damage Extent**:
   - Side: Depth (in inches)___________ Length (in inches)_________
   - Top: Depth (in inches)___________ Length (in inches)_________
   - Heads: Depth (in inches)___________ Length (in inches)_________
6. **Longitude Skid** (in feet): ____________
7. **Ground Condition** (check one): ☐ Shoulder ☐ Road ☐ Ditch
8. **Road Material** (check one): ☐ Gravel ☐ Asphalt ☐ Dirt ☐ Other: ___________

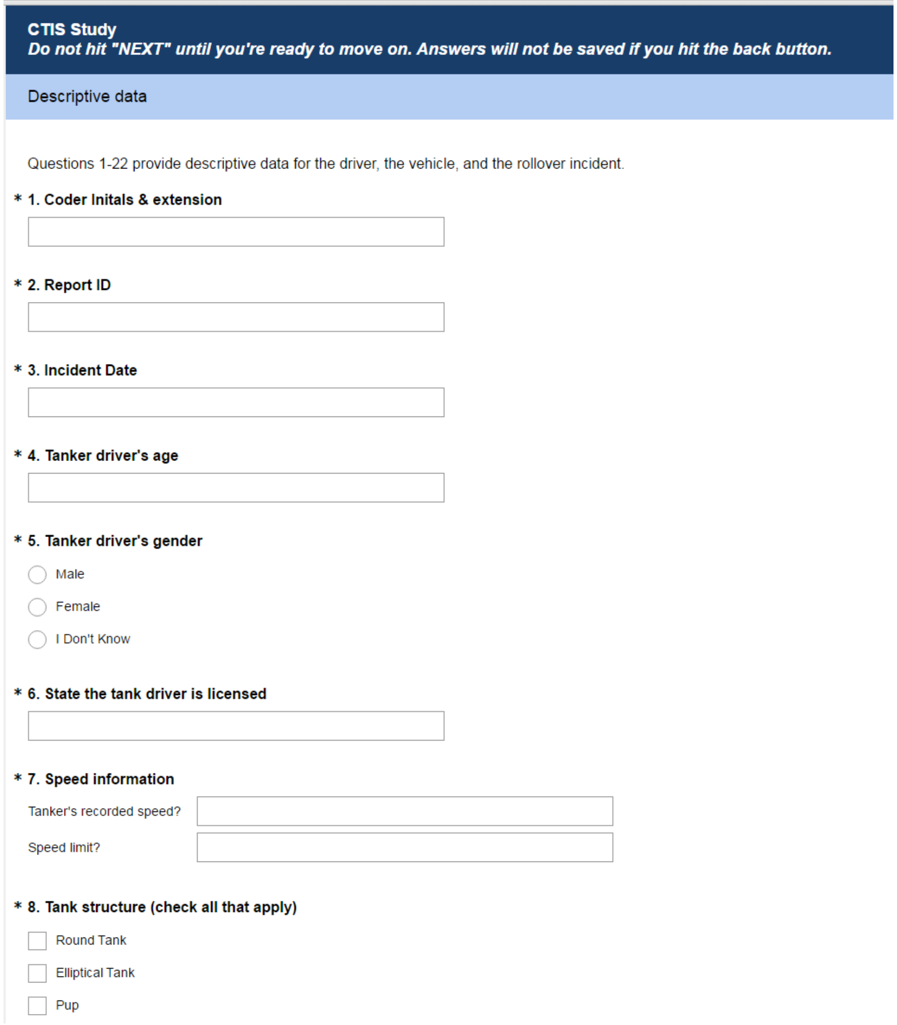
IV. General Information

Please describe the probable incident cause in detail (e.g., Driver took evasive action to avoid vehicle/animal/other; Driver fell asleep; Collision; etc.).

____

____

Appendix C



CTIS Study
Do not hit "NEXT" until you're ready to move on. Answers will not be saved if you hit the back button.

Descriptive data

Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.

*** 1. Coder Initals & extension**

*** 2. Report ID**

*** 3. Incident Date**

*** 4. Tanker driver's age**

*** 5. Tanker driver's gender**

○ Male
○ Female
○ I Don't Know

*** 6. State the tank driver is licensed**

*** 7. Speed information**

Tanker's recorded speed?

Speed limit?

*** 8. Tank structure (check all that apply)**

☐ Round Tank
☐ Elliptical Tank
☐ Pup

Appendix D

CTIS Causal Analysis Codebook
https://www.surveymonkey.com/r/L7TH6FT

Before coding an incident, verify that one of the vehicles was a cargo tanker. Column D in Excel database or question 24 of 5800.1 If the answer is no, skip the coding and make a note for the analysts in the tracking sheet.

WARNING: Do not click "NEXT" to move on to the next page until you're ready. You CANNOT go back. Your answers will be deleted if you try to hit the back button.

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
1	Coder initials & extension	Enter your own initials and 4-digit extension in this box in case we have to ask further clarifying questions.
2	Report ID	Enter 1-3 digit identifier code. *Note: ID can found in Column A of the Excel database.*
3	Incident date	Enter date as YYYY_MM_DD. *Note: date can be found on PAR or 5800.1, question 3.*
4	Tanker driver's age	Age in years. If DOB is given, calculate age. *Note: Remember to subtract from the date of the crash, not today's date. If there was more than 1 driver involved in the rollover, there will be information for D1 (driver 1) and D2 (driver 2). The tanker driver is not always D1 so be careful that you're filling out the information for the correct driver. If you can't find this information enter "no information provided" in the text box.* *Information found in PAR.*
5	Tanker driver's gender	• **Male** • **Female** • **I Don't Know** *Note: Driver gender is located on the PAR (if available) in the driver information section or PAR. If needed, check 5800.1 Part VI narrative for use of pronouns.*
6	State that tank driver is licensed	State abbreviation in which the driver is licensed.

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		Note: State of license is located on the PAR in the driver information section. Sometimes this information will be blacked out. If not provided, entered "not provided" in the text box.
7	Speed Information	• **Tanker's Recorded Speed:** Speed in MPH that the tanker was traveling (or estimated to be traveling) before the incident. If not provided, enter "not provided" in the text box • **Speed Limit:** Speed limit for the road on which the accident took place in MPH. If not provided, enter "not provided" in the text box *Note: Look for speed information in the PAR. If you can't find it there, use the Excel database Column G for estimated (recorded) speed. Alternatively, some carriers provided QUALCOMM data, which contains recorded speed; held in SharePoint folder. Indicate where you found the speed information if it's not straightforward.*
8	Tank structure	Check all that apply • **Round tank** • **Elliptical tank** • **Pup** • **Straight-bore = no baffles** • **Baffled core** • **Multiple compartments/bulkheads** • **I Don't Know** *Note: Tank structure data can be found on the PHMSA follow-up survey, question 1, when available. If you find the information elsewhere (i.e., a photo) please note where you found it. Use I Don't Know when there is no information provided.*
9	Rollover Protection Devices	Check all that apply • **Longitudinal Rails** • **Tombstone** • **Box** • **Roll Pipe** • **I Don't Know** • **Other (please specify)** *Note: Tank rollover protection devices are meant to protect the tank in case of a rollover, NOT to prevent the rollover to begin with.* *Rollover Protection data can be found on the PHMSA follow-up survey, question II.1, when available. If you find this information elsewhere,*

Page 1
Descriptive Data
Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.

		please note where in the tracking sheet. Use I Don't Know when there is no information provided.
10	Advanced Safety Technology	• **Rollover Stability Control (RSC)** • **Electronic Stability Control (ESC)** • **Collision Avoidance Systems (CAS)** • **Forward Collision Warning System (FCWS)** • **Lane Departure Warning System (LDWS)** • **Brake Stroke Monitoring (BSM) and Crash Imminent Braking (CIB)** • **Backup awareness and Blind Spot monitoring technologies** • **Drowsy driver monitoring and warning systems** • **Data Analysis models that produce Driver scorecards, or Fleet risk profiles, or flag safety-critical vehicle maintenance needs (e.g., QUALCOMM)** • **None** • **I Don't Know** • **Other (please specify)** *Note: This data may be found in other paperwork provided by the carrier. It could be found in the PAR, follow-up survey, or 5800.1. Use I Don't Know if the information does not specify whether or not there was advanced safety technology.*
11	Cargo Type	Enter the type of cargo the tanker was carrying (i.e., diesel gasoline) If unknown enter "unknown" If empty enter "none" *Note: 5800.1 Question 14 if not, look on follow-up survey or PAR.*
12	Cargo amount	Enter the amount of cargo that the tanker was carrying (e.g., 8500 gallons). Provide units. If unknown enter "unknown" If empty enter (0 gallons) *Note: 5800.1 Question 27*
13	Cargo capacity	Enter the amount of cargo that the tanker is capable of carrying (e.g., 9500 gallons). Provide units. If unknown enter "unknown" *Note: 5800.1 Question 27*
14	Time of the accident	Enter the time of the incident using the 24-hour clock. (example: if incident took place at 6:30PM, enter 1730). **Do not use a colon.** Use

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		time of police arrival if no accident time is provided. *Note: The time of the accident is on the PAR. If you cannot find it there, look for item #4 on the 5800.1 or Column N in the Excel database. (Eastern, Central, etc. doesn't matter.). Prioritize PAR when there is a discrepancy. Enter I Don't Know when there is no information provided.*
15	Lighting condition at the time of the accident	• **Dark – Lighted**: (dark outside but the road had streetlights) • **Dark – Not Lighted:** (Dark outside with no streetlights) • **Dark –Lighting unknown:** (No information provided regarding streetlights) • **Dawn** • **Daylight** • **Dusk** • **I Don't Know** • **Other (specify)** *Note: This information can usually be found on the PAR or in the Excel database (column J). You may be able to determine this information by looking up the location in Google Maps for streetlights and look up time and date for sunset/sunrise information. Choose I Don't Know when you cannot determine.*
16	Type of road	• **One-way trafficway not divided:** trafficway is undivided and traffic flows in but one direction (e.g., one-way streets), no median. • **Two-way trafficway divided positive barrier:** traffic is physically divided and the division is protected by any concrete, metal, or other type of longitudinal barrier (i.e., all manufactured barriers). • **Two-way trafficway divided unprotected median:** two-way trafficways that are physically divided by an unprotected median (e.g., painted median > 4ft., vegetation, gravel, trees, water, embankments and ravines that separate a trafficway). Raised curbed medians do not constitute a "positive barrier" by themselves and would be included here. • **Two-way trafficway not divided**: trafficway has no median and traffic travels both ways • **I Don't Know** • **Other (please specify)** *Note: Information should be located on the PAR. Also check Excel database (Column H). If information is not provided, look up the roadway that is listed on the 5800.1 (Question 7) using Google Maps to determine road type. Choose I Don't Know when there is no information*

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		provided or when you cannot determine.
17	Ramp details	• **Exit/off ramp** • **Entrance/on ramp** • **N/A** • **I don't know** *Note: Information about whether or not the incident occurred on a ramp will likely be found in the narrative on the PAR (or the diagram). When you cannot determine if the rollover took place on a ramp, enter "I Don't Know." Use Google Maps to clarify confusion.*
18	Guardrail	• **Yes** • **No** • **I Don't Know** • **Other (please specify)** *Note: Information about a guardrail is most likely found in the narrative in the PAR. When you cannot determine if there was a guardrail, enter "I Don't Know." If there was something other than a guardrail (e.g., a jersey barrier), choose Other and specify. Use Google Maps to clarify confusion.*
19	Road surface condition	• **Dry** • **Ice** • **Snow** • **Wet** • **I Don't Know** • **Other (please specify)** *Note: This information can usually be found on the PAR or in the Excel database (column K). Choose I Don't Know when there is no information provided.*
20	Injuries	• **None** • **1 injury: tanker driver** • **1 injury: other driver** • **>1 injury including tanker driver** • **>1 injury not including tanker driver** • **I Don't Know** *Note: Look for this information on the PAR (narrative) first. If you can't find it there, the information can be found in 5800.1, question 34. Choose I Don't Know when there is no information provided. Code as*

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		“yes” regardless of whether or not driver accepts treatment.
21	Fatalities	• **None** • **1 fatality: tanker driver** • **1 fatality: other driver** • **>1 fatality including tanker driver** • **>1 fatality not including tanker driver** • **I Don’t Know** *Note: Information can be found in the PAR (may need to read narrative) and 5800.1 (question 33a). Choose I Don’t Know when there is no information provided.*
22	Number of Vehicles and Vehicle Type	• **One vehicle (has to be a tanker)** • **Two+ vehicles: at least on tanker, one LDV** • **Two+ vehicles: at least on tanker, one heavy truck** • **I Don’t Know** *Note: Information can be found in the PAR (narrative, or by looking at the number of drivers that have information provided in the PAR). One vehicle has to be the tanker, by definition. The other vehicle (when applicable) will either be:* ***LDV:*** *(Light duty Vehicle—under 10,000 lbs.—example: pick-up truck, car, motorcycle) or* ***heavy truck:*** *(over 10,000 lbs.—example: another semi-truck, not necessarily a tanker. Can include delivery vans)* *When another vehicle may have caused the accident but did not crash (or end up on the PAR), it should be coded as a single vehicle accident.* *Choose I Don’t Know when there is no information provided. If you find this information some other way than the PAR, please note that in the coder-tracking sheet.*
Page 2 ***Accident Type*** ***Questions 23-27 provide data about the type of accident and the actions that may have led to the rollover incident.***		
23	Last Pre-crash Movement	• **Going Straight** • **Turning** • **Decelerating in traffic lane** • **Accelerating in traffic lane (suddenly speeding up)** • **Passing or overtaking another vehicle** • **Backing Up**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		• **Making a U-turn** • **Negotiating a curve** • **Changing lanes** • **Merging** • **I Don't Know** • **Other (please specify)** *Note: Last pre-crash movement refers to when things were still going OK (before the critical event). Use turning for when the vehicle is turning from one roadway to another. Turns can be 90 degrees. Using negotiating a curve when there is a bend in the roadway on which the tanker is driving. Use negotiating a curve for exit ramp incidents. Information in PAR, picture is useful, too. Choose I Don't Know when there is not enough information provided to determine the last pre-crash movement.*
24	Single vehicle accidents: Tanker…	• **Control/Traction Loss** • **Left Roadside Departure** • **Right Roadside Departure** • **Succeed in avoiding collision with other vehicle, pedestrian, animal, or other object (but still rollover)** • **Strike pedestrian, animal, or other object and then rollover** • **N/A** • **Other (specify)** *Note: Information in PAR. Use N/A if the incident is a multiple vehicle accident.*
25	Multiple-vehicle accidents: Tanker and V2 were traveling…	• **Opposite directions** • **Same Lane Same Direction** • **Same Trafficway Same Direction (more than one lane)** • **Perpendicular (i.e., at an intersection)** • **N/A** • **Other (please specify)** *Note: Information in PAR. Use N/A if the incident is a single vehicle accident.*
26	Multiple-vehicle accidents: Tanker…	• **Control/Traction Loss** • **Left Roadside Departure** • **Right Roadside Departure** • **Rear End** • **Sideswipe/Angle** • **Accident due to actions of other driver**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		• **N/A** • **Other (please specify)** *Note: Information in PAR. Use N/A if the incident is a single vehicle accident.*
27	Type of rollover	• **Tripped:** When a vehicle rolls over after the **tires** strike a curb, an object in the road, uneven pavement, a pothole, etc. Focus on the tires making the strike, not the truck itself. • **Untripped:** Instead of an object serving as a tripping mechanism for the tires, un-tripped rollovers usually occur during high-speed collision avoidance maneuvers or taking a turn too fast. • **I Don't Know** *Note: Information in PAR (decipher from narrative). Choose I Don't Know when there is no information provided.*
Page 3 ***Specific Critical Event*** ***Questions 28-33 provide data regarding the Specific Critical Event that led to the rollover.***		
28	Vehicle-related loss of control	• **Blow out / flat tire** • **Disabling vehicle failure (e.g., wheel fell off)** • **Non-disabling vehicle problem (e.g., hood flew up)** • **Poor road conditions (puddle, pothole, ice, etc.)** • **Cargo sloshing/surging** • **N/A** • **Other (please specify)** *Note: Information in PAR. "Road" includes paved shoulder. Use N/A when the tanker did not lose control.*
29	Tanker is traveling…	• **Over the lane line of travel lane** • **Off the edge of the road** • **End of road** • **Turning at intersection** • **Crossing over (passing through) intersection** • **Decelerating** • **Accelerating (suddenly speeding up)** • **N/A** *Note: Information in PAR. Use N/A when the above choices do not accurately describe how the tanker was traveling.*
30	Other motor vehicle in lane	• **Other vehicle stopped** • **Traveling in same direction**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		• **Traveling in opposite direction** • **Backing** • **N/A** • **Other ([please specify)** *Note: Information in PAR. Use N/A when Single Vehicle Incident or when incident does not involve another motor vehicle in the lane.*
31	Other motor vehicle encroaching into lane	• **From adjacent lane (same direction) over lane line** • **From opposite direction over lane line** • **From crossing street/driveway, across path** • **From crossing street/driveway, turning into same direction** • **From crossing street/driveway, turning in opposite direction** • **N/A** • **Other (please specify)** *Note: Information in PAR. Use N/A when Single Vehicle Incident or when incident does not involve another motor vehicle encroaching into the lane.*
32	Pedestrian, cyclist, or other non-motorist	• **Pedestrian in or near roadway** • **Cyclist or non-motorist in or near roadway** • **N/A** *Note: Information in PAR. Use N/A when incident does not involve a pedestrian, cyclist, or other non-motorist.*
33	Object or animal	• **Object in roadway** • **Animal in roadway** • **N/A** *Note: Information in PAR. Use N/A when the incident does not involve an object or an animal.*
Page 4 ***Driver Related Errors*** ***Questions 34-39 provide data on driver errors related to the rollover incident.***		
34	Driver decision error	(Check all that apply) • **Too fast for conditions** • **Misjudgment of gap or other's speed (merging decision error)** • **Following too closely to respond to unexpected actions** • **Illegal Maneuver** • **N/A** • **Other (please specify)**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		Definition: Driver decision error--driver makes an error of judgment/chooses to make wrong maneuver. *Note: If incident was not caused by a driver decision error, choose N/A. Use Other when the incident was a driver decision error, but the specific type is not provided as an option above. Specify the error.*
35	Driver performance error	(Check all that apply) • **Startle reaction** • **Overcompensation (overcorrection)** • **Poor directional control (weaving or drifting)** • **N/A** • **Other (please specify)** *Definition: Driver performance error--Driver fails to operate vehicle with skill normally expected* *Note: If incident was not caused by a driver performance error, choose N/A. Use Other when the incident was a driver performance error, but the specific type is not provided as an option above. Specify the error.*
36	Driver non-performance error	(Check all that apply) • **Driver fatigued asleep or drowsy** • **Under the influence of drugs or alcohol** • **Incapacitated by illness** • **N/A** • **Other (please specify)** *Definition: Driver non-performance error--fails to operate vehicle normally/fails to respond to need for action* *Note: If incident was not caused by a driver non-performance error, choose N/A. Use Other when the incident was a driver non-performance error, but the specific type is not provided as an option above. Specify the error.*
37	Driver recognition error	(Check all that apply) • **Internal distraction (specify in text box)** • **External distraction (specify in text box)** • **Failure to maintain Situational Awareness** • **N/A** • **Other (please specify)** • **Text Box entry for distraction type (if applicable)** *Definition: Driver recognition error--Driver fails to perceive need for*

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		decision/action *Note: If incident was not caused by a driver recognition error, choose N/A. Use Other when the incident was a driver recognition error, but the specific type is not provided as an option above. Specify the error.*
38	Driver experience deficiency	(Check all that apply) • **Unfamiliarity with route** • **Unfamiliarity with vehicle** • **Unfamiliarity with load type** • **N/A** • **Other (please specify)** *Note: If incident was not related to driver experience deficiencies, choose N/A. Use Other when the incident was a driver experience deficiency but the specific type is not provided as an option above. Specify the deficiency.*
39	Driver Safety History	(Check all that apply) • **Past crashes** • **Past speeding violations** • **Past HOS violations** • **N/A** • **Other (please specify)** **** SKIP THIS QUESTION FOR NOW (use N/A)** *Note: Must reference driver safety record data from MCMIS for this item. See columns X-X*
Page 5 ***Vehicle Related Factors*** ***Question 40 provides data on rollover factors related to a vehicle failure.***		
40	Vehicle failures	(Check all that apply) • **Tire, wheel, or tie rod failure** • **Brake failure** • **Steering failure** • **Trailer attachment failure** • **Leaking Cargo** • **Vehicle failure– unknown or unable to classify** • **Fire (before crash)** • **N/A** • **Other (please specify)**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		Note: Information in PAR. If incident did not involve a vehicle failure, choose N/A. Choose Other if there was another type of vehicle failure that is not specified above. Please specify the failure.
Page 6 ***Contributing Factors*** ***Questions 41-45 provide data regarding other factors that could be related to rollover incidents (other than tanker driver or vehicle).***		
41	Environment Related	(Check all that apply) • **Signs or signals defective or erroneous** • **Pedestrian on roadway** • **Animal on roadway** • **Object on roadway** • **Inadequate roadway maintenance (e.g., potholes)** • **Designated detour** • **Work Zone** • **N/A** • **Other (please specify)** *Note: Information in PAR. Choose N/A if the incident was not environment related. Choose Other if the incident was environment related but the specific reason is not provided. Specify.*
42	Weather/Visibility Related	(Check all that apply) • **Rain** • **Snow** • **Fog** • **High crosswinds** • **Sudden change in illumination** • **Glare** • **Dust, debris, or smoke aloft** • **N/A** • **Other (please specify)** *Note: Information in PAR (may need to look up a code for this one). Also can be found in Excel database Column L. Choose N/A if the incident was not weather/visibility related. Choose Other if the incident was visibility related but the specific reason is not provided. Specify.*
43	Other Vehicle Induced	(Check all that apply) • **Unable to avoid accident involving others** • **Lane change to avoid oncoming vehicle collision** • **Human error -- driver other vehicle**

Page 1 ***Descriptive Data*** ***Questions 1-22 provide descriptive data for the driver, the vehicle, and the rollover incident.***		
		• **Mechanical failure on other vehicle** • **Same trafficway, same direction: lane change to avoid vehicle attempting to pass** • **N/A** • **Other (please specify)** *Note: Information in PAR. Choose N/A if the incident was not induced by another vehicle. Choose Other if the incident was induced by another vehicle induced but the specific reason is not provided. Specify.*
44	Carrier Information	**Carrier Name** **Carrier DOT Number** **Carrier Headquarter State** *Note: Carrier name, DOT number, and state are in 5800.1 Question 10, or carrier name can be found in the Excel database Column E. Look for Carrier, not Shipper. Verify on PAR if necessary.*
45	Carrier Culture Related	(Check all that apply) • **CSA Unsafe Driving BASIC score ≥ threshold value** • **CSA HOS BASIC score ≥ threshold value** • **CSA Vehicle Maintenance BASIC score ≥ threshold value** • **CSA Drugs/Alcohol BASIC score ≥ threshold value** • **CSA Driver Fitness BASIC score ≥ threshold value** • **N/A** ****SKIP THIS QUESTION FOR NOW. (Use N/A)** *Note: Use Carrier name and DOT number to look up CSA scores. CSA scores can be found by looking up* https://ai.fmcsa.dot.gov/SMS/. Choose N/A when you cannot determine the carrier safety scores.
Page 7 ***Coder comments*** ***Question 46 allows the coders to enter any information that they believe is germane to the analysis that they have not entered elsewhere.***		
46	Comments	Any text that the coder feels is important but wasn't captured elsewhere. Any issues or difficulties when coding. Information the coder wants the analyst to consider.

Appendix E

Table 41. CDL Manual Contents

Section	Title	Contents
1	Introduction	• commercial driver license tests • driver disqualifications • other safety rules
2	Driving Safely	• vehicle inspection • basic vehicle control • shifting gears • visual search and using mirrors • communicating with other drivers and pedestrians • managing space between and among vehicles • speed control under various conditions • recognizing and anticipating hazards • districted driving • aggressive drivers and road rage • night driving • driving under foggy, wintry, and hot weather conditions • railroad-highway crossings • mountain driving • driving emergencies • antilock braking systems • skid control and recovery, accident procedures • fires • defensive driving • use of alcohol and drugs • staying alert and fit to drive • hazardous materials rules
3	Transporting Cargo Safely	• additional essential knowledge and skills associated with inspecting cargo • cargo weight and balance • securing cargo • cargo needing special attention (including dry bulk, but not liquid)
4	Transporting Passengers Safely	• pre-trip inspection of the passenger carrier vehicle • loading passengers and baggage/cargo • safety on the road • passenger supervision • railroad crossing stops • speed on curves • after-trip vehicle inspections • prohibited practices • use of brake-door interlocks

Section	Title	Contents
5	Air Brakes	• air brake system parts • dual air brake systems • inspection • use
6	Combination Vehicles	Provides the minimum information needed to pass the tests for combination vehicles: • tractor-trailer • doubles • triples • straight truck with trailer *drivers seeking the endorsement for doubles and triples must also study Section 7*
7	Double/Triple Trailers	• importance of careful driving (preventing rollovers and the crack-the-whip effect) • coupling and uncoupling • inspecting doubles and triples • checking air brakes
8	Tank Vehicles	• checking for leaks • driving safely by taking high center of gravity and the danger of surge into account • baffled vs. unbaffled tanks • loading, and maintaining an outage • braking; handling curves • topping distance • avoiding skids and jackknifes.
9	Hazardous Materials	• hazmat regulations and their intent • bulk tank and bulk packaging loading, unloading, and marking • driver responsibilities • driving and parking rules • communications rules • handling of various emergencies
10	School Buses	• state and local laws and regulations in relation to school bus operations • danger zones and use of mirrors • loading and unloading • emergency exits and evacuation • student management • antilock brake systems • special safety considerations
11	Pre-Trip Vehicle Inspection Test	• list and instructions for all aspects of internal and external vehicle inspection
12	Basic Vehicle Control Skills	• describes (with diagrams) the exercises on which the driver may be tested • explains scoring

Section	Title	Contents
13	On Road Driving Test	• where the driver will be tested (e.g., intersections) • behaviors the examiner will watch for in each instance