Rollover of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas and Subsequent Fire
Indianapolis, Indiana
October 22, 2009

Accident Report

NTSB/HAR-11/01
PB2011-916201

National
Transportation
Safety Board

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Highway Accident Report

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National
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490 L'Enfant Plaza, S.W.
Washington, DC 20594

National Transportation Safety Board. 2011. ***Rollover of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas and Subsequent Fire, Indianapolis, Indiana, October 22, 2009*****. NTSB/HAR-11/01. Washington, DC.**

Abstract: On October 22, 2009, about 10:38 a.m. eastern daylight time, a 2006 Navistar International truck-tractor in combination with a 1994 Mississippi Tank Company MC331 specification cargo tank semitrailer (the combination unit), operated by AmeriGas Propane, L.P., and laden with 9,001 gallons of liquefied petroleum gas, rolled over on a connection ramp after exiting Interstate 69 (I-69) southbound to proceed south on Interstate 465 (I-465), about 10 miles northeast of downtown Indianapolis, Indiana. The truck driver was negotiating a left curve in the right lane on the connection ramp when the combination unit began to encroach upon the left lane, occupied by a 2007 Volvo S40 passenger car. The truck driver responded to the Volvo's presence in the left lane by oversteering clockwise, causing the combination unit to veer to the right and travel onto the paved right shoulder. The truck driver's excessive, rapid, evasive steering maneuver to return the combination unit to the roadway triggered a sequence of events that caused the cargo tank semitrailer to roll over, decouple from the truck-tractor, penetrate a steel W-beam guardrail, and collide with a bridge footing and concrete pier column supporting the southbound I-465 overpass. The collision entirely displaced the outside bridge pier column from its footing and resulted in a breach at the front of the cargo tank that allowed the liquefied petroleum gas to escape, form a vapor cloud, and ignite. The truck driver and the Volvo driver sustained serious injuries in the accident and postaccident fire, and three occupants of passenger vehicles traveling on I-465 received minor injuries from the postaccident fire.

Major safety issues were identified in this investigation were cargo tank rollover prevention as they relate to highway and vehicle design. As a result of its investigation, the National Transportation Safety Board has issued safety recommendations to the U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Pipeline and Hazardous Materials Safety Administration, National Highway Traffic Safety Administration, Federal Highway Administration, and American Association of State Highway and Transportation Officials.

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Acronyms and Abbreviations

AAR	Association of American Railroads
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ABS	antilock braking system
AmeriGas/PTI	AmeriGas Propane, L.P./Propane Transport International
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BMCS	Bureau of Motor Carrier Safety
BP	blood pressure
CAMI	Civil Aerospace Medical Institute
CDL	commercial driver's license
CDLIS	Commercial Driver's License Information System
CFR	*Code of Federal Regulations*
CG	center of gravity
DOT	U.S. Department of Transportation
DVIR	Driver Vehicle Inspection Report
EDT	eastern daylight time
EIGA	European Industrial Gases Association
ESC	electronic stability control [system]
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSRs	*Federal Motor Carrier Safety Regulations*
g	acceleration of gravity
GES	General Estimates System
GVWR	gross vehicle weight rating
HMIS	Hazardous Materials Information System
hp	horsepower
HVOSM	Highway-Vehicle-Object-Simulation Model
I-69	Interstate 69

I-465	Interstate 465
IFD	Indianapolis Fire Department
IMPD	Indianapolis Metropolitan Police Department
INDOT	Indiana Department of Transportation
IN-TIME	Indiana Traffic Incident Management Effort
ISP	Indiana State Police
LRFD	Load and Resistance Factor Design
LTCCS	*Large Truck Crash Causation Study*
LTFD	Lawrence Township Fire Department
MC	motor carrier [number]
MCMIS	Motor Carrier Management Information System
MECA	Metropolitan Emergency Communications Agency
mg/dL	milligrams per deciliter
m/s^2	meters per second/per second
MUTCD	*Manual on Uniform Traffic Control Devices*
MY	model year
NADS	National Advanced Driving Simulator
NASS	National Accident Sampling System
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NQT	nonquenched and tempered
NTSB	National Transportation Safety Board
NTTC	National Tank Truck Carriers
PCP	phencyclidine
PHMSA	Pipeline and Hazardous Materials Safety Administration
psig	pounds per square inch, gauge
PTI	Propane Transport International
QT	quenched and tempered
RSC	rollover stability control [system]
RSPA	Research and Special Programs Administration
SAFER	Safety and Fitness Electronic Records

STAA-82	Surface Transportation Assistance Act
TL	test level
TRB	Transportation Research Board
UCP	unified command post
UMLER	Universal Machine Language Equipment Register
UMTRI	University of Michigan Transportation Research Institute
UN	United Nations
UNECE	United Nations Economic Commission for Europe
USDOT	U.S. Department of Transportation [number]
VDANL	Vehicle Dynamics Analysis, Non-Linear

Executive Summary

On October 22, 2009, about 10:38 a.m. eastern daylight time, a 2006 Navistar International truck-tractor in combination with a 1994 Mississippi Tank Company MC331 specification cargo tank semitrailer (the combination unit), operated by AmeriGas Propane, L.P., and laden with 9,001 gallons of liquefied petroleum gas, rolled over on a connection ramp after exiting Interstate 69 (I-69) southbound to proceed south on Interstate 465 (I-465), about 10 miles northeast of downtown Indianapolis, Indiana.

The truck driver was negotiating a left curve in the right lane on the connection ramp, which consisted of two southbound lanes, when the combination unit began to encroach upon the left lane, occupied by a 2007 Volvo S40 passenger car. The truck driver responded to the Volvo's presence in the left lane by oversteering clockwise, causing the combination unit to veer to the right and travel onto the paved right shoulder. Moments later, the truck driver steered counterclockwise to redirect and return the combination unit from the right shoulder to the right lane.

The truck driver's excessive, rapid, evasive steering maneuver triggered a sequence of events that caused the cargo tank semitrailer to roll over, decouple from the truck-tractor, penetrate a steel W-beam guardrail, and collide with a bridge footing and concrete pier column supporting the southbound I-465 overpass. The collision entirely displaced the outside bridge pier column from its footing and resulted in a breach at the front of the cargo tank that allowed the liquefied petroleum gas to escape, form a vapor cloud, and ignite. The truck-tractor came to rest on its right side south of the I-465 overpasses, and the decoupled cargo tank semitrailer came to rest on its left side, near the bridge footing supporting the southbound I-465 overpass.

The truck driver and the Volvo driver sustained serious injuries in the accident and postaccident fire, and three occupants of passenger vehicles traveling on I-465 received minor injuries from the postaccident fire. At the time of the accident, the sky was overcast, winds were calm, pavement was dry, and the temperature was about 58° F.

The National Transportation Safety Board determines that the probable cause of this accident was the excessive, rapid, evasive steering maneuver that the truck driver executed after the combination unit began to encroach upon the occupied left lane. Contributing to the rollover was the driver's quickly steering the combination unit from the right shoulder to the right lane, the reduced cross slope of the paved right shoulder, and the susceptibility of the combination unit to rollover because of its high center of gravity. Mitigating the severity of the accident was the bridge design, including the elements of continuity and redundancy, which prevented the structure from collapsing.

The following safety issues were identified in this investigation:

- Essential elements of a comprehensive rollover prevention program.
- Rollover propensity of cargo tank motor vehicles, which provides little tolerance for operator error.
- Safety implications of reduced shoulder cross slope on the roll stability of heavy commercial vehicles with a high center of gravity.
- Lack of quality data necessary for conducting meaningful risk analyses to evaluate the crash performance of U.S. Department of Transportation specification cargo tanks.
- Absence of guidelines for identifying and protecting bridges vulnerable to collapse if struck by errant heavy commercial vehicles negotiating direct and semi-direct connection ramps.

As a result of its investigation, the National Transportation Safety Board has issued safety recommendations to the U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Pipeline and Hazardous Materials Safety Administration, National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration, and American Association of State Highway and Transportation Officials (AASHTO). Additionally, this report reclassifies previously issued recommendations to NHTSA and AASHTO.

1. Factual Information

1.1 Accident Narrative

On October 22, 2009, about 10:38 a.m. eastern daylight time (EDT),[1] a 2006 Navistar International truck-tractor in combination with a 1994 Mississippi Tank Company MC331 specification 11,600-gallon cargo tank semitrailer[2] (the combination unit), operated by AmeriGas Propane, L.P., and laden with 9,001 gallons of liquefied petroleum gas,[3] rolled over on a connection ramp after exiting Interstate (I-69) southbound to proceed south on Interstate 465 (I-465), about 10 miles northeast of downtown Indianapolis, Indiana (see figure 1).[4]

The truck driver was negotiating a left curve in the right lane on the connection ramp, which consisted of two southbound lanes, when the combination unit began to encroach upon the left lane, occupied by a 2007 Volvo S40 passenger car (see figure 2).[5] During a postaccident interview, the Volvo driver told National Transportation Safety Board (NTSB) investigators that he sounded the horn a few times when the rear of the cargo tank (which was initially observed ahead of the Volvo in the right lane) started to move into the left lane. The truck driver responded to the Volvo's presence in the left lane by oversteering clockwise, causing the combination unit to veer to the right and travel onto the paved right shoulder. Moments later, the truck driver steered counterclockwise—as indicated by tire marks—to redirect the combination unit from the right shoulder to the right lane (see figure 3).

[1] Unless otherwise designated, all times in this report are eastern daylight time.

[2] *Cargo tank semitrailers* are the most common articulated commercial vehicles used to transport bulk liquids. Another type of vehicle used to transport bulk liquids, the *single-unit cargo tank truck*, consists of a power unit with a tank that is not coupled to a trailer. *Cargo tank motor vehicles* refer to the entire population of heavy trucks equipped with cargo tanks (regardless of size, configuration, and whether the commodity transported is a hazardous material).

[3] Liquefied petroleum gas is a flammable gas that is transported under pressure as a liquid with a lower explosive limit of 2.1-percent concentration with air and a flash point of -219.9° F. Liquefied petroleum gas is 270 times more compact as liquid than as gas, making it more economical to store and transport.

[4] The accident occurred at the transition between I-69, which runs in a north-south direction, and the west and south segments of I-465, a beltway around Indianapolis (see figure 2).

[5] No physical evidence or witness reports were available to independently corroborate the preaccident placement of vehicles and sequence of events that may have led to the encroachment of the combination unit upon the left lane; consequently, it is not known to what extent, if any, the combination unit had entered the left lane.

Figure 1. Accident location.

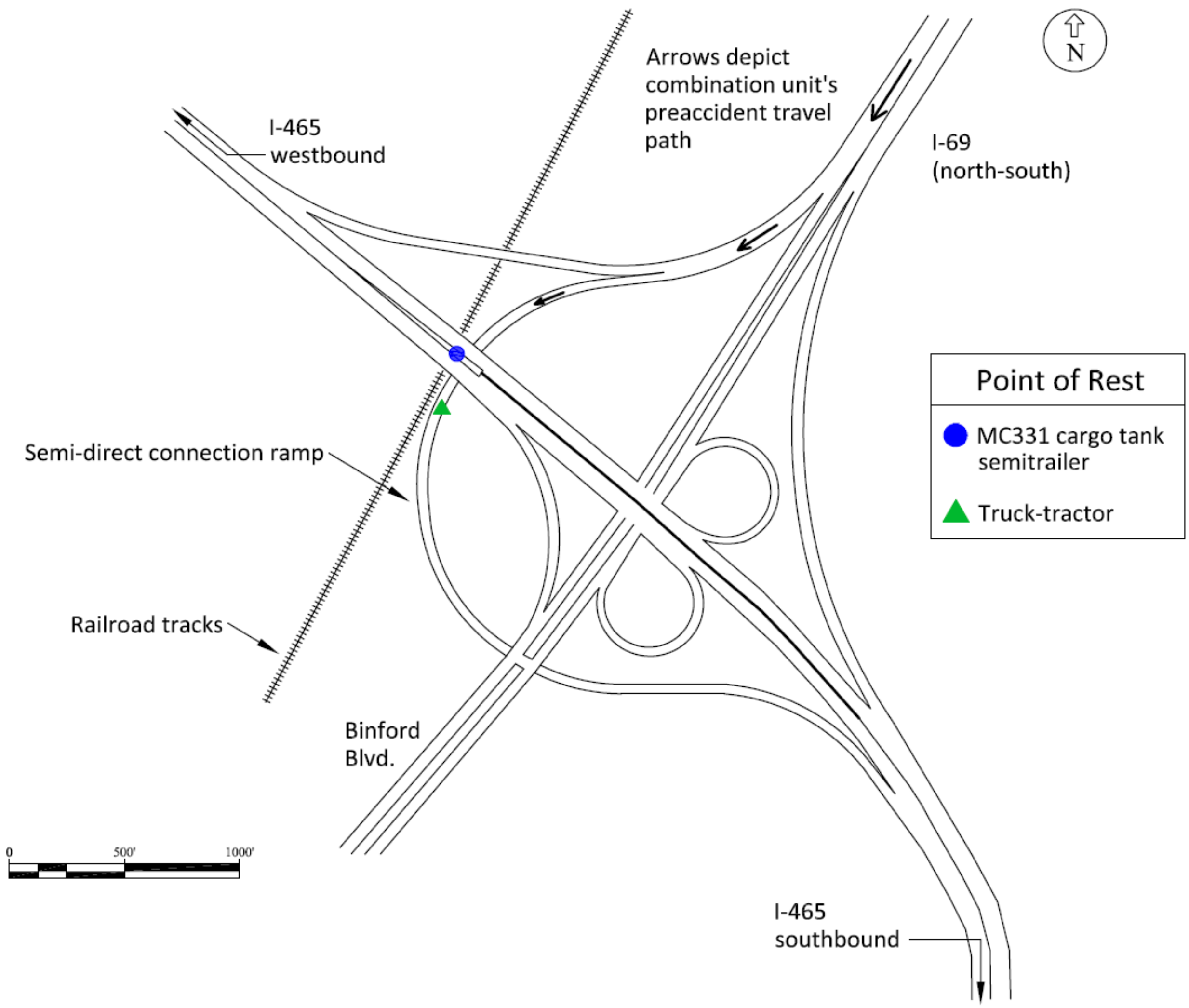

Figure 2. Plan view of connection ramp and direction of travel and final rest positions of the truck-tractor and cargo tank semitrailer.

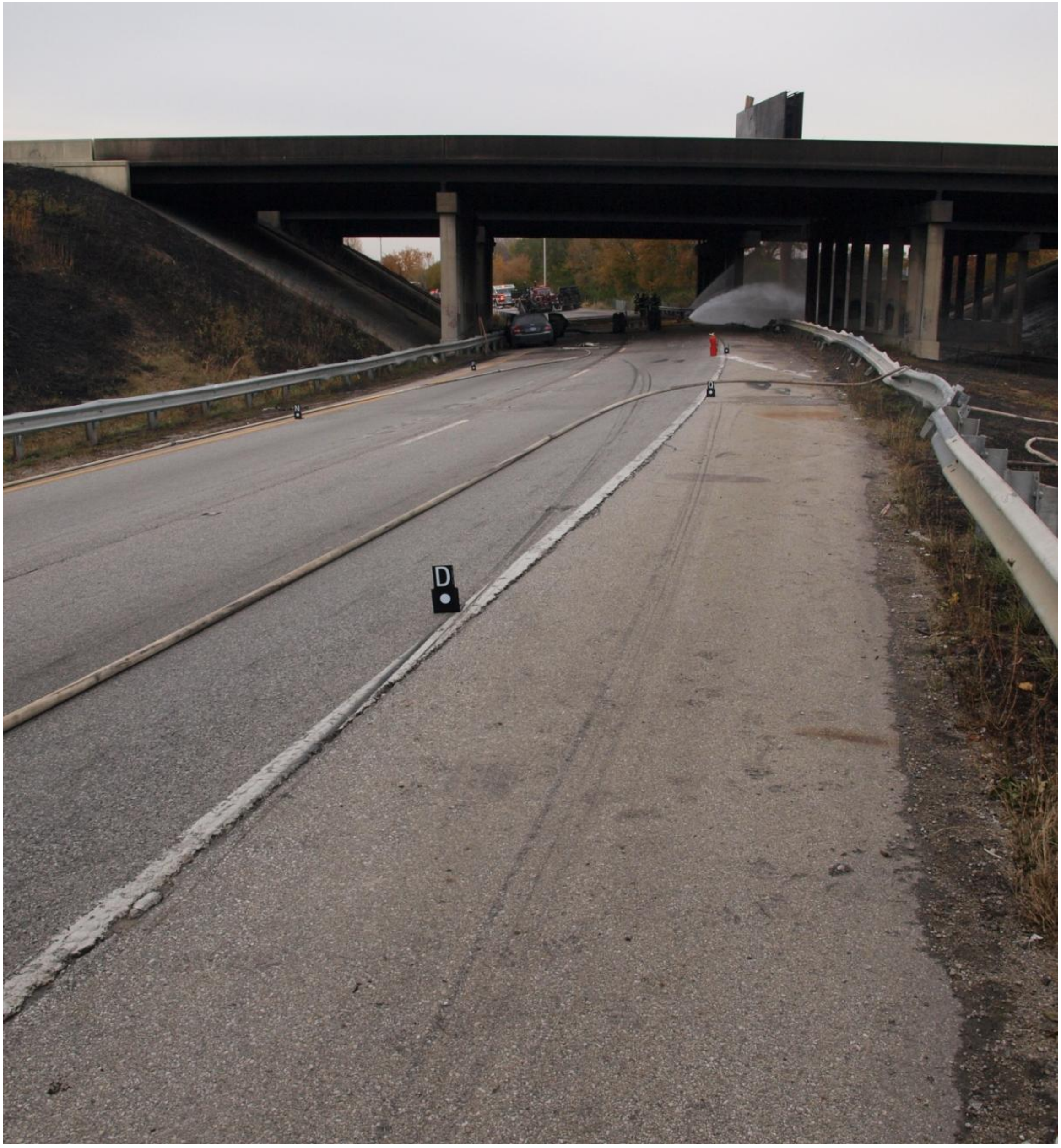

Figure 3. Tire marks indicating redirection of combination unit from the right shoulder to the right lane. (Source: Indiana State Police.)

The truck driver's excessive, rapid, evasive steering maneuver[6] triggered a sequence of events that caused the cargo tank semitrailer to roll over, decouple from the truck-tractor, penetrate a steel W-beam guardrail, and collide with a bridge footing and concrete pier column supporting the southbound I-465 overpass. The collision entirely displaced the outside bridge

[6] A *rapid, evasive maneuver* is defined by the National Highway Traffic Safety Administration (NHTSA) as steering, braking, accelerating, or any combination of control inputs that approaches the limits of a vehicle's capabilities. For further information, see *Evaluating the Relationship Between Near-Crashes and Crashes: Can Near-Crashes Serve as a Surrogate Safety Metric for Crashes?* DOT-HS-811-382 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2010).

pier column from its footing and resulted in a breach at the front of the cargo tank, which allowed the liquefied petroleum gas to escape, form a vapor cloud, and ignite. The truck-tractor came to rest on its right side south of the I-465 overpasses, and the decoupled cargo tank semitrailer came to rest on its left side, near the bridge footing supporting the southbound I-465 overpass (see figure 4).

Figure 4. Truck-tractor and cargo tank semitrailer at final rest. (Source: Lawrence Township Fire Department.)

After witnessing the cargo tank semitrailer rollover, the Volvo driver stated that he immediately stopped his vehicle but did not have time to call 911 before the vapor cloud that had emitted from the cargo tank was ignited. The Volvo driver immediately exited his vehicle and ran north on the connection ramp to get away from the fire. The vapor ignited and created a fireball that extended approximately 250 feet above the I-465 overpasses. The truck driver and the Volvo driver sustained serious injuries in the accident and from the postaccident fire; and three occupants of passenger vehicles traveling above the connection ramp on I-465 received minor injuries from the postaccident fire. At the time of the accident, the sky was overcast, the winds were calm, the pavement was dry, and the temperature was about 58° F.

1.2 Emergency Response

The accident was reported at 10:41 a.m. to the Marion County Sheriff's Department 911 system as a tanker spill on southbound I-465. The Indianapolis Metropolitan Police Department (IMPD) was notified moments later and arrived on scene at 10:47 a.m. The IMPD initially assumed command for law enforcement until a commander with the Indiana State Police (ISP) arrived on scene. The ISP sent approximately 25 units to the accident site, with the first 3 units dispatched at 10:41 a.m. and simultaneously arriving on scene at 10:48 a.m.

After arriving on scene, ISP troopers provided first aid and spoke with the truck driver, who told them he could not remember what happened. At 10:58 a.m., traffic approaching the interchange was diverted from southbound I-69 and, at 11:08 a.m., from both directions of I-465. The ISP incident commander arrived on scene at 11:19 a.m. and deployed the Indiana Traffic Incident Management Effort (IN-TIME)[7] traffic management plan to establish traffic control in the accident vicinity, alleviate traffic congestion in northeast Indianapolis, and initiate a contingency plan for road closures.

The fire department was notified at 10:42 a.m. and, moments later, the Lawrence Township Fire Department (LTFD)[8] and Indianapolis Fire Department (IFD) were dispatched. Shortly after that, the City of Lawrence and Town of Fishers fire departments were also dispatched. Four fire departments responded to the scene with approximately 39 firefighting apparatus units.

A LTFD captain, who arrived on scene at 10:44 a.m., was the initial incident commander. The IFD firefighter hazardous materials team, which arrived on scene at 10:48 a.m., was notified en route that the cargo tank displayed a placard with United Nations (UN) identification number 1075.[9] The placard's UN identification number, tank shape, and eruption of a fireball after impact indicated to firefighters that the incident involved liquefied petroleum gas. The firefighters also observed a boiling fog escaping from a breach near the front head of the cargo tank.

The first of five ambulances arrived on scene at 10:50 a.m. Three ambulances transported occupants with injuries to area hospitals (Wishard Hospital, Clarian Methodist Hospital, and Community North Hospital).

The Chief of the LTFD assumed command after arriving on scene at 11:04 a.m. as the unified command post (UCP) was being established east of the southbound I-465 overpass. Fire suppression units were located primarily north and south of the accident location to extinguish fires at the locations where the truck-tractor and the cargo tank semitrailer came to rest. At 11:08 a.m., the incident commander reported that the fires were primarily under control, with the exception of small brush fires that continued to burn until 12:10 p.m.

Combustible gas meter testing indicated the presence of flammable vapors in the area.[10] The IFD then focused on deploying water to cool the tank and dissipate flammable vapors. At 11:19 a.m., the IFD safety coordinator reported that liquefied petroleum gas vapors continued to accumulate near the damaged cargo tank. For 30–40 minutes, while fog continued escaping from

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[7] IN-TIME is a public–private sector group that develops and recommends policy and operational protocols for the safe and efficient mitigation of traffic incidents.

[8] The LTFD merged with the Indianapolis Fire Department on January 1, 2011.

[9] The four-digit numbers that follow UN letters are displayed on package labels and placards attached to the external surface of commercial motor vehicles to identify the presence and type of hazardous materials being transported. Firefighters can utilize UN numbers to obtain information about how to respond to hazardous material releases.

[10] The combustible gas meter detects the presence of gas concentrations up to 100 percent of the lower explosive limit, which is the lowest concentration of a flammable gas or vapor emitted into the air capable of producing a flash of fire in the presence of an ignition source.

the tank, burning embers falling from a nearby outdoor advertisement sign caused at least three minor flashbacks of the vapor trail. Meanwhile, the UCP was transferred into the Metropolitan Emergency Communications Agency (MECA)[11] van at 11:47 a.m.

At 2:50 p.m., the fire department was still measuring flammable vapor concentrations at the cargo tank. The flammable vapor was eliminated once the City of Lawrence Fire Department and the IFD established a steady supply of water from a fire hydrant at a nearby apartment complex. When no flammable vapor levels were measured at 4:18 p.m., water operations were terminated.

Unified command was transferred to the ISP at 6:59 p.m. By 8:00 p.m., the Indiana Department of Transportation (INDOT) and the ISP had opened the majority of the ramps that had been closed, except for the connection ramp (where the accident occurred) from southbound I-69 to southbound I-465, which was repaired and opened by 7:00 a.m. on October 27, 2009. I-465 remained closed to traffic for at least 1 day after the accident.[12]

The ISP and the LTFD had conducted recent disaster drills. A post-incident analysis of this accident was held by responding fire departments on October 28, 2009, to review the response, lessons learned, and problems encountered. The ISP facilitated an after-action review with all first responders on November 19, 2009.

1.3 Injuries

The truck driver sustained serious injuries, including multiple contusions, heat blistering to his shoulders and upper back, and a laceration to the right ear. The driver of the 2007 Volvo sustained second-degree burns to his face, head, and arms. Three occupants in passenger vehicles traveling above the connection ramp on I-465 sustained minor burns (see table 1).

Table 1. Injuries.

Injury Severity	Truck Driver	Passenger Vehicle Occupants	Total
Fatal	0	0	0
Serious	1	1	2
Minor	0	3	3
None	0	0	0
Total	1	4	5

Title 49 *Code of Federal Regulations* (CFR) 830.2 defines a fatal injury as any injury that results in death within 30 days of the accident. It defines a serious injury as an injury that requires hospitalization for more than 48 hours, commencing within 7 days of the date of injury; results in a fracture of any bone (except simple fractures of the fingers, toes, or nose); causes severe hemorrhages or nerve, muscle, or tendon damage; involves any internal organ; or involves second- or third-degree burns, or any burn affecting more than 5 percent of the body surface.

[11] The MECA vehicle is equipped with the necessary equipment and personnel to provide emergency communication and record management services.

[12] Correspondence received from INDOT, June 9, 2011.

1.4 Survival Factors

Motorists traveling on I-465 stopped and walked to where the truck-tractor came to rest on its right side. They observed the truck driver inside the cab compartment leaning against the passenger door attempting to reach the steering wheel, with his seat belt slightly outstretched. One motorist first used his foot to dislodge and then his hands to remove the windshield from the truck-tractor before helping the truck driver exit the cab compartment. The truck driver was able to walk with assistance from others to move away from the truck-tractor. The truck driver stated in a postaccident interview with NTSB investigators that he was wearing his seat belt.[13]

1.5 Scene Evidence

The ISP reconstruction team documented evidence at the accident scene using close-range photogrammetry.[14] Tire marks extended in an arc from the right shoulder to the right lane, with the longest (on a scaled diagram prepared by ISP) measuring approximately 322 feet. Gouge marks were adjacent to where the right W-beam guardrail was damaged, and tire imprints were on the right shoulder and in the right lane directly north of the westbound I-465 overpass. Three scrape marks, 13–35 feet long, were in the right lane below the westbound I-465 overpass. The cargo tank semitrailer came to rest on its left side under the southbound I-465 overpass, with the front of the tank near the I-465 bridge footing and the rear bumper approximately 2 feet from railroad tracks. The rearmost axle[15] on the cargo tank semitrailer (axle 5) separated and came to rest straddling the centerline on the connection ramp. The truck-tractor came to rest across both lanes of the ramp, approximately 135 feet from the front head of the cargo tank semitrailer. With the exception of the right rear tire, the Volvo passenger car was stopped entirely on the left paved shoulder adjacent to the left W-beam guardrail and below the westbound I-465 overpass, approximately 103 feet from where the cargo tank came to rest.

1.6 Weather

Astronomical data reported near the accident location on October 22, 2009, the day of the accident, showed that sunrise occurred at 8:03 a.m. and that the sun's altitude was 33.5° and azimuth was 149.1° east of true north at 10:45 a.m.[16] A weather station near the accident site

[13] Title 49 CFR 392.16 states that "a commercial motor vehicle which has a seat belt assembly installed at the driver's seat shall not be driven unless the driver has properly restrained himself/herself with the seat belt assembly." The 2009 overall seat belt usage rate for drivers of all medium and heavy duty trucks and buses combined was 74 percent. For more information, see *Commercial Motor Vehicle Driver Safety Belt Usage*, Commercial Truck and Bus Safety Synthesis 8 (Washington, DC: Transportation Research Board) and *Seat Belt Usage by Commercial Motor Vehicle Drivers*, 2009 Survey, December 2009 (Washington, DC: Federal Motor Carrier Safety Administration).

[14] Photogrammetry takes two or more two-dimensional images from different angles, with at least one known distance within the field of view, and translates them into three-dimensional models to analyze and obtain measurements of objects or distances within a spatial area.

[15] For reference purposes, the five axles on the articulated combination unit are referred to by a single-digit number beginning with the steering axle (axle 1), followed by the first drive axle (2), second drive axle (3), first semitrailer axle (4), and second semitrailer axle (5).

[16] Information obtained from the U.S. Naval Observatory website <http://aa.usno.navy.mil>, accessed October 25, 2009.

reported a temperature of 58° F, a dew point of 54° F, and southerly winds of 4 mph at 10:44 a.m. No precipitation was recorded on October 22, 2009. At 10:54 a.m. that day, the Indianapolis International Airport—located approximately 16 miles southwest of the accident scene—reported overcast, dry conditions and visibility of 10 statute miles.

1.7 Damage

The entire cab of the three-axle truck-tractor, upper sections of the fuel tanks, and combustible materials near the engine compartment—including brake system air lines—were consumed by the postaccident fire (see figure 5). The brake chamber mounting brackets on the steering axle were bent. The left- and right-quarter fenders on the truck-tractor were damaged. The frame rails at the rear of the truck-tractor were twisted, and the fifth wheel plate was entirely separated from the slide rail bracket. The tires on the steering axle were almost completely destroyed by fire. The inboard and outboard tires on the right side of axle 2 and the outboard tire on axle 3 were deflated, and the outboard right wheels were damaged.

Figure 5. Fire-damaged truck-tractor.

The lower front head of the MC331 cargo tank semitrailer was deformed after impacting the bridge pier column. The impact resulted in a breach at the lower and right side of the front head, which generally followed the fillet weld around the perimeter of the mounting pad that attached the bottom of the tank to the upper coupler assembly.[17] The majority of the opened portion of the breach measured approximately 20 inches by 29 inches, with the adjacent head and shell material peeled outward (see figure 6).

[17] The upper coupler assembly, which consists of the coupler plate, kingpin, and supporting framework at the front of a semitrailer, interfaces with and couples to a truck-tractor's fifth wheel.

Figure 6. Collision damage and breach at the lower right side of the cargo tank.

The flammable gas placard on the right side of the tank was destroyed. A wide scrape extended along the entire right shell of the cargo tank. The rear head sustained a cylindrically shaped transverse dent centered near the edge of the head, measuring approximately 37 inches long, 18 inches wide, and 4 inches deep. Black soot coated the right two-thirds of the rear head. The transverse baffles inside the tank were bowed forward about 6 inches. Axle 5 separated from the semitrailer during the crash, and axle 4 became detached when the cargo tank trailer was recovered from the scene. All outboard tires on axles 4 and 5 and the inboard left tire on axle 4 were deflated, and all outboard wheels were damaged. The outboard tire on the right side of axle 4 was detached from the wheel, and the outer sidewall of the outboard tire on the left side of axle 4 was lacerated.

The steel W-beam guardrail along the connection ramp was damaged, and the outermost concrete bridge pier column that supported the southbound I-465 overpass separated from the bridge footing and pier cap (see figure 7).

The heat of the postaccident fire damaged two outdoor advertisement signs and a telecommunication tower (see figure 8). Eight passenger vehicles traveling on the connection ramp and on the I-465 overpasses received minor-to-extensive heat-related damage, with two vehicles being towed from the accident scene. Damage from the fire extended approximately 280 feet north and 110 feet south of where the cargo tank semitrailer came to rest under the I-465 overpasses.

Figure 7. Displaced bridge pier column struck by cargo tank semitrailer. (Source: Indiana State Police.)

Figure 8. Aerial view of the connection ramp and Interstate 465 overpasses. (Source: Indiana State Police.)

1.8 Vehicle Information (Cargo Tank Combination Unit)

The 2006 Navistar International truck-tractor and 1994 Mississippi Tank Company cargo tank semitrailer were operated by AmeriGas Propane, L.P./Propane Transport International (AmeriGas/PTI), which has a corporate office in King of Prussia, Pennsylvania. The five-axle articulated combination unit was approximately 8 feet wide, with an overall length of approximately 60 feet. NTSB investigators, together with the ISP and a representative of the Mississippi Tank Company, conducted a postaccident examination of the combination unit.

1.8.1 Truck-Tractor

The three-axle truck-tractor, manufactured in October 2005 by Navistar International Corporation, had a shipped weight[18] when built of 16,921 pounds. The truck-tractor was factory-equipped with a 430-horsepower (hp) Caterpillar C13 diesel engine, 10-speed manual transmission, leaf spring suspension on the steer axle, air ride suspension on the drive axles, air brake system with S-cam service brakes, and antilock braking system (ABS). The truck-tractor received its last periodic inspection on May 22, 2009 (invoice date June 3, 2009), from Selking International, Fort Wayne, Indiana. The odometer was destroyed in the postaccident fire; maintenance records indicated an odometer reading of 268,713 miles when the truck-tractor was serviced on October 13, 2009 (invoice date October 22, 2009), by Star Truck Rentals, Inc., Grand Rapids, Michigan.

Damage from the fire restricted testing on the pneumatic portion of the truck-tractor's braking system. All service brakes, except for the brakes on the steering axle, which were damaged and could not be measured, were found to be within proper adjustment limits.[19]

The steering linkage was intact despite damage at both outboard ends and the underside of the front axle. The steering gear (R.H. Sheppard model M100PMX3) was removed and an internal examination was conducted in the presence of an NTSB investigator by a representative of R.H. Sheppard Company, Inc., Hanover, Pennsylvania. The internal examination revealed signs of excessive heat throughout the steering gear. No damage or cracks were observed on the pitman arm splines, sector teeth, or piston teeth. In addition, no damage was observed to the upper thrust bearing or washers, rotary valve, and lower thrust washer.

[18] *Shipped weight* is a vehicle's unladed dry weight with minimal or no fuel, fluids, or optional equipment.

[19] The applied pushrod stroke of each brake chamber that could be measured was within the maximum applied readjustment limits specified in 49 CFR Part 396, Appendix G, and the North American Out-of-Service Criteria that are utilized by the Commercial Vehicle Safety Alliance at roadside inspections.

During the accident, the truck-tractor and cargo tank semitrailer decoupled at the fifth wheel before coming to rest. The fifth wheel coupler assembly[20] was examined by NTSB investigators and a Fontaine Fifth Wheel Company representative. Postaccident examination revealed that the frame rails at the rear of the truck-tractor were twisted (left rail higher than right rail), and the cross bars at the base of the mounting brackets of the fifth wheel plate were significantly buckled and deformed (see figure 9). Signs of deformation were also observed on the frame rails and tracks where the slide rail bracket was fastened to the rear of the truck-tractor. The examination also found that the locks that keep the fifth wheel plate in a fixed position on the slide rail bracket were fully engaged in the locked position. The welded stop bars on the slide rail bracket that prevent the fifth wheel plate from inadvertently separating from the slide rail bracket were intact and undamaged. Observations made during the examination were consistent with the extended outboard edges of the cross bars of the fifth wheel plate becoming deformed and the grooved section of the slide rail bracket twisting sufficiently for the fifth wheel plate to separate from the slide rail bracket during the rollover sequence.

Figure 9. Fifth wheel plate.

In addition to separating from the slide rail bracket, the fifth wheel plate also separated from the cargo tank semitrailer's kingpin. The fifth wheel plate was found, with the pull handle severely deformed, approximately 70 feet north of where the cargo tank semitrailer came to rest. The jaw-and-wedge mechanism found in the open position at the scene and the deformation of

[20] The fifth wheel coupler assembly at the rear of a truck-tractor consists of two joined components. The cross bars at the base of the fifth wheel plate (upper section) fit within metal slotted grooves on each side of the slide rail bracket (lower section). The fifth wheel plate is therefore connected to the slide rail bracket, which, in turn, is mounted to the frame rails at the rear of the truck-tractor with high-grade hexagonally shaped bolts. The fifth wheel plate is equipped with a jaw-and-wedge mechanism to allow the truck-tractor to couple to the cargo tank semitrailer's kingpin, which serves as an anchor pin and articulation point and is located behind and under the front of the tank.

the pull handle (as noted in figure 9) suggest that the pull handle became snagged as the cargo tank semitrailer slid on its right side, allowing the fifth wheel plate to separate from the trailer kingpin. The pull handle, located on the right side of the truck-tractor, is physically extended outward by a driver to release the fifth wheel plate from the kingpin to decouple the truck-tractor from the semitrailer.

The truck-tractor's Eaton Fuller 10-speed transmission was examined to determine the gear position at the time of the accident. The most forward of three synchronizers was observed to be engaged in fourth or ninth gear, depending on whether the vehicle was in low or high range, respectively. The Caterpillar C13 diesel engine had the capability, if enabled, of recording time-series and vehicle-related speed data that may have been instrumental in reconstructing accident events. Fire damage to the unit prevented NTSB investigators from recovering data that may have been captured from the engine's electronic control module.

1.8.2 Cargo Tank Semitrailer

The MC331 cargo tank semitrailer was manufactured in March 1994 by the Mississippi Tank Company. The chassis was factory-equipped with a tandem three-leaf spring suspension and an adjustable kingpin, which appeared undamaged. The hubometer on axle 4 displayed 298,827 miles when examined after the accident. Class 2 flammable gas placards with identification number 1075 and the words LIQUEFIED PETROLEUM GAS were displayed on the front, rear, and sides of the cargo tank.

The empty weight of the MC331 cargo tank semitrailer was 21,860 pounds. The bill of lading indicated that the cargo tank was loaded with 9,001 gallons of liquefied petroleum gas weighing approximately 37,900 pounds. The estimated weight of the combination unit laden with 9,001 gallons of liquefied petroleum gas was 76,681 pounds.

The MC331 cargo tank was fabricated of quenched and tempered (QT)[21] SA 517E steel segments joined by butt welds that satisfied applicable American Society of Mechanical Engineers (ASME) code requirements and Federal regulations (49 CFR 178.337). The 0.25-inch-thick hemispherical front and rear heads were each constructed from a central circular plate and six approximately identical trapezoidally shaped gores. The tank's shell consisted of four 0.378-inch-thick shell sections that were cut and shaped into cylinders to match the diameter of the head (see figure 10). The tank was 43 feet 11.5 inches long and had an inside diameter of 83.5 inches. The tank's water capacity was 11,600 gallons, with a maximum allowable working pressure of 250 pounds per square inch, gauge (psig).

[21] *Quenching* is the process of heating and rapidly cooling steel to increase hardness. *Tempering* is a heat treatment that follows quenching to reduce the brittleness of steel without significantly lowering its hardness or strength. Quenched and tempered (QT) and nonquenched and tempered (NQT) carbon steel plate is commonly used in the construction of MC330 and MC331 cargo tanks.

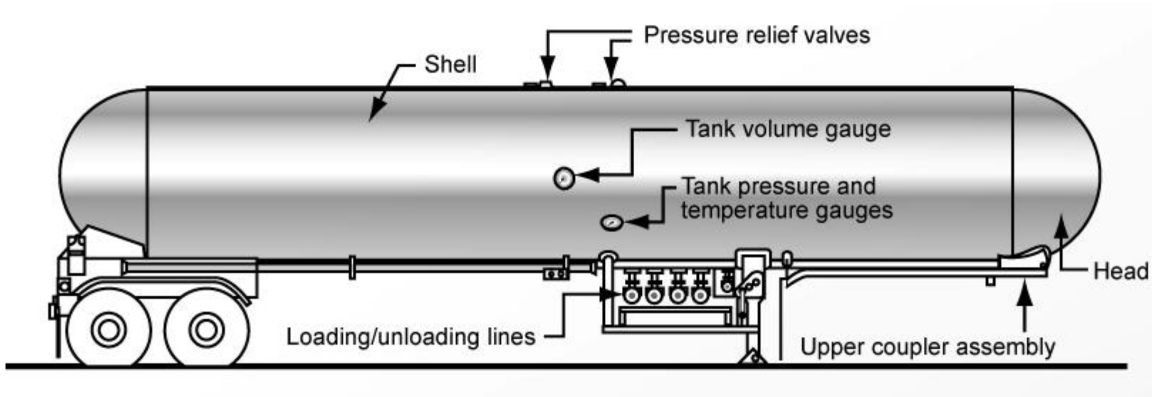

Figure 10. Cargo tank semitrailer (MC331).

Two X-shaped transverse baffles divided the interior volume of the MC331 cargo tank by thirds to minimize the longitudinal surge of liquid in the tank against the front and rear heads. The baffles were bolted to support clips and fastened to the tank shell by fillet-welded mounting pads. Four pipe lines and fixtures used to load and unload product were contained in a steel piping protection device. The cargo tank semitrailer was equipped with a pump to offload product and aftermarket equipment designed to automatically close internal valves when a leak is detected. Brake interlock devices were installed to prevent the trailer from being moved when loading and unloading lines are connected.

Postaccident examination by the NTSB found that the head and shell cracks in the area of impact were consistent with ductile overstress, with no indications of preexisting damage or degradation. The majority of the cracking occurred along the fillet welds where the support structure was attached to the tank, which is to be expected because the support structure creates reinforcement where bending stresses are maximized. The weld geometry also introduces a stress concentration, and the welding process could alter the microstructure of the steel to reduce the material's toughness. Cracking was also observed in the head of the tank within deep folds caused by the impact with the bridge pier column, away from any fillet or butt welds.

No evidence was found of physical damage to the external piping and fittings, corrosion pitting on the interior or exterior of the shell or heads of the tank, or weld defects in the tank structure, such as lack of fusion. Postaccident examination of the two spring-loaded Fisher type H732-250 pressure relief valves mounted on the top center of the tank revealed that the plastic rain cap remained fully inserted in the forward pressure relief valve cup, but the rain cap and specification tag for the rearmost pressure relief valve were missing.[22] The internal valve stems and springs of both valves revealed no visible signs of damage, such as corrosion, bending, marks, or chipped paint. Postaccident bench testing determined that both valves functioned as designed by opening within 110 percent of the maximum allowable working pressure of 250 psig.

[22] The plastic cap is fully inserted into a cup located at the top of a pressure relief valve to seal and prevent rainwater from accumulating and leaking into the valve, which could lead to corrosion and affect the ability of a valve to function as designed.

1.8.3 Periodic Testing and Refurbishment

Title 49 CFR Part 180.407 requires that MC330 and MC331 semitrailer pressure vessels receive annual external visual inspections and leakage tests. Additionally, the following must be completed every 5 years: an internal visual inspection, a wet fluorescent magnetic particle inspection[23] of all welds in and on the interior of QT and NQT cargo tanks, and a hydrostatic pressure test. The accident vehicle's most recent cargo tank test inspections were conducted when the MC331 semitrailer's chassis and cargo tank were refurbished by the Mississippi Tank Company (Indiana Division) in July 2009. The cargo tank refurbishment included the installation of several new components, including two pressure relief valves and a tank pressure gauge. Once the refurbishment was completed, the wet fluorescent magnetic particle inspection and hydrostatic pressure test were performed, and external and internal visual inspections of the tank were conducted to check for weld defects, evidence of corrosion, abrasion, dents, and gouges. The refurbishment of the chassis primarily involved installing new brake hardware, fabricating a new steel plate and kingpin, and retrofitting the chassis with an ABS. The cargo tank and chassis were sandblasted and repainted and passed all U.S. Department of Transportation (DOT) mandated inspections.

1.9 Truck Driver Information

The truck driver was 73 years old and held a valid class "A" Indiana commercial driver's license (CDL) with an expiration date of December 3, 2011,[24] which had a restriction requiring him to wear corrective lenses while driving. The truck driver also held endorsements for operating a cargo tank motor vehicle and transporting hazardous materials. There were no suspensions or disqualifications on the license. Information from the Indiana Department of Motor Vehicles and the Commercial Driver's License Information System (CDLIS) database indicated that the truck driver had accumulated three moving violations during the 5 years before the accident (see table 2). Two of the violations were for speeding, and one was for failure to signal.

Table 2. Moving violations (2004–2009).

Violation	Travel Above Posted Speed Limit	Vehicle Type	Conviction Date
Failure to use/improper signal	N/A	Commercial vehicle	October 29, 2007
Speeding*	16 mph	Commercial vehicle	June 7, 2007
Speeding*	17 mph	Commercial vehicle	May 13, 2004
*Withdrawn after the truck driver attended a safe driving course.			

[23] A wet fluorescent magnetic particle inspection is a nondestructive testing process for detecting surface and near-surface flaws.

[24] An Indiana CDL must be renewed every 4 years.

1.9.1 Driving Experience

At the time of the accident, the truck driver had been driving heavy trucks for about 45 years, with the past 15 years spent transporting bulk liquid hazardous materials in cargo tank motor vehicles. The truck driver said he had been involved in two accidents while driving commercial vehicles, with the most recent occurring more than 5 years before this accident.

The truck driver had been employed by AmeriGas/PTI for about 14 years.[25] He delivered liquefied petroleum gas for AmeriGas/PTI from loading terminals in Huntington, Griffith, and Milford, Indiana, to customer locations throughout Indiana, Illinois, and Ohio. He received delivery assignments each day from a dispatch office in Houston, Texas, which were transmitted to an onboard *Qualcomm* vehicle-tracking system[26] that provided details about each load and delivery location. Although the truck driver could be dispatched anywhere if required, most loads were delivered within the state, allowing him to become familiar with Indiana's network of highways.

The truck driver was allowed to set his own work hours as long as he complied with delivery schedules. Most working days were 14 hours. When the combination unit was not in service, it was parked at a local AmeriGas Propane, L.P., retail facility located approximately 13 miles from the truck driver's residence. Depending on workload, he either slept at home or in the sleeper berth of his truck-tractor. The truck driver had been driving the same truck-tractor for approximately 2 years before the accident occurred.

1.9.2 Medical Information

The truck driver had a 15-year history of hypertension and Type II diabetes controlled by prescription medication. He was prescribed enalapril, hydrochlorothiazide, and atenolol to control high blood pressure (BP) and glyburide and metformin to control blood glucose. He also took tamsulosin to control symptoms of an enlarged prostate. The truck driver told NTSB investigators that he tested his blood glucose level twice daily and had two pill carriers—one for daytime and one for nighttime medication. Although he acknowledged taking all prescribed medication at the usual times during the 3 days before the accident, he did not test his blood glucose level on the morning that the accident occurred.

The truck driver had undergone cataract surgery on his left eye in 1995 and his right eye in 1998. A complete ophthalmological exam in 2007 revealed no evidence of diabetic retinopathy, and another eye exam in 2009 found the truck driver to have 20/20 corrected distance visual acuity. The truck driver experienced an ischemic stroke approximately 10 years

[25] The truck driver completed an application for employment with AmeriGas/PTI on June 23, 1995.

[26] AmeriGas/PTI vehicles are equipped with a wireless communication device that provides two-way text data messaging and automatic satellite-tracking capabilities that include periodic reporting of the date, time, vehicle's approximate location in relation to a nearby town, and status of the ignition key. Vehicle position history data can be used to locate the vehicle in real-time, later determine the route and time required to travel between two points, or review handwritten logbooks completed by commercial drivers.

before the accident.[27] Medical records indicate that he had a complete recovery from the stroke except for dysarthria.[28]

The accident truck driver possessed a current medical certificate (signed April 21, 2009), which expired in April 2010. The truck driver was required to be examined yearly (rather than the typical 2-year examination period for commercial drivers)[29] because of his hypertension and diabetes.[30] Commercial driver fitness examinations at AmeriGas/PTI are completed by a physician retained by the company for that purpose. The truck driver's most recent commercial driver medical examination report noted his diabetes, high BP, and stroke but did not mention any abnormalities with his extremities. An orthopedic clinic note of July 22, 2009, reported the truck driver's height as 72 inches and weight as 210 pounds.

The truck driver was on a 6-month medical leave in 2009 to have knee replacement surgery for severe and painful arthritis of both knees. The right knee surgery was performed on May 4, 2009, and the left knee on June 1, 2009. The truck driver underwent physical therapy and was allowed by his surgeon to return to regular duties on September 28, 2009.

Postaccident hospitalization records indicated that the truck driver did not lose consciousness, and an inpatient postaccident evaluation did not identify any neurologic or cardiologic abnormalities that may have contributed to the accident. The truck driver's weight was noted as 224 pounds and his blood sugar as 258 milligrams per deciliter (mg/dL) at the time of arrival at the emergency room. The hospital records also noted his most recent meal was at 9:45 a.m., and a laboratory record indicated his hemoglobin A1C was 6.3 percent.[31]

1.9.3 72-Hour History

From October 19–22, 2009, the truck driver received six loads of liquefied petroleum gas from Dome Petroleum Corporation (the loading terminal), located approximately 2.6 miles east of Huntington, Indiana. Five of the six loads were delivered to four locations in Indiana (see figure 11). The one-way travel distance from the loading terminal to each of the four delivery locations ranged from 30–133 miles.

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[27] Ischemic strokes account for approximately 85 percent of all stroke cases and occur when there is an obstruction by blood clots or fatty deposits within a blood vessel that supplies blood to the brain.

[28] Dysarthria is characterized by distorted speech that results from the inability to properly move the muscles of the tongue and mouth to produce speech.

[29] Title 49 CFR 391.45 requires a 2-year examination cycle, unless the examining physician recommends a shorter time period.

[30] Title 49 CFR 391.43 requires a driver diagnosed with stage 1 hypertension (BP 140/90–159/99) to be certified for 1 year only. Upon recertification, if the driver's BP is 140/90 or lower, he or she may be certified for a 1-year reexamination cycle. However, if the driver's BP is greater than 140/90 but less than 160/100, a one-time certificate for 3 months can be issued. A driver diagnosed with stage 2 hypertension (BP 160/100–179/109) should be treated and a one-time certificate for 3 months issued. Once the driver has reduced his or her BP to 140/90 or lower, the driver may be recertified annually thereafter. A driver diagnosed with stage 3 hypertension (BP 180/110 or higher) should not be certified until his or her BP is 140/90 or lower and should be recertified every 6 months.

[31] The A1C is a common blood test that reflects the average blood sugar level for the past 2–3 months. Diabetics are recommended to maintain an A1C level below 7 percent.

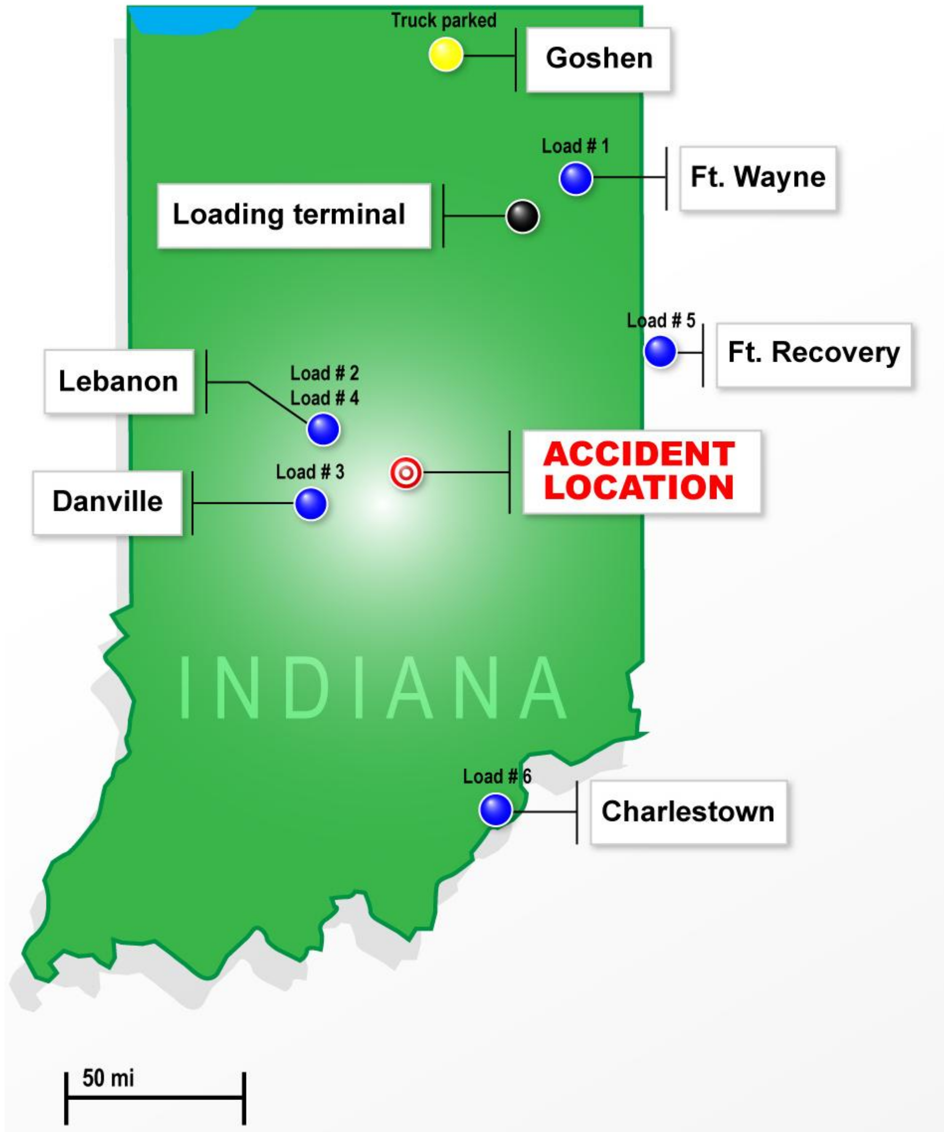

Figure 11. Location of loading terminal in relation to October 19–22 deliveries.

A review of information recorded by the *Qualcomm* vehicle-tracking system revealed that data and time-stamped information about the accident vehicle's approximate location were recorded approximately 80 times in the 3 days before the accident, with the first available record generated at 11:48 a.m. near Columbia City, Indiana, on October 19, 2009, and the last at 8:44 a.m. near Chesterfield, Indiana, on October 22.

NTSB investigators utilized a software program (PC*MILER) to verify distances and the approximate time for the truck driver to travel from the loading terminal to deliver five loads throughout Indiana during the 3 days before the accident.[32] NTSB investigators also reviewed hours-of-service records that were provided by AmeriGas/PTI for trips that had been completed by the truck driver in March 2009 (before the medical leave) and during the 2 weeks before the accident. These records indicate that the truck driver worked on October 9, 12, 15, and 16, 2009, and 3 consecutive days (October 19–21, 2009) before the accident occurred on October 22.

Hours-of-service logbooks completed by the truck driver from October 19–22, 2009, were destroyed in the postaccident fire. Consequently, NTSB investigators obtained copies of shipping documents, information from a postaccident interview, and *Qualcomm* vehicle position history data from AmeriGas/PTI to reconstruct a 72-hour history of the truck driver's activities before the accident (see figure 12 and table 3). While the reconstruction of the truck driver's activities provides general information about his schedule, including available time for sleep, it does not necessarily reflect the actual time that sleep was initiated or duration of sleep during the 3 nights before the accident. Based on the reconstruction of the handwritten hours-of-service logbooks, the truck driver had driven the combination unit approximately 63 hours during 7 of 14 days from October 9–22, 2009.

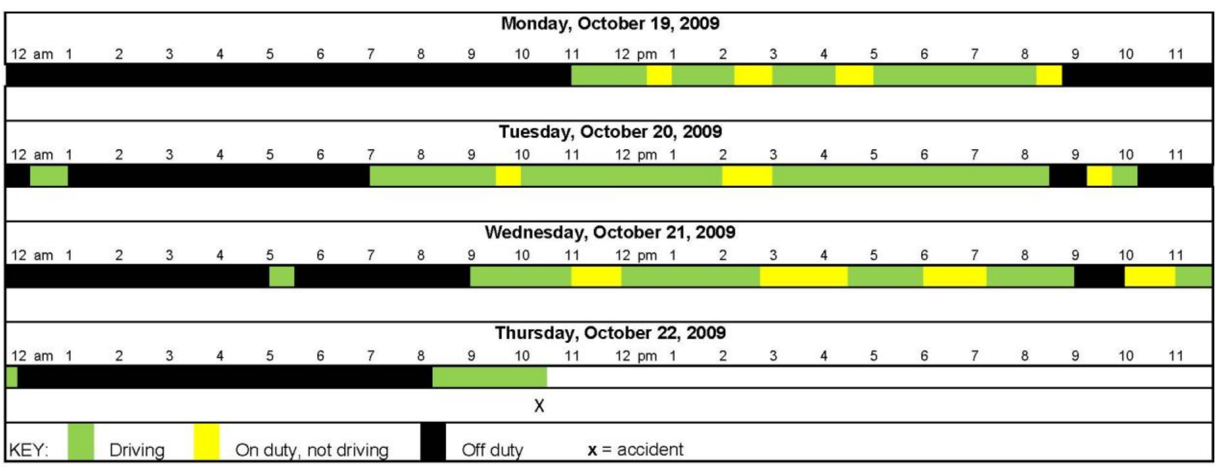

Figure 12. Truck driver's 72-hour history of activities before the accident.

[32] PC*MILER is a routing and mapping software that is used by motor carriers for route navigation, rate calculation, fuel tax reporting, mileage verification, bid preparation, and freight auditing purposes.

Table 3. Reconstruction of accident truck driver's activities, October 19–22, 2009 (based on postaccident interview, shipping documents, and *Qualcomm* vehicle position history data).

Time (EDT)	Activities	Location
Monday, October 19		
7:00 a.m.	Awakens at residence	Syracuse, IN
11:00 a.m.	Begins driving	Goshen, IN
12:30 p.m.	On duty, loading (load #1)	Huntington, IN
1:00 p.m.	Begins driving	Huntington, IN
2:15 p.m.	On duty, unloading	Ft. Wayne, IN
3:00 p.m.	Begins driving	Ft. Wayne, IN
4:15 p.m.	On duty, loading (load #2)	Huntington, IN
5:00 p.m.	Begins driving	Huntington, IN
8:15 p.m.	On duty, unloading	Lebanon, IN
8:45 p.m.	Time available for sleep (3 hours 30 minutes)	Lebanon, IN
Tuesday, October 20		
Time (EDT)	**Activities**	**Location**
12:15 a.m.	Begins driving	Lebanon, IN
1:00 a.m.	Time available for sleep (6 hours)	Westfield, IN
7:00 a.m.	Begins driving	Westfield, IN
9:30 a.m.	On duty, loading (load #3)	Huntington, IN
10:00 a.m.	Begins driving	Huntington, IN
2:00 p.m.	On duty, unloading	Danville, IN
3:00 p.m.	Begins driving	Danville, IN
8:30 p.m.	Time available for sleep (45 minutes)	Huntington, IN
9:15 p.m.	On duty, loading (load #4)	Huntington, IN
9:45 p.m.	Begins driving	Huntington, IN
10:15 p.m.	Time available for sleep (6 hours 45 minutes)	Wabash, IN
Wednesday, October 21		
Time (EDT)	**Activities**	**Location**
5:00 a.m.	Begins driving	Wabash, IN
5:30 a.m.	Off duty, not driving	Mexico, IN
9:00 a.m.	Begins driving	Mexico, IN
11:00 a.m.	On duty, unloading	Lebanon, IN
12:00 p.m.	Begins driving	Lebanon, IN
2:45 p.m.	On duty, loading (load #5)	Huntington, IN
4:30 p.m.	Begins driving	Huntington, IN
6:00 p.m.	On duty, unloading	Fort Recovery, OH
7:15 p.m.	Begins driving	Fort Recovery, OH
9:00 p.m.	Time available for sleep (1 hour)	Huntington, IN
10:00 p.m.	On duty, loading (load #6)	Huntington, IN
11:00 p.m.	Begins driving	Huntington, IN
Thursday, October 22		
Time (EDT)	**Activities**	**Location**
12:00 a.m. (midnight)	Time available for sleep (8 hours 15 minutes)	Gaston, IN
8:15 a.m.	Begins driving	Gaston, IN
10:38 a.m.*	Accident occurs	I-69 connection to I-465

*The accident truck driver took more than 2 hours to travel approximately 45 miles, possibly due to an unscheduled stop between exit 45 and I-69 and the accident location. Vehicle position history data recorded by the *Qualcomm* vehicle-tracking system at 8:44 a.m. on October 22 and the truck driver's last meal before the accident at approximately 9:45 a.m. (according to postaccident hospital records) suggest that he did not travel directly from a rest area at exit 45 and I-69 near Gaston, Indiana, to the accident location but instead stopped for a meal at exit 34 and I-69 near Chesterfield, Indiana.

The truck driver told NTSB investigators that there were no internal or external distractions before the accident and that he was not using the citizens band radio, manipulating the controls of an AM/FM radio, using the *Qualcomm* vehicle-tracking system to send text messages, or engaging in a cellular telephone conversation. He also said that his vision was not temporarily obscured by sun glare nor was his concentration reduced or shifted by the large outdoor advertising sign located directly in the line of sight of motorists traveling south on the connection ramp. A review of the truck driver's cellular telephone record indicated that he was not using the telephone for talking or texting at the time of the accident.

1.9.4 Toxicology

During a postaccident interview with NTSB investigators, the truck driver indicated that he had not consumed alcohol during the 3 days before the accident. A blood sample, taken at the request of the ISP, was obtained from the truck driver at Clarian Methodist Hospital approximately 3 hours after the accident (1:38 p.m.) and split into two samples. Toxicological testing on one sample by the Indiana University Department of Pharmacology and Toxicology did not detect alcohol or 17 other drug types.[33] Toxicological testing of the other sample by the Civil Aerospace Medical Institute (CAMI) in Oklahoma City, Oklahoma, was negative for a wide range of legal and illegal drugs.[34] The CAMI blood sample detected an antihypertensive prescription medication, atenolol.

1.10 Motor Carrier Operations

The combination unit was operated by Propane Transport International (PTI), the transportation division of AmeriGas Propane, L.P. PTI was established in the 1950s and operated as a common carrier until it was acquired by AmeriGas Propane, L.P., in 1987 (referred to as AmeriGas/PTI). AmeriGas Propane, L.P., is a subsidiary of AmeriGas Partners, L.P., a retail propane marketer with distribution locations in 50 states.[35]

AmeriGas Propane, L.P. (legal name), doing business as PTI, was assigned U.S. Department of Transportation (USDOT) number 388004 and motor carrier (MC) number 114969.[36] AmeriGas/PTI delivers bulk commodities such as propane, butane, and liquid asphalt as a common and contract carrier within the United States, several Canadian provinces,

[33] Amphetamines, barbiturates, benzodiazepines, cocaine, methadone, opiates, phencyclidine (PCP), cannabinoids (marijuana), oxycodone, opioids, LSD, fentanyl, MDMA (colloquially known as "Ecstasy"), propoxyphene, methqualone, buprenorphine, and ketamine.

[34] Amphetamines, opiates, marijuana, cocaine, PCP, benzodiazepines, barbiturates, antidepressants, antihistamines, meprobamate, methaqualone, and nicotine.

[35] *2010 Annual Report*, AmeriGas Partners, L.P.

[36] A USDOT number is a unique identifier used to track safety information collected during carrier audits, compliance reviews, accident investigations, and vehicle inspections. The MC number is required to operate as a "for-hire" motor carrier of regulated commodities or passengers in interstate commerce, unless the "for-hire" operation is limited to transportation of exempt commodities, or the area operated within is exempt from interstate operating authority rules (49 CFR 392.9a).

and Mexico. According to Safety and Fitness Electronic Records (SAFER)[37] data administered by the Federal Motor Carrier Safety Administration (FMCSA), AmeriGas/PTI operated 2,761 power units with 3,645 drivers, for 45,657,197 total miles traveled in 2007. The overall distance traveled by AmeriGas/PTI increased significantly in 2010 to 92,109,000 miles, with additional power units (5,272) and fewer drivers (3,510).

AmeriGas/PTI vehicles were involved in 84 recordable accidents, including three fatal accidents, 34 injury accidents, and 47 tow-away accidents from October 25, 2007, to October 25, 2009. SAFER data indicate that AmeriGas/PTI received 3,468 roadside inspections during the 24 months before the accident. The company's out-of-service inspection rates for vehicles (10.7 percent), drivers (1 percent), and hazardous materials (2.5 percent) were lower than the national average out-of-service inspection rates (22.2, 6.6, and 5.0 percent, respectively). AmeriGas/PTI received satisfactory ratings for FMCSA compliance reviews conducted on February 19, 1998, and September 2, 2010.[38] The FMCSA also conducted nonrated safety reviews at AmeriGas/PTI on May 24, 2006,[39] and February 5, 2010.[40]

AmeriGas/PTI has developed criteria for the hiring of all new company drivers, fleet operators, and owner-operators. In addition to meeting Federal requirements (*Federal Motor Carrier Safety Regulations* [FMCSRs], Part 391), new drivers must have at least 3 years and 150,000 miles of recent verifiable over-the-road experience driving a tractor-trailer and no more than two moving violations within the last 2 years. The accident truck driver received a satisfactory rating from the company during a road test on July 27, 1995. AmeriGas/PTI drivers are paid by the mile and on a set scale for loading and unloading. The company does not compensate drivers with premium pay (overtime) for working beyond regular hours.

AmeriGas/PTI conducts preemployment, random, postaccident, and reasonable cause drug and alcohol testing. The company contracts with a substance abuse screening company to select employees for random testing and comply with requirements of 49 CFR Part 382 to test a percentage of employees every year. Selected management personnel are trained for "reasonable cause" drug detection.

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[37] SAFER is an FMCSA summary of a company's Motor Carrier Management Information System data that includes roadside inspections and accident history. For further information, see <www.safer.fmcsa.dot.gov>, accessed April 11, 2011.

[38] A compliance review is an on-site examination of a motor carrier's operations that includes—but is not limited to—examining hours-of-service, maintenance, inspection, and other safety and transportation records; driver qualification and CDL requirements; and hazardous materials training to determine whether a carrier meets safety fitness standards. The results of a compliance review are used to assign a motor carrier a safety rating of satisfactory, conditional, or unsatisfactory.

[39] The FMCSA conducted a nonrated security contact review on May 24, 2006, at an AmeriGas/PTI terminal located in Columbia Station, Ohio.

[40] The FMCSA conducted a nonrated compliance review focusing on Parts 382 and 383 on February 5, 2010, because of a recordable accident involving the arrest of an AmeriGas/PTI driver for driving under the influence.

1.10.1 Driver Training

AmeriGas/PTI drivers are required to attend four separate in-service training sessions annually, lasting 8–72 hours and covering topics such as safe loading procedures and driving, with each session requiring the driver to pass a written test. Drivers are also provided employee training that meets the requirements of 49 CFR Part 172.[41] The company has a committee that reviews accidents and recommends remedial actions. AmeriGas Propane, L.P., management told NTSB investigators that the company does not have a formal fatigue management program.

The company developed a *Vehicle Incident Prevention Training* program for preventing backing, rear-ending, and rollover accidents. Materials to support the program include a slide presentation, participant handbook, and instructor guide. The company also displays safety posters and provides information in a safety bulletin about what can be done to prevent, as noted in a company newsletter, “an epidemic” of rollover accidents that have occurred in recent years, including the rollover of 19 single-unit cargo tank trucks in 2009. Driver training handouts identify excessive speed, inattention, and overcorrected steering as the root causes of rollovers. The company’s training recommends that drivers not swerve to avoid an animal or debris on the road because the inertia of the propane load could shift and lead to a rollover. Drivers were also informed that the shifting of a partially filled tank can make a rollover situation even more likely once the vehicle starts to tip. The accident truck driver attended the company’s rollover awareness and prevention training and completed a *Vehicle Incident Prevention Posttest* on August 15, 2008.

1.10.2 Hours-of-Service Records

AmeriGas/PTI drivers must submit handwritten logbooks to the company weekly, which are then monitored and audited with a computer-based program (Rapid Log). Each logbook page is reviewed for hours-of-service violations, and drivers are disciplined using a sliding scale system if violations are found. AmeriGas/PTI provided the handwritten logs that had been completed by the accident truck driver when he worked on October 9, 12, 15, and 16, 2009.[42] The NTSB also received shipping documents and a vehicle position history report generated by the *Qualcomm* vehicle-tracking system for the months of March 2009 and October 2009.[43] A detailed review that compared the truck driver’s handwritten logbook entries with shipping documents and vehicle position history data revealed five instances of false log entries and hours-of-service violations on 3 separate days in October 2009 (see table 4).

[41] Title 49 CFR Part 172 requires that employees who work with hazardous materials receive training including general awareness/familiarization, function-specific information, emergency response procedures, hazardous materials protection, and accident prevention.

[42] Title 49 CFR 395.8(K) requires the carrier to retain drivers’ records of duty (logbooks) for 6 months.

[43] NTSB investigators did not receive hours-of-service records for the 6 months the driver was on medical leave (April–September 2009).

Table 4. Discrepancies between handwritten logbook and *Qualcomm* vehicle position history data.

Date	Driver Status (handwritten log)	Truck Status (*Qualcomm* vehicle position history data)*	Discrepancy
October 9, 2009	Departed Huntington, Indiana, at 1:30 p.m.	Departed Huntington, Indiana, ~1:06 p.m.	~24 minutes
	Departed Noblesville, Indiana, at 6:30 p.m.	Departed Noblesville, Indiana, ~7:18 p.m.	~48 minutes
	Arrived Goshen, Indiana, at 9:30 p.m.	Arrived Goshen, Indiana, ~11:05 p.m.	~95 minutes
October 12, 2009	Off duty, Goshen, Indiana, at 7:30 p.m.	Parked in White Pigeon, Michigan, ~10:01 p.m. on October 12 until ~5:06 a.m. and returned to Goshen, Indiana, ~6:18 a.m. on October 13	~642 minutes
October 15, 2009	Off duty, Huntington, Indiana, at 8:30 p.m.	Parked in New Paris, Indiana, ~7:57 p.m. on October 15 until ~5:07 a.m. and returned to Huntington, Indiana, ~10:09 a.m. on October 16	~819 minutes

*Vehicle position history data, which are captured approximately every 60 minutes, do not reflect the specific time that the combination unit departed from or arrived at a particular location.

1.10.3 Vehicle Maintenance

The 2006 International truck-tractor was leased by AmeriGas/PTI from Star Truck Rentals in Grand Rapids, Michigan, as a new truck-tractor and brought into fleet service in January 2006. The regular preventative maintenance on the truck-tractor was outsourced by AmeriGas/PTI to Star Truck Rentals, Inc., in Grand Rapids, Michigan, and Donlen Corporation in Northbrook, Illinois. The last preventative maintenance service on the truck-tractor occurred on February 20, 2009 (invoice date February 26, 2009).

The FMCSRs require that AmeriGas/PTI and other commercial motor vehicles be inspected annually.[44] The truck-tractor received its most recent periodic inspection on May 22, 2009, and the cargo tank semitrailer, on July 8, 2009. The most recent repairs to the truck-tractor were performed by Star Truck Rentals, Inc., on September 18, 2009 (invoice date October 1, 2009), to resolve an electrical problem and axle leak; and on October 13, 2009 (invoice date October 22, 2009), to install new lining and wheel seals on the steering axle, repair rear shocks, and tighten air tanks.

Three Driver Vehicle Inspection Reports (DVIR) (October 9, 12, and 15, 2009) were obtained from AmeriGas/PTI and reviewed. No maintenance-related concerns were noted by the accident truck driver on these reports. DVIRs for October 19–22, 2009, were not available for review and presumed to have been destroyed in the postaccident fire. The truck driver told NTSB investigators that there were no mechanical problems with the combination unit on the day of the accident.

[44] Title 49 CFR 396.17 requires that all components identified in appendix G, 49 CFR Subtitle B, Subchapter B, Chapter III, be inspected yearly and that the vehicle comply with out-of-service criteria for the brake system, coupling devices, exhaust system, fuel system, lighting devices, safe loading, steering mechanism, suspension, frame, tires, wheels and rims, and windshield wipers. Documentation of this inspection must be carried in the vehicle.

1.11 Highway Information

The accident occurred on an urban interstate approximately 10 miles northeast of downtown Indianapolis, Indiana, at the I-69/I-465 interchange, on a semi-direct connection ramp that carries the southbound lanes of I-69 to the southbound lanes of I-465 (the connection ramp).[45]

The connection ramp was constructed in 1970. The twin bridges that carry the westbound and southbound lanes of I-465 over the ramp, including the bridge pier columns that support the superstructure and deck, were constructed in 1968. (See figure 8.) The ramp is a one-way, two-lane roadway consisting of 12-foot-wide left and right lanes. The ramp's paved shoulders range from 8–9.5 feet on the right and 6–7.5 feet on the left.

The design speed for I-69 southbound approaching the connection ramp is 70 mph. The posted regulatory speed limit for I-69 southbound north of the ramp is 55 mph. The posted speed limit sign is on the right side of the southbound lanes of I-69, approximately 2,700 feet north of the accident site. Approximately 0.5 mile north of the I-69 and I-465 interchange, the four southbound lanes of I-69 expand to five lanes before splitting into two left lanes continuing south and becoming Binford Boulevard and the three right lanes becoming a connection ramp to channel vehicles westbound or southbound on I-465. (See figure 2.) The three lanes of the connection ramp expand to four lanes before splitting into two right lanes curving to the right to direct vehicles westbound on I-465 and two left lanes curving to the left to guide vehicles southbound on I-465.

Two advisory speed limit signs posted for 50 mph are on the right side of the ramp approximately 650 feet and 1,500 feet north of the accident site. The computed effective design speed for the connection ramp is approximately 53 mph. Two spot-speed studies[46] conducted on the ramp by INDOT at separate locations on November 2, 2009, indicated that the 85th percentile speed at the first location (approximately 750 feet north of the accident site) was 56 mph for passenger cars and 53 mph for heavy trucks. The study further indicated that the 85th percentile speed at the second location (approximately 2,450 feet south of the accident site) was 58 mph for passenger cars and 55 mph for heavy trucks.

The connection ramp north of the accident location has a −0.8 percent downgrade slope. The radius of the ramp's leftward horizontal curve (direction of travel) is 881 feet. The ramp has the following markings: a 6-inch-wide solid yellow line separating the left lane from the left paved shoulder; 6-inch-wide, 10-foot-long broken white lines every 30 feet separating the left lane from the right lane; and a 6-inch-wide solid white line separating the right lane from the

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[45] A semi-direct connection ramp channels vehicles from one high-speed highway to another by negotiating two curves—the first headed in a direction away from the intended route and the second gradually reversing back to connect with the other high-speed highway. For further information, see *A Policy on Geometric Design of Highways and Streets*, 5th ed. (Washington, DC: American Association of State Highway and Transportation Officials, 2004), p. 824.

[46] A spot speed study uses automated methods with radar or laser speed detection equipment to measure the speed characteristics of vehicles at a specified location under the traffic and environmental conditions prevailing at the time of the study.

right paved shoulder. No longitudinal rumble strips are on the ramp's shoulders.[47] The average daily traffic on the ramp increased from 25,000 vehicles per day on April 1, 1998, to 34,000 vehicles per day on October 28, 2009. A full vehicle classification study conducted by INDOT from October 28–30, 2009, found that traffic on the connection ramp consisted of approximately 87.5 percent passenger vehicles (class 1–3) and 12.5 percent trucks (class 4–13).[48] From 2004–2008, 122 accidents occurred on the ramp, including one fatal accident in 2006.[49]

1.11.1. Cross-Slope Break

The cross-slope break, located at the edge of the paved traveled way or at the interface between the traveled way and the shoulder, is calculated by taking the algebraic difference in traverse grades between the traveled way and the shoulder. For example, a cross-slope break for a traveled way with a positive 8 percent cross slope, sloped upward from left to right (in the direction of travel), and a shoulder that has a negative 2 percent cross slope, sloped downward from left to right (in the direction of travel)—such as existed in the vicinity of the connection ramp—would be 10 percent (see figure 13).

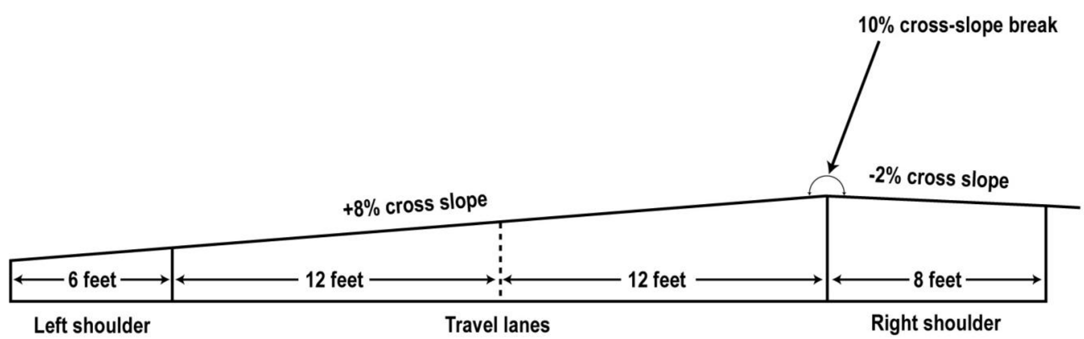

Figure 13. Cross-slope break.

On straight roads, right shoulders are usually sloped downward to provide water drainage away from the roadway. On curved roads, travel lanes should be sloped (superelevated) to reduce the instability that could result in spinout or rollover accidents as vehicles negotiate curves, and shoulders should be sloped sufficiently to prevent excessive rainwater drainage onto the traveled way, but not so much as to create a hazard for vehicles that drive onto the shoulder.

[47] Longitudinal rumble strips are raised or grooved patterns in the pavement that cause vehicles traveling over them to vibrate, alerting the driver. INDOT does not typically install longitudinal rumble strips on the shoulders of ramps.

[48] The FHWA 13-category classification system includes class 1–3 vehicles, consisting of motorcycles, passenger cars, and four-tire single unit vehicles, and class 4–13 vehicles, consisting of buses, multi-axle single-unit trucks, and articulated heavy combination vehicles.

[49] The fatality resulted from a high-speed, run-off-the-road motorcycle accident.

During the on-scene investigation, measurements were taken with a standard survey level rod every 20 feet along the connection ramp up to the location where the cargo tank semitrailer collided with the bridge pier column. These measurements found that the cross slope of the left southbound lane varied from +7.20 to +8.27 percent, sloping upward from left to right (in the direction of travel); the cross slope of the right southbound lane on the ramp varied from +6.58 to +8.25 percent, sloping upward from left to right (in the direction of travel); and the cross slope of the right shoulder varied from −1.25 to −2.75 percent, sloping downward from left to right (in the direction of travel). Cross-slope measurements obtained on the connection ramp after the accident indicated a cross-slope break between the right southbound lane and right shoulder varying from 8.08–10.75 percent.

AASHTO Standards for Cross-Slope Break. The design plans for the connection ramp developed in 1968 followed the 1957 American Association of State Highway Officials (AASHO) *A Policy on Arterial Highways in Urban Areas* (commonly known as the Red Book) and the 1965 AASHO *A Policy on Geometric Design of Rural Highways* (commonly known as the Blue Book). Both the AASHO 1957 Red Book and 1965 Blue Book recommended a maximum cross-slope break of 7 percent. Little change in the standards and philosophy of cross-slope breaks has occurred from 1957 to the present, with the exception of a decision published in the 2004 American Association of State Highway and Transportation Officials (AASHTO)[50] *A Policy on Geometric Design of Highways and Streets*[51] (commonly known as the Green Book) recommending that "the grade break at the edge of the paved surface be limited to approximately 8 percent."

Cross-Slope Break in Original Design Plans. INDOT's original design plans for construction of the connection ramp where this accident occurred included a +8 percent cross slope for the left and right southbound lanes and a −4 percent cross slope for the right shoulder, equaling a cross-slope break between the right southbound lane and right shoulder of approximately 12 percent. Following this accident, INDOT conducted a records search to determine why the ramp's cross-slope break differed from the 7 percent maximum recommended by AASHO standards developed in 1957 (Red Book) and 1965 (Blue Book).

The cross-slope break on the connection ramp was designed using a standard INDOT ramp section sheet dated June 19, 1968,[52] which appears as Sheet Number 5 on the original design plans. The June 1968 standard INDOT ramp section sheet indicates that the ramp's traveled way was designed with a +8 percent cross slope and its right shoulder with a −4 percent cross slope, corresponding to an original cross-slope break of approximately 12 percent between the traveled way and right shoulder. The as-built plans confirmed that the cross-slope break was constructed as shown on the original design plans. However, sometime after the connection ramp was constructed with a 12 percent cross-slope break in 1970, the right shoulder on the ramp was

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[50] AASHTO (formerly AASHO) is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico that fosters the development, operation, and maintenance of an integral national transportation system.

[51] *A Policy on Geometric Design of Highways and Streets*, 5th ed. (2004), p. 316.

[52] The standard INDOT ramp section sheet dated June 19, 1968, would only have been used in situations where the traveled way was in full superelevation or +8 percent cross slope.

modified by INDOT from a −4 percent cross slope, as illustrated on the original design plans for the ramp, to a −2 percent cross slope. INDOT could not determine from available records when the right shoulder was modified, resulting in a 10 percent cross-slope break; the agency surmised that it occurred when the most recent work on the ramp—a 1997 pavement resurfacing project—was conducted.

INDOT also determined from a records search that two changes occurred after the original plans were developed in June 1968. A standard INDOT ramp section sheet, dated August 12, 1968, illustrates the traveled way with a +8 percent cross slope and the right shoulder with a cross slope dependent on the ramp degree of curvature. Had the ramp been designed using the August 1968 standard INDOT ramp section sheet with a ramp curvature of 6° 30' (radius of 881 feet), the slope of the right shoulder would have been flat or zero percent. Another standard INDOT ramp section sheet, dated October 3, 1968, illustrates the right shoulder following the same 8 percent plane of superelevation[53] as the traveled way. Had the ramp been designed and built using the October 1968 standard INDOT ramp section sheet, the right shoulder would have been superelevated +8 percent in the same direction as the traveled way.

INDOT records revealed that the October 1968 standard INDOT ramp section sheet was utilized for designing cross-slope breaks on fully superelevated ramps until December 1, 1986, when the standard drawings for typical cross-sections were developed and included in the *Indiana Design Manual*, [54] which contains a list of typical applications for determining cross slopes on shoulders based on the superelevation of the traveled way. If the ramp had been designed today using the standards contained in the current *Indiana Design Manual* (January 2010), the right shoulder would have been superelevated +1 percent, resulting in a cross-slope break between the traveled way and the right shoulder of 7 percent.

Cross-Slope Break Research. A limited Federal Highway Administration (FHWA) study was conducted in 1981 to verify the adequacy of a maximum 7 percent cross-slope break requirement in the 1965 AASHO Blue Book.[55] A Highway-Vehicle-Object-Simulation Model (HVOSM) was used to evaluate various cross-slope break designs by testing the effects of curvature, speed, and path of a simulated passenger car. The simulations were performed with a moderate (rather than shallow or severe) departure from the travel lane onto the shoulder.[56] Because a moderate traversal is not a single definitive path but could be an infinite number of paths, the study selected a nominal path that had a smaller radius than the highway curve and permitted the simulated vehicle to come within 1.6 feet of the outside edge of the shoulder before returning to the travel lane. The simulated vehicle traveled at the design speed, and the simulated

[53] *Superelevation*, or *cross slope*, is expressed as a decimal and represents the ratio of the pavement width to elevation.

[54] "Horizontal Alignment," Section 43-3.06(01) "High-Side Shoulder," *Indiana Design Manual*, Part 5, Chapter 43, January 21, 2010 <http://www.in.gov/dot/div/contracts/standards/dm/2011/index.html>, accessed April 28, 2011.

[55] J.C. Glennon and others, *HVOSM Studies of Cross-Slope Breaks on Highway Curves*, DOT-FH-11-9575 (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, 1981).

[56] A *moderate departure* onto the shoulder occurs when the vehicle could be steered back to the pavement if the shoulder is wide enough, and the cross-slope break and shoulder slope do not cause the vehicle to exceed available skid resistance or result in intolerable centrifugal force on the driver.

driver released its foot from the accelerator pedal at the first point of encounter with the cross-slope break.

A series of HVOSM runs were performed to compare the dynamic differences between partial (straddling with right side wheels only) and full placement (entire vehicle) traversals onto the shoulder. A maximum 0.3 *g* lateral acceleration for driver discomfort was established, which was considered to be the level of apprehension most drivers could withstand during shoulder traversals without the driver subsequently initiating a hard brake application or excessive steer input that could result in a loss of control maneuver. The 0.3 *g* criterion was found to correspond with the 1965 AASHO Blue Book recommendation for a maximum 7 percent cross-slope break.

The four-wheel traversals onto the shoulder (rather than two-wheel traversals) produced the most extreme dynamic responses. Driver discomfort mainly increased with shoulder slope and very little, if any, with the amount of cross-slope break. Thus, for a given design speed and superelevation of a horizontal curve, the maximum tolerable cross-slope break was a function of the shoulder cross slope. The most important conclusion from the study (according to the authors) is that for a negative shoulder cross slope to be tolerable for a recovery maneuver, it should be designed with just the minimum cross slope necessary to keep water from pooling in the travel lanes.

1.11.2 Protection of Bridge Pier Columns

The support structure for the southbound I-465 overpass consisted of a concrete bridge footing (crash wall), seven concrete cylindrical pier columns, and a pier cap. The bridge footing was raised approximately 1.5 feet from the ground. The reinforced pier columns were 24 inches in diameter and stood approximately 14.3 feet high, as measured from the top of the bridge footing to the bottom of the pier cap. The outermost bridge pier column on the southbound I-465 overpass, which was struck by the cargo tank, was the first in a row of seven uniformly spaced columns approximately 10 feet on center.

Strong post blocked-out W-beam guardrails were located on both sides of the connection ramp adjacent to the paved shoulders to protect the bridge pier columns from vehicle impacts. The strong posts that were connected to the steel W-beam rail element consisted of steel I-beams spaced 6.25 feet apart and embedded approximately 4–5 feet in the ground. The W-beam rail element was extended away (blocked out) from the posts with steel or timber spacer blocks. The W-beam guardrail was 30 inches tall, as measured from the pavement surface to the top of the W-beam rail element. The W-beam guardrail on the right side of the ramp began approximately 340 feet north of the I-465 overpasses, and the W-beam guardrail on the left side, approximately 930 feet. The concrete bridge pier column impacted by the semitrailer was offset from the W-beam guardrail by approximately 6 feet (see figure 14).

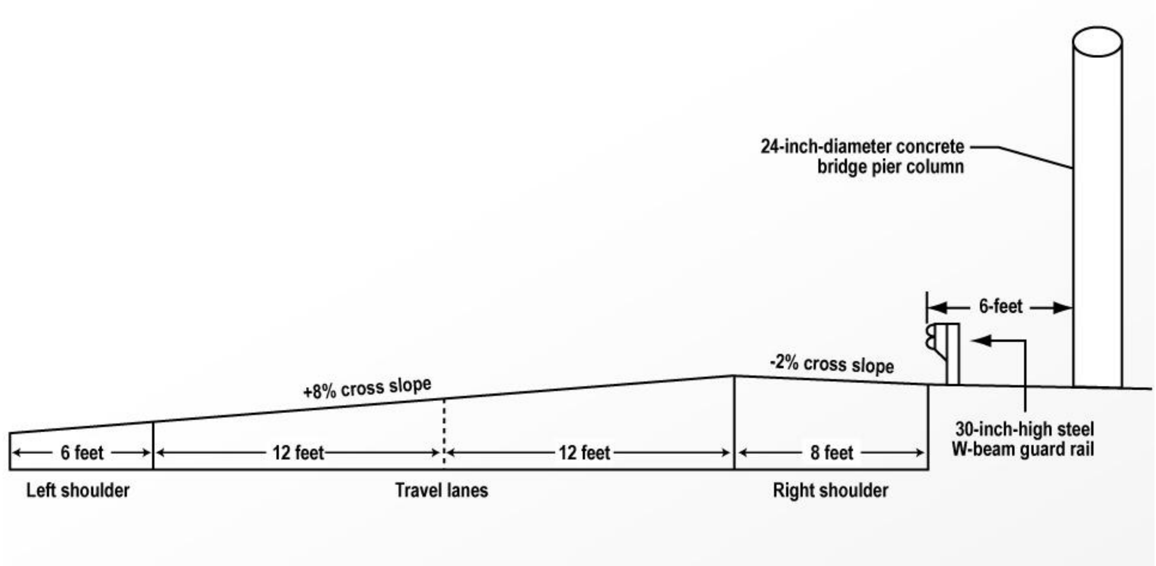

Figure 14. Bridge pier column protection (before accident).

Temporary construction shoring was erected after the accident behind the bridge pier column to provide vertical support for the three outside beam lines of the southbound I-465 overpass. A reinforced concrete wall, measuring approximately 14 feet high by 12 feet long by 2 feet wide, was then erected between the bridge footing and pier cap to fill the void space created after the bridge pier column was struck. I-465 remained closed to traffic for at least 1 day after the accident. The connection ramp was reopened on October 27, 2009.

AASHTO Standards. Since the adoption of the first AASHO specifications in 1931, the body of knowledge in bridge research and design has grown significantly. The most recent framework—*Load and Resistance Factor Design (LRFD) Bridge Design Specifications*—utilizes state-of-the-art analysis and design methodologies and makes use of load and resistance factors based on the known variability of applied loads and material properties.[57] A phased approach was taken to implement the requirements of *LRFD Bridge Design Specifications*, with a transition schedule extending from 1994–2007. All five editions of the *LRFD Bridge Design Specifications*[58] contain similar provisions for bridge pier protection, with the most recent edition published by AASHTO in 2010. AASHTO and the FHWA determined that, after October 1, 2007, all new bridges and replacements of existing bridges should be designed using the most current edition of the *LRFD Bridge Design Specifications,*[59] which requires that bridge pier columns be protected if located within an area that extends approximately 30 feet from the edge of the traveled way (clear zone). Further, obstacles located within the clear zone should be removed, relocated, redesigned, or shielded by traffic barriers or crash cushions.

[57] *LRFD Implementation Plan*, Initial Draft, Federal Highway Administration. <http://www.fhwa.dot.gov/bridge/lrfd/plan.cfm>, accessed June 22, 2011.

[58] Publication dates for the *LRFD Bridge Design Specifications* are as follows: 1st ed. (1994), 2nd ed. (1998), 3rd ed. (2004), 4th ed. (2007), and 5th ed. (2010).

[59] *Design Standards for Highways*, 23 CFR Part 625.

The Transportation Research Board (TRB) National Cooperative Highway Research Program (NCHRP) has established the following criteria for barrier protection testing:[60]

- **Test levels 1–3 (TL-1, TL-2, and TL-3):** An 1,800-pound car striking a barrier at a 20° angle and a 4,400-pound pickup truck striking a barrier at a 25° angle at speeds of 30 mph (TL-1), 45 mph (TL-2), and 60 mph (TL-3), respectively.
- **Test level 4 (TL-4):** A 17,600-pound single-unit truck striking a barrier at an angle of 15° at 50 mph.
- **Test level (TL-5):** An 80,000-pound truck-tractor and a van-type semitrailer striking a barrier at an angle of 15° at 50 mph.
- **Test level (TL-6):** An 80,000-pound truck-tractor and a cargo tank semitrailer striking a barrier at an angle of 15° at 50 mph.

Minimum height requirements for bridge railings, which are contained in the AASHTO *LRFD Bridge Design Specifications*, are as follows: TL-1, TL-2, and TL-3 barriers—27 inches; TL-4 barrier—32 inches; TL-5 barrier—42 inches; and TL-6 barrier—90 inches.

Bridge pier columns in the clear zone can be protected by either providing structural resistance to the bridge pier column or by redirecting or absorbing an impact from an errant vehicle. The option to redirect or absorb can be provided with an embankment or a 54-inch-high concrete barrier if the bridge pier column is located within 10 feet of the edge of the traveled way or a 42-inch-high concrete barrier if the bridge pier column is located more than 10 feet but less than 30 feet from the edge of the traveled way.[61] These barriers must be structurally and geometrically capable of withstanding the impact specified for a TL-5 barrier. The option to provide structural resistance requires that the bridge pier column be designed for an equivalent static force of 400 kips[62] (400,000 pounds), acting in any direction in a horizontal plane at a distance of 4 feet above the ground. Based on the results of a Transportation Pooled Fund Program[63] study entitled *Guidelines for Designing Bridge Piers and Abutments for Vehicle Collisions*,[64] a recommendation was made to AASHTO's Subcommittee on Bridges and Structures in May 2010 that the equivalent static force of 400 kips be increased to 600 kips.

New and Replacement Bridges. The *LRFD Bridge Design Specifications* contain Federal requirements for the protection of bridge pier columns on approximately 500 new and replacement bridges built in the United States each year (see table 5).[65] This new construction

[60] *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report 350 (Washington, DC: Transportation Research Board, 1993).

[61] The requirements of AASHTO *LRFD Bridge Design Specifications* for protecting bridge pier columns differ and are independent from test levels for roadside barriers.

[62] A kip is a unit of force equaling 1,000 pounds.

[63] A Transportation Pooled Fund Program study is generally conducted to solve transportation-related problems with significant or widespread interest and may be funded jointly by several Federal, state, regional, and local transportation agencies. The Texas Department of Transportation was the sponsoring agency for this study.

[64] *Guidelines for Designing Bridge Piers and Abutments for Vehicle Collisions* (College Station, Texas: Texas Transportation Institute, Texas A&M University, December 2009).

[65] FHWA Office of Bridge Technology, e-mail to the NTSB (November 17, 2010).

represents a small percentage of the approximately 41,000 bridges in the United States[66] with a roadway passing underneath bridge spans, where intermediate columns are subject to vehicle impacts.[67]

Table 5. New and replacement of bridges built in the United States, 2005–2009.

Year	New and Replacement Bridges
2009	476
2008	640
2007	540
2006	597
2005	548

The *AASHTO Roadside Design Guide* provides guidance to highway agencies on the use of roadside barriers to protect bridge pier columns that are part of new projects and major projects involving the addition of a lane, significant changes to a roadway's horizontal or vertical alignment, or reconstruction of an interchange. The 2006 *Roadside Design Guide* does not contain objective warrants but suggests that higher performance traffic barriers (TL-4 and above) be utilized at locations with above-average heavy truck traffic, adverse geometrics with poor sight distance, or severe consequences associated with the penetration of a barrier by a large vehicle.

Existing Bridges. Although AASHTO's *LRFD Bridge Design Specifications* and *Roadside Design Guide* are adequate for planned highway improvements, documentation is limited for assessing the protection of bridge pier columns on existing bridges not scheduled for construction. The FHWA Office of Bridge Technology did indicate, however, that the criteria contained in the *LRFD Bridge Design Specifications,* which specifies minimum requirements for new bridges, may also be used by bridge owners to evaluate existing bridges,[68] including structures and piers.

An inventory conducted by INDOT on December 3, 2009, of all direct and semi-direct connection ramps and roadside bridge pier protection revealed that approximately 44 direct or semi-direct connection ramps were classified as underpasses[69] in Indiana and each had some type of roadside barrier for protecting bridge pier columns. The level of protection varied from a W-beam guardrail (TL-3) to a concrete barrier (TL-4 or TL-5).

INDOT indicated that ramps in Indiana cannot be systematically ranked in terms of traffic safety performance when a systemwide evaluation of roads is conducted because the large number of accidents on ramps makes it impossible to assign precise latitude and longitude coordinates. This limitation restricts the ability to compare accidents that occur on a particular

[66] New and replacement bridges or other structures are built because of substandard load-carrying capacity or substandard bridge roadway geometry (FHWA Office of Safety e-mail to the NTSB, November 4, 2010).

[67] The National Bridge Inventory, which aggregates structure inventory and appraisal data collected by each state, consists of approximately 600,000 bridges.

[68] FHWA Office of Bridge Technology e-mail to the NTSB (December 9, 2010).

[69] Underpasses are considered direct or semi-direct connection ramps when the ramp is carried under another roadway, rather than over.

ramp with other types of ramps or road segments, road intersections, and road interchanges. To address this circumstance unique to ramps, INDOT plans to use supplementary analysis to gauge the performance of ramps when it conducts future evaluations of the traffic safety performance of its road system. The objective of such analysis will be to identify ramps operating poorly so that they can be improved with infrastructure or engineering treatments, modification of traffic control devices, enforcement, or other measures.[70]

1.12 Cargo Tank Motor Vehicles

Cargo tank motor vehicles represented 8.3 percent of the national fleet with five axles or more in 1997; approximately 80 percent of these vehicles transport bulk liquids or gases and approximately 20 percent, dry bulk materials.[71] About 85 percent of all tractor-semitrailers traveling with hazardous materials are cargo tank motor vehicles; the remainder are van-type semitrailers.[72]

1.12.1 DOT Specification Cargo Tanks

Federal regulations for the design and construction of cargo tanks that transport bulk liquid hazardous materials ("DOT specification cargo tanks") are established by the Pipeline and Hazardous Materials Safety Administration (PHMSA). Design requirements for cargo tanks contained in 49 CFR Part 178 (*specifications for packaging*) are supported by ASME standards. Testing and inspection requirements for cargo tanks are contained in 49 CFR Part 180 (*continuing qualification for maintenance of packaging*). Depending on the specification of the cargo tank, the following tests and inspections are required either annually or every 5 years: periodic external and internal visual inspection, lining inspection, leakage testing, thickness testing, wet fluorescent magnetic particle inspection of interior welds, and a hydrostatic pressure test.

The MC331 cargo tank and its predecessor, the MC330, transport liquefied compressed gases[73] in a smooth-bore (single) compartment, noninsulated, straight round cargo tank with hemispherical (half dome) or torispherical (shallow dome) heads and a maximum allowable working pressure between 100 and 500 psig. The average useful life of an MC331 cargo tank ranges from 25–50 years.[74] MC330 cargo tanks, which were last manufactured in 1965, still

[70] INDOT Director of Bridge Design, Inspection, Hydraulics, and Technical Support, response (September 2, 2010) to a question during the August 2010 NTSB public hearing on the Indianapolis rollover accident. For further information, see "Rollover and Fire of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas in Indianapolis, Indiana, October 22, 2009," public hearing, Washington, DC, August 3–4, 2010 <http://www.ntsb.gov/events/2010/Indianapolis-IN/Default.html>, accessed June, 22, 2011.

[71] *Analysis of the Vehicle Inventory and Use Survey for Trucks with Five-Axles or More* (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, May 2001).

[72] K.L. Campbell, *National Estimates of the Number of Trucks, Travel, and Accident Experience of Tractor Semitrailers Used to Transport Hazardous Materials*, Report No. UMTRI-89-1 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1989).

[73] Compressed gases such as propane, butane, anhydrous ammonia, chlorine, and sulphur dioxide are transported in a liquid form under pressure.

[74] Testimony delivered by cargo tank manufacturers on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

represent approximately 15–20 percent of the cargo tanks currently transporting liquefied compressed flammable gases.[75] The most common articulated commercial motor vehicle for transporting liquefied petroleum gas is a three-axle truck-tractor and two-axle cargo tank semitrailer, the type of combination unit involved in this accident.

1.12.2 Crashworthiness of DOT Specification Cargo Tanks

The NTSB examined the crashworthiness of DOT specification cargo tanks in its investigation of a 1994 accident[76] involving a cargo tank motor vehicle rollover. In that accident, a truck-tractor in combination with a specification MC331 cargo tank semitrailer transporting 9,200 gallons of liquefied petroleum gas, drifted across the left lane and left shoulder, struck a guardrail, rolled over, and collided with a cylindrically shaped concrete bridge pier column. The front head of the tank fractured, releasing liquefied petroleum gas, which vaporized and ignited. The blast propelled the tank approximately 300 feet onto a wood-framed house. The driver was killed, 23 people were injured, and an area with a radius of approximately 400 feet was engulfed by fire. As a result of its investigation, the NTSB issued the following recommendation to the Research and Special Programs Administration (RSPA)[77]:

> In cooperation with the Federal Highway Administration, study methods and develop standards to improve the crashworthiness of front heads on cargo tanks used to transport liquefied flammable gases and potentially lethal nonflammable compressed gases. (H-95-37)

The recommendation prompted RSPA to sponsor two studies to determine the response of MC331 cargo tank heads when striking various obstacles and the effect of head shielding on improving the crashworthiness of cargo tanks in various impact scenarios. The first study established a correlation between analytical models and damage resulting from actual accidents, examined failure criteria for the puncture of unprotected heads and those with a full or partial shield, compared the shape and thickness of heads to determine practical designs for unprotected heads, and evaluated head shielding at various distances and energy-absorbing material.[78] The work involved developing a three-dimensional finite element model to determine the speed at which the unprotected hemispherically shaped front head of an MC331—similar to the cargo tank involved in the White Plains, New York, accident—would fail during four accident scenarios: (1) frontal impact with a rigid wall, (2) angled impact at 45° into a rigid wall, (3) impact into a 6-inch-diameter immovable circular post, and (4) impact with the tank rotated onto its side into a 42-inch-diameter cylindrical column. The models indicated that the front head

[75] Testimony delivered by Mike Pitts, Vice-President, Sales, Mississippi Tank Company, on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[76] *Propane Truck Collision with Bridge Column and Fire, White Plains, New York, July 27, 1994*, Highway Accident Report NTSB/HAR-95/02 (Washington, DC: National Transportation Safety Board, 1995).

[77] Within DOT, RSPA was reorganized in 2004 into PHMSA and the Research and Innovative Technology Administration.

[78] A. Selz and C.F. Heberling, Pressure Sciences Incorporated, *Improving Crashworthiness of Front Head of MC331 Cargo Tank Motor Vehicles* (Washington, DC: Research and Special Programs Administration, February 2000).

would fail at approximately 25 mph after striking a rigid wall and at less than 15 mph after impacting a 42-inch-diameter concrete column.

Despite concerns about the adequacy of minimum construction requirements allowing the front head to be thinner than the tank shell, researchers were surprised to find that the thicker hemispherical head—as revealed by the models—had a lower failure speed than the thinner one when both struck a rigid wall; and, furthermore, that the 0.25-inch and 0.378-inch-thick hemispherical front heads of the cargo tanks both failed at impact speeds below 15 mph when a cylindrical concrete column was struck. The study results indicated that protection against angled impacts into rigid surfaces or collisions with bridge pier columns may be enhanced by placing energy-absorbing material between the front head and a secondary head on the MC331 cargo tank. Researchers recommended that a cost-benefit analysis be conducted for a conceptual head shielding design to improve the crashworthiness of MC331 cargo tanks.

The second study sponsored by RSPA evaluated the feasibility, manufacturing costs, and marketability considerations for reducing the probability of fractures and/or penetrations to the front heads and adjacent structure of the MC331 cargo tank.[79] Finite element models were again used to evaluate different approaches to protect the front heads of MC331 cargo tanks. Various densities and thicknesses of foam were examined to determine which configuration of energy-absorbing material would prevent a cargo tank from rupturing during a collision. It was determined that a foam thickness of 18 inches would protect the front head of the tank from failure during a 45° angle impact into a rigid wall at 52 mph and into a rigid 42-inch-diameter column at up to 59 mph. The estimated cost of installing an 18-inch-thick layer of energy-absorbing foam covered with a 0.060-inch-thick layer of sheet steel over the head of an MC331 cargo tank was $27,939 per trailer. The study concluded that although the modification would protect the tank from failure during the crash and impact scenarios that were studied, at speeds up to approximately 55 mph, the increased manufacturing cost and weight of 4,376 pounds of additional material for each cargo tank would not be cost effective.

In an August 18, 2003, letter to the Acting Administrator, RSPA, the NTSB acknowledged the cost constraints of improving cargo tank crashworthiness but also asserted that crashworthiness remains a critical issue for cargo tanks transporting liquefied petroleum gas, with the concomitant potential for flammable gas explosions, toxic gas releases, and rocketing of cargo tanks. Consequently, Safety Recommendation H-95-37 and its companion recommendation to the FHWA, H-95-35, were classified “Closed—Unacceptable Action.”

1.12.3 Hazardous Materials Carrier Registration

An objective assessment of DOT specification cargo tank involvement in reportable incidents requires access to accurate information about the population of cargo tanks by DOT specification. Information associated with the operation of DOT specification cargo tanks is collected and maintained by the FMCSA and PHMSA. According to the FMCSA, approximately

[79] A. Selz and P. Burnside, Pressure Sciences Incorporated, *Further Work to Improve Crashworthiness of Front Head of MC331 Cargo Tank Motor Vehicles* (Washington, DC: Research and Special Programs Administration, March 2001).

6,500 motor carriers operate a fleet of cargo tank motor vehicles that transport liquefied petroleum gas.[80]

The FMCSA registration process requires all interstate motor carriers, commercial motor vehicle registrants from select states, and commercial intrastate hazardous materials carriers hauling quantities requiring a safety permit to complete and submit a *Motor Carrier Identification Report* (MCS-150) to obtain a USDOT number. Carriers are also required to file biennial updates to report changes in operations, including the number of vehicles operated in the United States. Data contained on the MCS-150 form are stored in the Motor Carrier Management Information System (MCMIS), a system of databases containing information from field offices and other sources. These data include police-reported accidents involving cargo tank motor vehicles in which no release of hazardous materials occurred. MCMIS is a source of inspection, crash, compliance review, safety audit, and registration data.

Since 1992, PHMSA has required entities transporting certain hazardous materials, including hazardous wastes, to submit a *Hazardous Materials Registration Statement* (DOT Form F 5800.2) and pay an annual registration fee. DOT Form F 5800.2 requests the identity of the hazardous materials carrier, the mode(s) of transportation used, business category, basic description of hazardous materials activity, and states where operations are conducted. Registration fees collected from hazardous materials carriers provide funding for grants distributed to states and other professional organizations for hazardous materials emergency response planning and for training through the Hazardous Materials Emergency Preparedness Grants Program.

1.12.4 Rollover Awareness

More than 1,300 rollovers involving cargo tank motor vehicles occur yearly in the United States.[81] Approximately 60 percent of these rollovers involve semitrailers and 40 percent, single-unit trucks.[82] The rollover rate of cargo tank semitrailers is more than double that of all other semitrailers.[83] Rollovers occur in 24 percent of all hazardous material accidents and account for 75 percent of all spills.[84] About 50 percent of truck driver deaths and 47 percent of

[80] "Effectiveness of Driver Training for Preventing Rollover Accidents," PowerPoint presentation delivered by James O. Simmons, FMCSA, on August 3, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[81] "Tank Truck Drivers: This Sign's for You!" *Safety News* (Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration, May 13, 2008).

[82] D.B. Pape and others, Battelle, *Cargo Tank Roll Stability Study*, final report, contract no. GS23-F-0011L (Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration, April 30, 2007).

[83] UMTRI-89-1.

[84] *Hazardous Materials Serious Crash Analysis: Phase 2*, final report (Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration, April 2005).

incapacitating injuries occur from rollovers.[85] Driver error (such as decision or recognition error) was found to be a factor in approximately 75 percent of cargo tank rollovers.[86]

Government and industry have been involved in a number of rollover awareness initiatives. In 2005, the National Tank Truck Carriers (NTTC) partnered with J.J. Keller & Associates, Inc., to develop an educational campaign consisting of a monthly poster, fact sheet, and payroll stuffers to raise the awareness of drivers on how to prevent cargo tank rollovers.[87] In 2006, the FMCSA sponsored a *Cargo Tank Roll Stability Study* to learn more about the factors contributing to and strategies for reducing cargo tank rollovers.[88] The study examined how rollovers can be reduced by outfitting cargo tank motor vehicles with stability control systems, enhancing the basic roll stability of cargo tank motor vehicles, employing strategies to address difficult geometric and surface challenges, and improving driver training. The *Cargo Tank Roll Stability Study* concluded that although the tasks of safely operating a cargo tank motor vehicle are essentially the same as those for operating other class A heavy trucks, they must be mastered to a greater proficiency. To date, traditional approaches for raising cargo tank vehicle driver skills, such as disseminating instructional materials, have been employed in this effort. For example, the FHWA's Office of Motor Carriers (predecessor to the FMCSA) has issued educational materials on the skills required for operating and controlling cargo tank motor vehicles through its *On Guard* bulletins.

Following its investigation of a 1991 tractor-semitrailer (cargo tank) rollover,[89] the NTSB issued the following recommendation to the FHWA:

> Issue periodic *On Guard* bulletins to remind all carriers and drivers to be attentive and aware of the conditions that can lead to a loss of stability and rollover in a tank truck. (H-91-33)

In response to the recommendation, the FHWA published two additional safety bulletins, in August 1992 and March 1995, in addition to one previously published in June 1980 on cargo tank motor vehicle safety,[90] to remind drivers about the need to review the special handling requirements for cargo tank motor vehicles with partial loads. Because the FHWA had published several *On Guard* bulletins since 1980 regarding the loss of stability and potential for rollover of cargo tank motor vehicles and stated it would continue to publish future bulletins if necessary, the NTSB classified Safety Recommendation H-91-33 "Closed—Exceeds Recommended Action" on June 24, 1996.

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[85] *1995 Truck and Bus Crash Fact Book*, Report No. UMTRI-97-30 (Ann Arbor, Michigan: Center for National Truck Statistics, University of Michigan Transportation Research Institute, 1997).

[86] *Cargo Tank Roll Stability Study*.

[87] "NTTC, J.J. Keller Launch Anti-Rollover Campaign," *Bulk Transporter*, June 1, 2005.

[88] *Cargo Tank Roll Stability Study*.

[89] *Overturn of a Tractor-Semitrailer (Cargo Tank) With Release of Automotive Gasoline and Fire, Carmichael, California, February 13, 1991*, Hazardous Materials Accident Report NTSB/HZM-91/01 (Washington, DC: National Transportation Safety Board, 1991).

[90] "Anything Other Than Full or Empty," *On Guard* (Washington, DC: Office of Motor Carriers, Federal Highway Administration, June 1980, August 1992, and March 1995).

In late 2007, the FMCSA scheduled a series of Tank Truck Rollover Prevention Summits to discuss and review approaches for rollover reduction and develop training and management materials.[91] To further address the problem, the FMCSA, in association with PHMSA and industry partners, created a *Cargo Tank Driver Rollover Prevention Video,* which was released on August 3, 2010, to serve as a training aid for commercial drivers of cargo tank motor vehicles transporting hazardous materials.

The long-term effectiveness of traditional approaches (such as brochures and videos) for raising driver awareness of rollover prevention strategies is generally unknown. A study currently under development by the TRB, *Role of Human Factors in Preventing Cargo Tank Truck Rollovers,* which seeks to identify and analyze the root causes of cargo tank rollovers, may provide greater insight on increasing the awareness of drivers about actions necessary to prevent the rollover of cargo tank motor vehicles.[92]

A *Heavy Vehicle Rollover Prevention Program* introduced by VicRoads[93] to approximately 5,000 commercial drivers in July 2009 was effective in reducing rollover accidents. The program used truck models to visually demonstrate the effect of CG height on heavy commercial truck rollovers and encouraged motor carriers to develop a written code of behavior on the shared role of drivers and management in developing workable solutions for preventing rollover accidents, as opposed to merely presenting driver- or management-driven objectives. The program operated with the understanding that management would reduce the risk of rollovers by purchasing trailers with as low a CG height as practical, selecting routes to avoid high risk locations, and monitoring drivers' schedules to prevent fatigue.

1.13 Vehicle-Based Rollover Prevention

Two primary vehicle-related approaches are available to prevent cargo tank motor vehicle rollovers. One approach involves equipping vehicles with stability control systems to reduce "untripped" rollovers[94] resulting from excessive speed in a curve, which represent approximately 10–15 percent of rollovers involving cargo tank motor vehicles. The second approach involves vehicle design strategies for improving roll stability to reduce the number of tripped and untripped rollovers.

1.13.1 Stability Control Systems

The NTSB has long advocated the study and implementation of advanced crash avoidance technologies to assist drivers in maintaining control of commercial motor vehicles.

[91] "Tank Truck Rollover Prevention Summits," *Bulk Transporter,* October 1, 2007.

[92] The study was initiated in October 2010, with a final report anticipated in January 2012.

[93] VicRoads is a statutory authority of the State of Victoria in the Commonwealth of Australia. For further information, see *Heavy Vehicle Rollover Prevention Program*, VicRoads, Australia <http://www.vicroads.vic.gov.au/truckrollover>, accessed May 1, 2011.

[94] *Untripped* rollovers occur when tire/road interface friction is the only external force acting on a vehicle that rolls over. In contrast, *tripped* rollovers are caused when vehicles impact curbs, potholes, and guardrails or when wheel rims burrow into soft soil or pavement.

For example, in its investigation of a multiple-fatality mid-size bus rollover accident that occurred in Dolan Springs, Arizona, in January 2009,[95] the NTSB addressed the benefits of equipping buses with a gross vehicle weight rating (GVWR) greater than 10,000 pounds with stability control systems. As a result of that investigation, the NTSB issued the following recommendations to NHTSA:

> Develop stability control system performance standards applicable to newly manufactured buses with a gross vehicle weight rating above 10,000 pounds. (H-10-5)
>
> Once the performance standards from Safety Recommendation H-10-5 have been developed, require the installation of stability control systems in all newly manufactured buses in which this technology could have a safety benefit. (H-10-6)

In November 2009, NHTSA announced the availability[96] of its *Final Vehicle Safety Rulemaking and Research Priority Plan for 2009–2011*,[97] which indicated test procedures would be developed to support a stability control standard for truck-tractors. The planned research involves testing rollover stability control (RSC) systems and electronic stability control (ESC) systems for heavy trucks and vehicles greater than 10,000 pounds GVWR, including truck-tractors, single-unit trucks, buses, and motorcoaches. In its initial response since Safety Recommendations H-10-5 and -6 were issued in July 2010, NHTSA indicated to the NTSB that efforts were underway to develop test procedures supporting a potential standard on ESC systems.

In March 2011, NHTSA published a notice to announce the availability of its *Final Vehicle Safety Rulemaking and Research Priority Plan 2011–2013*,[98] which was developed to apprise the public on the status of efforts delineated in the October 2009–2011 plan. The next milestone in the 2011–2013 plan for developing stability control systems to address rollover and loss-of-control accidents is a notice of proposed rulemaking in 2011, which will contain test procedures for truck-tractors and motorcoaches.[99] NHTSA also plans to make a decision in 2014 about developing test procedures as part of a stability control standard for trucks, buses, and all other vehicles greater than 10,000 pounds GVWR that are not included in the truck-tractor and motorcoach rulemaking activity. Therefore, pending the completion of these recommended actions, Safety Recommendations H-10-5 and -6 were reclassified "Open—Acceptable Response."

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

[96] *Federal Register*, vol. 74, no. 215 (November 9, 2009), p. 57623.

[97] Final Notice Rulemaking and Research Priority Plan 2009–2011, National Highway Traffic Safety Administration, Document ID Number 2009-0108-0022, <http://www.regulations.gov/search/Regs/home.html#documentDetail?R=0900006480a53424>, accessed May 1, 2011.

[98] *Federal Register*, vol. 76, no. 62 (March 31, 2011), p. 17808.

[99] *NHTSA Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan 2011–2013*, March 2011.

The benefits of stability control systems for passenger cars have been recognized for several years. A study using National Accident Sampling System (NASS) General Estimates System (GES) data from NHTSA to analyze different makes and models, but similar model years (MYs), of passenger vehicles found that by installing ESC systems, loss-of-control accidents could be reduced approximately 40.3 percent for cars and 71.5 percent for sport utility vehicles.[100] In addition, NHTSA issued a final rule in April 2007 requiring the installation of ESC in 100 percent of light vehicles with a GVWR of 10,000 pounds or less by MY 2012 (except some vehicles manufactured in stages or by small volume manufacturers).[101] ESC systems are becoming increasingly common standard equipment in passenger vehicles—an estimated 71 percent of MY 2010 light vehicles sold in the United States were equipped with ESC.

Stability control systems are an emerging technology that also holds promise for reducing heavy commercial motor vehicle accidents by preventing untripped rollovers (excessive speed in a curve), mitigating severe oversteer and understeer conditions that could lead to loss of control, and providing objective feedback to assist carriers monitor and improve driver performance. NHTSA has conducted field operational tests and several studies since 1998 to examine the effectiveness and safety benefits of active safety systems for enhancing the dynamic stability of heavy truck operations. Two stability control systems, tractor- or trailer-based RSC systems and tractor-based ESC, have been developed for commercial motor vehicles. RSC systems use accelerometers to continually monitor and compare the lateral acceleration of vehicles to a known critical rollover threshold. When the threshold has been reached, a tractor-based RSC system automatically reduces delivery of fuel to the engine and applies the foundation brakes on the drive axles and trailer to slow the speed of the vehicle in a curve. A trailer-based RSC system only applies the foundation brakes on the trailer when a critical rollover threshold has been detected. RSC is designed to prevent "untripped" rollovers in which the speed of a vehicle entering a curve is too fast.[102]

A tractor-based ESC system utilizes the same technology as RSC to prevent untripped rollovers but has the added benefits of a steer-angle sensor and yaw-rate sensor to automatically correct situations of understeer or oversteer, which can lead to loss of directional stability, and—unlike a tractor-based RSC—the capability of also applying the steer axle brakes. Sensor information (including wheel speed) is collected and analyzed by an electronic control module to determine whether a signal should be sent to automatically apply all brakes to slow the vehicle or a selective number of brakes to redirect the vehicle. To ensure wheels do not lock when brakes are applied, the ABS determines whether to maintain a constant high pressure or to modulate pressure to prevent wheel lockup.

Although a trailer-based RSC system can be retrofitted as aftermarket equipment, tractor-based RSC and ESC systems must be factory installed to ensure the full integration of sensors and other equipment with the vehicle's internal communication system. Tractor-based

[100] *The Effect of Stability Control on Motor Vehicle Crash Prevention*, Report No. UMTRI-2006-12 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 2006).

[101] *Electronic Stability Control Systems; Controls and Displays*, Final Rule, Federal Motor Vehicle Safety Standards, Docket No. NHTSA-2007-27662, June 22, 2007.

[102] *Cargo Tank Roll Stability Study*.

RSC and ESC systems are offered by the three major suppliers of brake components in the North American heavy vehicle market; the estimated retail cost of outfitting a vehicle with RSC or ESC is between $620[103] and $2,000.[104] Such systems became commercially available for class 8 truck-tractors in 2003 and 2005, respectively.[105] NHTSA estimates that 25 percent of truck-tractors will be equipped with ESC by 2012.[106] Manufacturer estimates as to ESC and RSC installation vary widely: One cargo tank manufacturer stated that 26 percent of new cargo tank semitrailers were equipped with RSC;[107] another indicated that although less than 5 percent of new cargo tank semitrailers were equipped with RSC between 2005 and 2008, that number increased to approximately 80 percent of cargo tank semitrailers manufactured since 2009;[108] and a third manufacturer indicated that less than 5 percent of newly manufactured cargo tank semitrailers were equipped with RSC.[109]

A 2009 NHTSA study conducted using the National Advanced Driving Simulator (NADS) to assess the effectiveness of stability control systems in reducing the incidences of rollovers and jackknifes for heavy trucks found performance differences between tractor-based RSC and ESC systems.[110] Sixty participants with a class A CDL were recruited to each complete five experimental drives on the simulator while executing an emergency maneuver, negotiating a decreasing radius curve, and traveling too fast around an exit ramp. Drivers were instructed to maintain speed for each event at the critical range necessary for RSC and ESC systems to provide a benefit. The RSC system showed strong reductions of rollovers in geometry-based situations, such as excessive speed in tight curves and exit ramps. The ESC system was effective in avoiding jackknifes but not to the same degree as the RSC system in preventing rollovers in curves.[111] Neither the ESC nor RSC system was effective in responding to emergency scenarios (right and left lane incursions) due to aggressive steering inputs resulting in highly dynamic vehicle stability changes. The swing of the trailer inertia in an emergency situation on dry road proved very difficult for stability control systems to overcome. Similar conclusions were drawn after a series of maneuvers were conducted on a test track, indicating that further study is required to understand how stability control technology and other factors influence the dynamic

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[103] The *Cargo Tank Roll Stability Study* cited a cost of $619 for tractor-based RSC; factory-option costs for tractor-based, all-inclusive ESC systems are estimated to be $2,100.

[104] Testimony delivered by Alan Korn, Director, Vehicle Dynamics and Control, Meritor WABCO, Vehicle Control Systems, on August 3, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[105] Class 8 truck-tractors have a GVWR greater than 33,001 pounds.

[106] "Effectiveness of Stability Control Systems for Truck-Tractors," *Traffic Safety Factors*, DOT-HS-811-437 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2011).

[107] Testimony delivered by Thomas J. Anderson, Vice-President of Product and Market Development, LBT, Inc., on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[108] NTSB telephone call with a cargo tank manufacturer, December 28, 2010.

[109] NTSB telephone call with a cargo tank manufacturer, June 1, 2011.

[110] T. Brown and others, *Heavy Truck ESC Effectiveness Study Using NADS*, DOT-HS-811-233 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2009).

[111] The RSC system activated at lateral acceleration levels of approximately 0.24 *g* compared to approximately 0.33 *g* for the ESC system.

response of heavy vehicles.[112] The performance of ESC and RSC systems can also be compromised by the lateral displacement of sloshing liquid loads.[113]

1.13.2 Vehicle Design

Solutions for reducing the number of rollovers should also consider measures available to improve the design and manufacture of cargo tank motor vehicles. British Petroleum realized, after 36 rollover accidents occurred in 9 months in 2005, that certain vehicle designs were less stable and prone to rollover. The company subsequently made design changes to its cargo tank motor vehicles to improve their rollover threshold.[114] The static roll stability of cargo tank motor vehicles can be improved to prevent tripped and untripped rollover accidents by maximizing the track width (distance between the centerline of dual tires) and selecting several available options for lowering the center of gravity (CG) height (see figure 15).

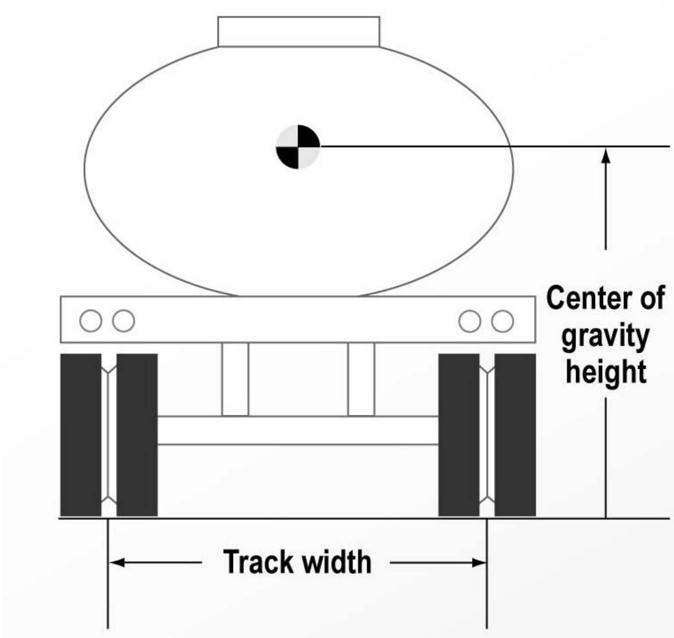

Figure 15. Fundamental design considerations for improving the roll stability of cargo tank motor vehicles.

Several factors must be considered in designing and manufacturing cargo tank motor vehicles that transport hazardous materials. These include responding to customer operational requirements; complying with Federal requirements for minimum ground clearance, maximum

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[112] F.S. Barickman and others, "NHTSA's Class 8 Truck-Tractor Stability Control Test Track Effectiveness," Paper No. 09-0552, *21st Annual Conference on Enhanced Safety of Vehicles, Stuttgart, Germany, June 15–18, 2009*.

[113] Marco P. daSilva, Greg Ayres, and Wassim G. Najm, *Crash Problem Definition and Safety Benefits Methodology for Stability Control for Single-Unit Medium and Heavy Trucks and Large-Platform Buses*, DOT-HS-811-099 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2009).

[114] *Rollover Awareness Training Pack* (2005), British Petroleum, PowerPoint presentation.

dimensions, and structural integrity of cargo tanks; and conforming to American Petroleum Institute (API) requirements on allowable heights for bottom-loading cargo tanks. API loading height requirements stipulate that the center of the loading pipes mounted on the side of cargo tanks be positioned 24–54 inches above the ground. Roll stability can be influenced by decisions made when cargo tank motor vehicles are designed and manufactured, such as limiting the overall length of a cargo tank motor vehicle to optimize maneuverability without revising the tank-carrying capacity or tire selections that unnecessarily raise the CG height.

Despite design constraints that tend to increase the CG height considerably above the frame rails, measures can be taken to reduce the propensity of cargo tank motor vehicles to roll over. Manufacturers can voluntarily select design options to strategically and effectively improve the roll stability of cargo tank motor vehicles, such as reducing the CG height as much as possible and maximizing track width (see table 6).

Table 6. Design options for improving the roll stability of cargo tank motor vehicles.

	Design Option	Truck-Tractor	Single-Unit Truck	Cargo Tank Trailer
Lower CG Height				
1	Minimize excess frame height	√	√	√
2	Minimize suspension ride height	√	√	√
3	Install low profile tires	√	√	√
4	Minimize fifth wheel mounting bracket height	√	—	—
5	Minimize height of subframe that cradles cargo tank	—	√	√
6	Install inserted upper coupler	—	—	√
7	Lower overall height of cargo tank	—	√	√
8	Change geometric shape of cargo tank	—	√	√
Increase Track Width				
9	Increase track width from 71.5–77.5 inches (dual tires)	√	√	√
10	Install wide-base tires on outset wheels*	√	√	√
*An outset wheel increases the track width by extending the hub mounting surface outward from the centerline of the wheel.				

Center of Gravity Height. Although each option noted in table 6 may result in a relatively small or modest drop in CG height (1–4 inches), collectively, these options can incrementally amount to a considerable reduction, contributing to a significant improvement in the roll stability of cargo tank motor vehicles.

For example, the vertical distance between the ground and the top of the fifth wheel coupler on truck-tractors (regarded as the fifth wheel height) can be reduced by minimizing excess frame height above the suspension components, minimizing the suspension ride height[115] within allowable limits, and minimizing the fifth wheel mounting bracket height. The typical fifth wheel height of truck-tractors ranges from 47–52 inches, with an estimated 80 percent of truck-tractors with a fifth wheel height between 49–50 inches.[116] A fifth wheel height of

[115] A suspension's designed ride height is defined as the distance from the suspension mounting surface to the center of the axle. For further information, see *Technical Procedure Trailer Systems,* Literature Number L1388, Hendrickson, November 2008.

[116] Truck-tractor fifth wheel height influences the design and effective CG height of newly manufactured DOT specification cargo tank semitrailers.

40.5 inches has been achieved on a truck-tractor equipped with 22.5-inch-diameter wheels and low profile tires.[117] Similarly, the CG height of single-unit trucks and trailers with cargo tanks can be reduced by minimizing excess frame height and suspension ride height and also by limiting the surplus height of subframes that cradle the tank. The CG height of cargo tank semitrailers can also be reduced by installing an "inserted" upper coupler that is recessed at the front of the trailer between the frame rails instead of a standard upper coupler, which is mounted below the frame.

Geometric Shape. The roll stability of cargo tank motor vehicles can also be enhanced by changing the geometric shape to reduce a tank's CG height by making it wider or extending the center bottom of the shell lower than the front and rear heads. The option of modifying geometric shape to lower the CG height of DOT specification cargo tanks that transport compressed gases at high allowable working pressures, such as the tank involved in this accident, is not available because these tanks must comply with Section VIII of the ASME *Boiler and Pressure Vessel Code* by maintaining a circular shape with no more than a 1 percent difference between the maximum and minimum inside diameters of any cross section.

Elliptically shaped cargo tanks with a dropped-center height[118] to reduce CG height were introduced more than 50 years ago, when tank bottoms were straight. Initially, the base of the tank was sloped downward in one direction, which eventually evolved into the *double tapered* design, where the front and rear of the tank bottom slope toward the center (see figure 16). The dropped-center height of DOT specification cargo tanks for transporting bulk liquid petroleum products (DOT 406) ranges from 6–18 inches. Approximately 26–28 percent of new DOT 406 cargo tanks built are the double tapered design.[119]

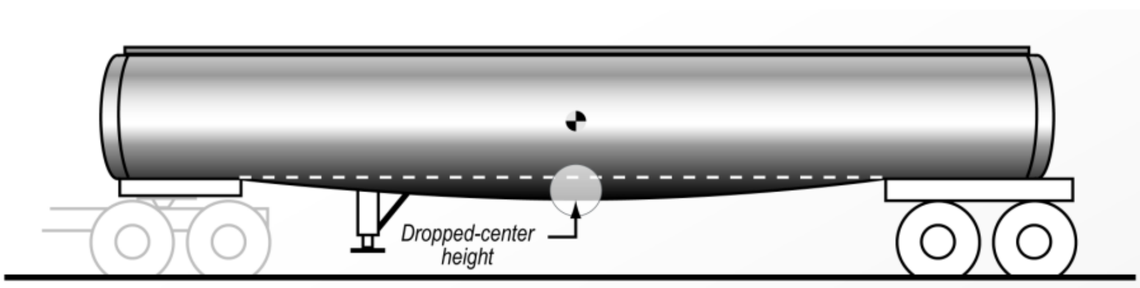

Figure 16. Double tapered cargo tank with dropped center.

The *double conical* design, consisting of two truncated circular cones welded together at the center, has been manufactured for about 35 years and represents approximately 20 percent of cargo tanks built since 2005 for transporting bulk liquid chemical products (DOT 407).[120] A

[117] P.S. Fancher and others, *A Factbook of the Mechanical Properties of the Components for Single-Unit and Articulated Heavy Trucks*, Report No. UMTRI-86-12 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1986).

[118] Dropped-center height is the difference between the maximum vertical diameter at the center of the tank compared to the front and rear heads of the tank. The greater the dropped-center height, the more the CG height (as a fraction of dropped-center height) is lowered.

[119] NTSB telephone calls with a cargo tank manufacturer, December 15, 2010, and July 25, 2011.

[120] NTSB telephone call with a cargo tank manufacturer, December 28, 2010.

typical dropped-center height for a double conical tank with the center bottom lower than the front and rear heads (which, if viewed from the side, would appear similar to figure 16) is approximately 10–12 inches, which does not necessarily result in a lower ground clearance than straight-round tanks.[121] DOT specification cargo tanks for transporting bulk liquid corrosives (DOT 412) are predominantly round, but approximately 10 percent built since 2005 have a double conical design with dropped-center heights ranging from 6–20 inches. The additional cost of manufacturing a double conical/tapered cargo tank ranges from $1,500–$5,000 (depending on the extent of dropped-center height and DOT specification).[122]

Increased Vehicle Width. The maximum allowable overall width of commercial motor vehicles was increased from 96–102 inches by the 1982 Surface Transportation Assistance Act (STAA-82). The roll stability of cargo tank motor vehicles with dual tires can be improved substantially by increasing the track width from the 71.5 inches found on 96-inch-wide vehicles to the 77.5 inches found on 102-inch-wide vehicles (see figure 17).[123]

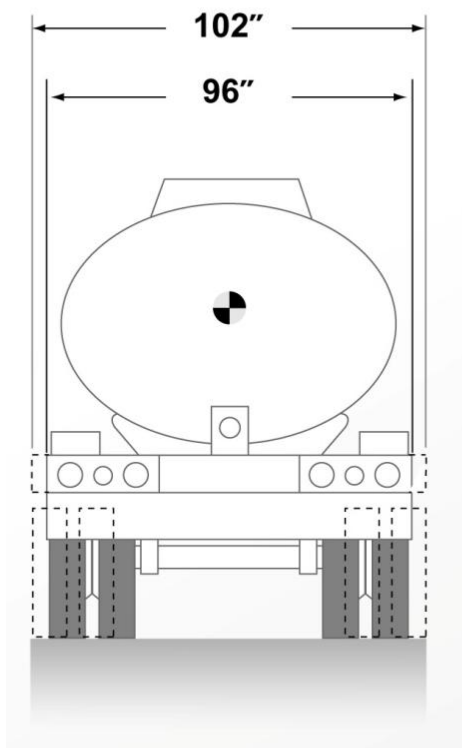

Figure 17. Roll stability improved by increased track width of 102-inch-wide vehicles.

[121] Because product transported in a DOT 407 cargo tank is usually drained from the rear (and not the center) of the tank, some motor carriers cannot use a double conical tank.

[122] Slight differences in the design and manufacture of individual double tapered and double conical cargo tanks may affect the actual reduction in CG height in relation to the amount of dropped-center height.

[123] T.D. Gillespie and R.D. Ervin, *Comparative Study of Vehicle Roll Stability*, Report No. UMTRI-83-25 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1983).

STAA-82 permitted 20,000-pound single-axle limits and designated a National Network for Large Trucks consisting of federally designated interstates and approximately 160,000 miles of other roads on which wider (102-inch) and longer tractor-semitrailers and twin trailers could travel without restriction.[124] STAA-82 also required states to allow trucks with authorized dimensions to operate on the National Highway System (NHS) network and to provide "reasonable access" between the network and terminals and other facilities for food, fuel, repairs, and rest.[125] Currently, 41 states allow 102-inch-wide vehicles to operate throughout their states. The remaining states and the District of Columbia restrict the operation of 102-inch-wide vehicles on certain roads.[126]

Although the regulation allowing 102-inch-wide vehicles to operate has been in effect since 1982, motor carriers have been reluctant to voluntarily request increased track width on newly manufactured cargo tank motor vehicles. Consequently, only 10–30 percent of newly manufactured cargo tank motor vehicles feature increased track width for improving roll stability—as estimated by cargo tank manufacturers during the August 2010 NTSB public hearing and noted in published reports—which is significantly lower than for other major body types, such as enclosed van-type semitrailers.[127] In contrast, more than 90 percent of cargo tank motor vehicles built by one cargo tank manufacturer and sold to Canadian fleets are equipped with the wider 102-inch axles.[128]

Overall Tank Height. The CG height of cargo tank motor vehicles can also be reduced by lowering the overall height of the tank, achievable by either expanding the overall width of the tank closer to the outboard edge of the vehicle[129] or dropping the entire height of the tank or rear-only section lower to the ground. Lowering overall tank height is a feasible option for improving the roll stability of cargo tanks that cannot be converted from the standard geometric shape to a double conical or double tapered design. This limitation to altering tank geometry particularly applies to the straight-round profile of MC331 and MC338 specification cargo tanks, which transport compressed gases at maximum allowable working pressures as high as 500 psig. Methods for improving the roll stability of these DOT specification cargo tanks include extending the width of the frame rails to allow the tank to be positioned lower, installing

[124] Title 23 CFR Part 658, Appendix A, contains a description of federally designated routes on the NHS network.

[125] *Report of the Subcommittee of Truck Size and Weight of the AASHTO Joint Committee on Domestic Freight Policy* (Washington, DC: American Association of State Highway and Transportation Officials, 1995). Public roads that restrict the operation of 102-inch-wide vehicles may be identified by utilizing routing and mapping software (for example, *PC*MILER* or *TomTom*) or referencing the *Vehicle Sizes and Weights Manual* (Neenah, Wisconsin: J.J. Keller & Associates, Inc.).

[126] Testimony delivered by John Nicholas, Truck Size and Weight Program Manager, Federal Highway Administration, on August 4, 2010 , at the NTSB public hearing concerning the Indianapolis rollover accident.

[127] *Analysis of the Vehicle Inventory and Use Survey for Trucks With Five-Axles or More* (Washington, DC: Federal Highway Administration, May 2001).

[128] Testimony delivered by John F. Cannon, Vice-President of Engineering, Walker Group Holdings, on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[129] The feasibility of manufacturing a wider tank depends on whether changing the original shape of the tank by making it wider and shorter would make it necessary to increase the original shell thickness of the tank (adding weight) to maintain a minimum required level of beam strength.

wide-base tires to increase the track width (see figure 18), and limiting the height of the subframe that cradles the tank.

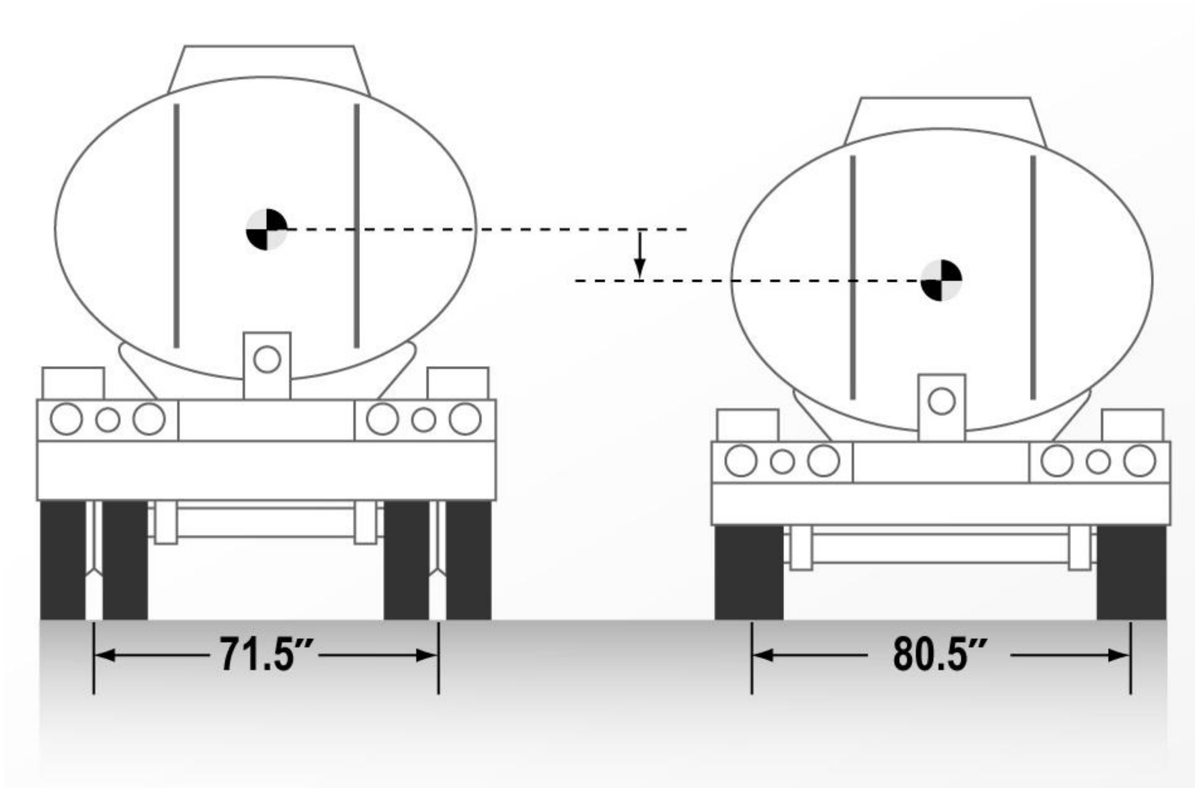

Figure 18. Lower CG height and increased track width.

Lowering tank height is still possible even when it is not practical or possible to lower both the front and rear sections of cargo tanks equally. For instance, in Australia, the rear section of a tank is lowered as much as possible, resulting in a noticeable downward slope (when viewed sideways) between the front and rear sections of the tank.

Tire Selection. The CG height of cargo tank motor vehicles can also be reduced by installing low-profile tires with reduced section height (radial distance from the nominal rim diameter to the outer diameter of the tire), thus lowering the tires' static-loaded diameter (distance from the ground to the top of tire mounted on a vehicle, calculated by adding half the overall diameter with the static-loaded radius provided by the tire manufacturer). The static-loaded diameter of the accident vehicle's replacement tires was 40.2 inches, as compared to 30.1–35.1 inches for low-profile tires manufactured for heavy trucks and commercial trailers (see table 7). Although the installation of low-profile tires can lower the CG height of cargo tank vehicles by several inches, the proportion of newly manufactured vehicles equipped with low-profile tires is approximately 5–20 percent.[130]

[130] NTSB telephone calls with cargo tank manufacturers, December 15, 2010, and June 1, 2011.

Table 7. Difference in static-loaded diameter of standard tires and low-profile tires.

Tire Type	Application	Tire Description	Tire Size	Static-Loaded Diameter (inches)
Standard aspect ratio	Tires on accident truck-tractor and cargo tank semitrailer	Goodyear G149[a]	11R-22.5	40.2
Low profile	Truck	Michelin XDA2[b]	295/60R22.5	35.1
Low profile	Trailer	Bridgestone R184[c]	245/70R17.5	30.1

[a]See <http://www.goodyear.com/truck/pdf/gy_engdata_images.pdf>, accessed July 8, 2011.

[b]See <http://www.michelintruck.com/michelintruck/tires-retreads/tireInfo.do?tread=XDA2%2B%20ENERGY>, accessed April 13, 2011.

[c]See<https://www.bfentirenet.com/product_catalogs/trucktires/app?task=TruckTiresPC&subtask=ttDetail&ctry=USA&language=en_us&modelID=17&partial=true>, accessed April 13, 2011.

The roll stability of cargo tank motor vehicles can also be improved by installing wide-base tires on 2-inch outset wheels,[131] which would effectively increase (as noted in figure 18) the track width of a cargo tank motor vehicle equipped with dual tires.

1.13.3 Performance-Based Standards

Performance-based standards can be used to design and manufacture vehicles with rollover-resistant characteristics. After its investigation of a rollover and subsequent fire involving a truck-tractor and cargo tank semitrailer laden with liquefied petroleum gas,[132] an accident that triggered collisions involving 29 vehicles and resulted in 6 fatalities and 3 serious injuries, the NTSB made the following recommendation to NHTSA:

> Set a high priority on establishing performance requirements for new buses, trucks, trailers, and combinations in regard to: (1) improved braking capabilities with balanced skid resistance, reduced "fade," and shorter stopping with maximum load; (2) the use of energy-absorbing underride and override barriers to reduce passenger-car impact decelerations through controlled yielding; and (3) *minimum limits on stability factors for loaded vehicles*. (H-71-18)

NHTSA stated in a May 4, 1971, letter that the NTSB report was referred to its Research Institute for review and indicated specific comments on the recommendations would be provided directly to the NTSB. Safety Recommendation H-71-18 was classified "Closed—Acceptable Action" on January 1, 1980.

Europe and Canada have already made progress in this area. For example, Canada has established performance-based standards to harmonize the large discrepancies in size and weight regulations among provinces that allowed the manufacture of heavy truck configurations with

[131] A wheel is outset when the hub mounting surface is outboard of the centerline of the wheel.

[132] *Multiple-Vehicle Collisions Under Fog Conditions, Followed by Fires, New Jersey Turnpike, North of Gate 2, November 29, 1969*, Highway Accident Report NTSB/HAR-71/03 (Washington, DC: National Transportation Safety Board, 1971).

poor dynamic performance.[133] The *Vehicle Weights and Dimension Study*,[134] completed in 1986, produced a set of performance metrics for establishing vehicle configuration specifications that has resulted in desirable dynamic characteristics. All provinces and territories have since implemented the Canadian national memorandum of understanding on vehicle weights and dimensions,[135] which defines dimensional and dynamic performance requirements for heavy vehicle configurations.

The European Industrial Gases Association (EIGA) believes that rollover prevention should focus not only on the behaviors of drivers and managers but also on the design and engineering of vehicles used to transport gases. The EIGA recognizes that trailer design can be instrumental in lowering the CG height of cargo tank motor vehicles.[136]

Geneva Regulation UNECE (United Nations Economic Commission for Europe)[137] No. R111 established a minimum rollover threshold for cargo tank motor vehicles that transport dangerous goods.[138] Compliance with R111 requirements must be verified by a tilt-table test or a calculation method. The static rollover threshold of the vehicle at the point at which overturning occurs[139] must be greater than 23° when tested in both directions on a tilt table[140] or at least 4 meters per second/per second (m/s^2) when calculated by simulation in a steady-state circular test (constant radius, speed, and lateral acceleration). UNECE regulations were also developed to provide guidance for the construction of cargo tank motor vehicles first registered on July 1, 2003.[141]

Further, the National Research Council of Canada conducted tilt-table tests to determine the rollover threshold and characteristics of 17 tank-truck configurations that are deployed across

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[133] J. Woodrooffe and others, *Review of Canadian Experience With the Regulation of Large Commercial Motor Vehicles*, NCHRP Report No. 671 (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2010).

[134] *Vehicle Weights and Dimensions Study*, Technical Reports, vols. 1-16 (Ottawa, Canada: Roads Transportation Association of Canada, July 1986).

[135] *Memorandum of Understanding on Interprovincial Heavy Vehicle Weights and Dimensions, Task Force on Vehicle Weights and Dimension Policy, Council of Ministers Responsible for Transportation and Highway Safety,* October 2009 <http://www.comt.ca/english/programs/trucking/MOU%202009.pdf>, accessed July 18, 2011.

[136] "Vehicle Rollover Incidents," *Safety Newsletter* (Brussels, Belgium: European Industrial Gases Association, 2009).

[137] UNECE is one of five regional commissions of the United Nations that brings together 56 countries located in the European Union, non-EU Western and Eastern Europe, southeastern Europe, the Commonwealth of Independent States, and North America.

[138] *Agreement Concerning the Approval of Tank Vehicles of Categories N and O with Regard to Rollover Stability*, Regulation No.111, December 28, 2000, World Forum for Harmonization of Vehicle Regulations <http://live.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r111e.pdf>, accessed April 28, 2011.

[139] UNECE Regulation No. R111 considers "rollover threshold" as the instant when all wheels on one side of a vehicle have lost contact with the supporting surface of a tilt-table platform.

[140] A tilt table is a test device used to quantify the rollover threshold of a heavy commercial vehicle in a steady-state curve. After the vehicle is driven onto the tilt table and constrained with safety restraints, one side of the platform is very slowly lifted until the vehicle reaches the point of roll instability. This phase of the test is determined when the semitrailer tires on the unladen side of the vehicle begin to lift off the tilt-table platform.

[141] *Requirements Concerning the Construction and Approval of Vehicles*, European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), annex B, part 9, chapter 9.7, point 9.7.5.2.

Canada and travel to the United States.[142] A computer simulation was used to determine the lowest rollover threshold of each vehicle configuration with tanks full and loaded to the maximum allowable gross weight. The results of the simulations and tilt-table tests were compared to the following minimum rollover thresholds: 0.35 *g* (acceleration of gravity)[143] for all heavy vehicles, as required in New Zealand;[144] 0.40 *g* for tank trucks by tilt-table test or 0.42 *g* by the calculation method, as established by the UNECE; and 0.40 *g* for special permit vehicles, as developed by the Transportation Association of Canada.

Tilt-table test results indicated that 7 of the 17 tank-truck configurations (41 percent) had a rollover threshold less than 0.35 *g*, and 14 of the 17 tank-truck configurations (83 percent) had a rollover threshold less than 0.40 *g*. The authors concluded that although a minimum rollover threshold requirement for new tank trucks would improve the roll resistance of the Canadian tank truck fleet, based on a tank truck fleet replacement rate of 3–5 percent per year and the long service life of cargo tanks, it would take 25–30 years after a performance-based standard became effective before the existing fleet of tank trucks was replaced. The study suggested that an operational requirement for all in-use tank trucks transporting hazardous materials to comply with a specific rollover threshold would decrease the time it would take to improve the rollover threshold of the tank truck fleet.

1.13.4 Partial Loads

The dynamic movement of fluid within a partially filled cargo tank was suggested as an explanation for why the involvement rate of five-axle cargo tank semitrailers by rollover threshold was markedly higher than for five-axle van-type semitrailers.[145] Fluid slosh generated by dynamic motions encountered under braking, acceleration, cornering, or lane-change maneuvers can yield significant transient load shifts in the roll and pitch planes and alter the directional properties of a cargo tank motor vehicle.[146] Dynamic slosh motions can be readily excited on a cargo tank motor vehicle, especially when executing a lane change or an evasive maneuver with a counter-steer input.[147]

The maximum carrying capacity of a highway-operated cargo tank is generally decided (when the vehicle is being purchased) by the lightest density of product that will be transported. Densities of bulk liquid loads transported by cargo tank motor vehicles differ considerably, with petroleum products ranging from 6–8 pounds per gallon and common industrial acids,

[142] J.R. Billing and J.D. Patten, *An Assessment of Tank Truck Roll Stability*, Report No. TP 14237E (Ottawa, Canada: Centre for Surface Transportation Technology, National Research Council of Canada, 2005).

[143] The acceleration rate of gravity is approximately 32.2 feet (9.8 meters) per second/per second.

[144] Restricted tank volumes and modest axle/gross axle weights raise the roll stability of cargo tank motor vehicles beyond the minimum rollover threshold of 0.35 *g* established for all heavy trucks in New Zealand.

[145] P. Fancher and others, *Turner Truck Handling and Stability Properties Affecting Safety*, Report No. UMTRI-89-11 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1989).

[146] G.R. Yan, S. Rakheja, and K. Siddiqui, "Analysis of Transient Fluid Slosh in Partly-Filled Tanks With and Without Baffles; Part 1—Model Validation," *International Journal of Heavy Vehicle Systems,* vol. 17, no. 3/4 (October 2010).

[147] *Future Configuration of Tank Vehicles Hauling Flammable Liquids in Michigan*, Report No. UM-HSRI-80-73-1 (Ann Arbor, Michigan: University of Michigan Highway Safety Research Institute, April 1983).

9–16 pounds per gallon.[148] A single-compartment cargo tank transporting product with a density of 9 pounds per gallon could have limited void space above the fill level; the same trailer transporting a product with a density of 16 pounds per gallon could have significant outage.[149]

Factors that can lead to the *sloshing* (splashing lateral motion) and *surging* (rolling forward like a wave) of partially filled compartments include the density and viscosity of the commodity hauled; number and size of compartments; customer requirements; axle and vehicle weight restrictions; and filling level of the tank, as determined by the density of a product in relation to its total liquid carrying capacity. The fill level and geometric shape of a tank may determine how significantly the lateral sloshing and longitudinal surging of bulk liquid affect the directional stability and rollover threshold of cargo tank motor vehicles. A substantial number of partial loads are transported in smooth bore (single-compartment) cargo tanks that are not outfitted with interior bulkheads or baffles to mitigate the sloshing and surging of bulk liquid loads.[150] Partial liquid loading is involved in 94 percent of cargo tank rollover accidents.[151]

[148] L.A. Botkin, *Safe Highway Transportation of Bulk Liquids*, Technical Paper No. 700872 (Warrendale, Pennsylvania: SAE International, 1970).

[149] *Outage* refers to the amount that a package (such as a cargo tank) falls short of being fully loaded, usually expressed in percent by volume (49 CFR 171.8).

[150] R.D. Ervin, M. Barnes, and A. Wolfe, *Liquid Cargo Shifting and the Stability of Cargo Tank Trucks*, Report No. UMTRI-85-35/2 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1985).

[151] *Cargo Tank Driver Rollover Prevention Video*, Federal Motor Carrier Safety Administration, August 2010.

2. Analysis

The analysis begins with a discussion of the factors and conditions that the NTSB has excluded as having caused or contributed to the accident, the sequence of events and speed during the combination unit's rollover, and an evaluation of driver fatigue. Next, the analysis reviews measures for mitigating the rollover of cargo tank motor vehicles, which include a comprehensive rollover prevention program, stability control systems, vehicle design enhancements, highway design, and the effect of the lateral displacement (sloshing) of partially filled loads. The analysis then examines initiatives for reducing the release of hazardous materials when DOT specification cargo tanks are involved in motor vehicle accidents and for preventing vulnerable bridges from collapsing when bridge pier columns located near the traveled way are struck by an errant heavy commercial vehicle.

2.1 Exclusions

At the time of the accident, skies were overcast, with a temperature of 58° F and winds of 4 mph. The truck driver did not report any problems with illumination or glare. The NTSB concludes that the weather did not contribute to the accident.

Postaccident examination found no preexisting defects on the truck-tractor or cargo tank semitrailer. The steering gear was functionally operational, and damage to internal components was determined to have been caused by the impact loading and excessive heat generated by the postaccident fire. With the exception of the steer axle brakes, which were damaged and could not be measured, the service brakes on the truck-tractor and cargo tank semitrailer were within proper readjustment limits. The truck-tractor and semitrailer decoupled as a result of the excessive twisting of the frame rails and buckling of the cross bars during the rollover, which allowed the fifth wheel plate to separate from the slide rail bracket. The patterns of damage and fracturing of the front head of the tank indicated that the breach of the cargo tank head and shell resulted from the collision with the bridge pier column and not from preexisting damage, fatigue cracking, corrosion, or weld defects such as lack of fusion. Further, mechanical properties of the materials and cargo tank design met or exceeded all of the structural integrity requirements imposed by Federal regulations (49 CFR 178.337). Therefore, the NTSB concludes that there was no evidence of mechanical defects or preexisting damage to the combination unit and cargo tank.

The truck driver was properly licensed and had the requisite endorsements to operate a truck-tractor semitrailer. He had approximately 45 years of experience driving heavy commercial vehicles and had spent the past 15 years transporting bulk liquid hazardous materials in cargo tank motor vehicles. The truck driver drove the same truck-tractor for approximately 2 years and was familiar with traveling on highways throughout Indiana, including the interchange where the accident occurred. Therefore, the NTSB concludes that the truck driver was adequately licensed and familiar with both the route and driving the combination unit.

Blood samples obtained from the truck driver after the accident were negative for alcohol and a wide range of over-the-counter and illicit drugs. Atenolol, an antihypertensive medication that had been prescribed to the driver, was the only drug for which the driver tested positive. The NTSB therefore concludes that the truck driver's performance was not impaired by alcohol or any of the prescription, over-the-counter, or illicit drugs for which he was tested following the accident.

Although NTSB investigators were informed by one witness that another witness allegedly observed the accident truck driver talking on a cellular telephone, a review of cellular records confirmed that the driver was not using a cellular telephone before the accident. Therefore, the NTSB concludes that there was no evidence that the truck driver was distracted by his cellular telephone immediately before the accident.

Other than a speech deficit, the truck driver had no neurologic abnormalities from a stroke that occurred approximately 10 years before the accident. The truck driver indicated that he had no difficulties with the knee replacements that he received less than 6 months before the accident. Further, although the truck driver's prescribed medications would not have been expected to directly result in impairment, one of them, glyburide, can result in hypoglycemia (low blood sugar), particularly when used in combination with other glucose-lowering medications such as metformin.[152] Based on his average blood glucose, blood glucose in the emergency room, and the expected rise in blood glucose following trauma,[153] it seems most probable that the truck driver's blood glucose level was 135–200 mg/dL at the time of the accident, a level at which no significant adverse effects in performance would be expected.[154] No evidence exists that the truck driver—who had made several steering inputs prior to the rollover—had an incapacitating event. Therefore, the NTSB concludes that neither the staged bilateral knee replacement surgery[155] nor the general health of the truck driver caused or contributed to the accident.

Emergency response from the LTFD, ISP, and other responding agencies and fire suppression units occurred as expeditiously as possible, considering the number of high-volume highway lanes that had to be rerouted and the hazards of working in a relatively confined area surrounded by flammable vapors. In addition, the unified incident command, traffic control, transport of the injured, and scene safety were well coordinated. The absence of shipping papers, which were destroyed in the fire, did not prevent first responders from identifying the product and responding to the incident in an appropriate manner. Therefore, the NTSB concludes that the emergency response was timely and adequate.

[152] J.A. Davidson, A.J. Scheen, and H.C. Howlett, "Tolerability Profile of Metformin/Glibenclamide Combination Tablets (Glucovance): A New Treatment for the Management of Type 2 Diabetes Mellitus," *DrugSafe*, vol. 27, no. 15 (2004), pp. 1205–1216.

[153] L. Li and J.L. Messina, "Acute Insulin Resistance Following Injury," *Trends in Endocrinology and Metabolism*, vol. 20, no. 9 (2009), pp. 429–435.

[154] I. Pais and others, "Mood and Cognitive Functions During Acute Euglycaemia and Mild Hyperglycaemia in Type 2 Diabetic Patients," *Experimental and Clinical Endocrinology Diabetes*, vol. 115, no. 1 (2007), pp. 42–46.

[155] Bilateral knee replacement surgery replaces both knees in a staged procedure on separate days that could be several days, weeks, or months apart.

2.2 Accident Discussion

When the accident occurred, the AmeriGas/PTI combination unit had just exited southbound I-69 and was on a connection ramp to travel southbound on I-465. While in the right lane of the I-465 southbound connection ramp, the combination unit, negotiating a left curve with a +8 percent cross slope (left side of lane lower than right side), began to encroach upon the left lane, occupied by a Volvo passenger car. The truck driver responded to the Volvo's presence in the left lane by executing an excessive, rapid, evasive steering maneuver that caused the combination unit to veer right and travel onto the paved right shoulder, which had a −2 percent cross slope (left side higher than right side). The truck driver then made a rapid counterclockwise steering input to redirect the combination unit from the shoulder to the right lane (see figure 19). Therefore, the NTSB concludes that the truck driver's excessive, rapid, evasive steering maneuver triggered the subsequent accident sequence.

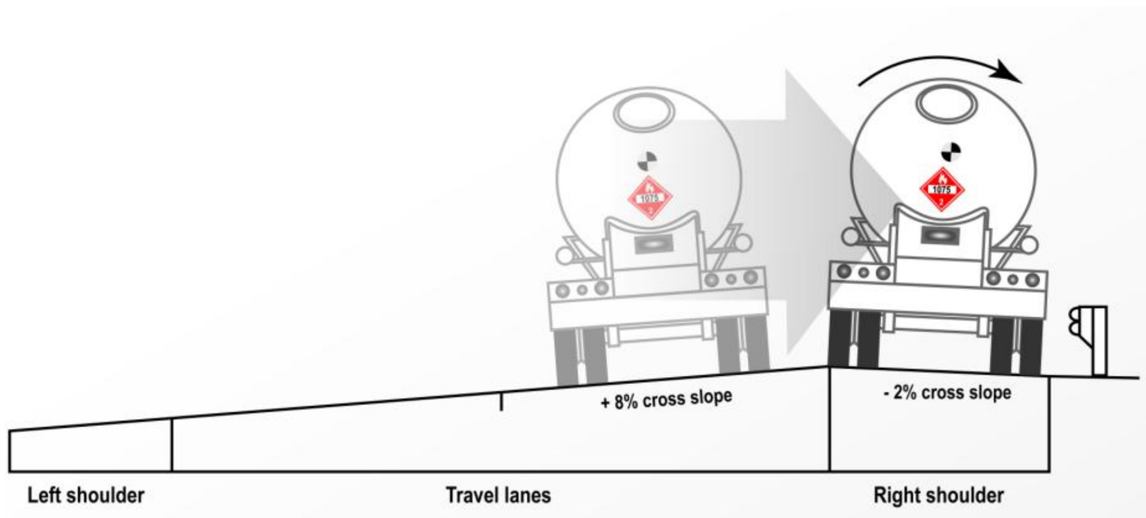

Figure 19. Rollover sequence.

As the combination unit advanced closer to the I-465 overpasses, the lateral displacement of the vehicle's CG allowed weight to transfer off the inside wheels and create a rolling motion, which caused the cargo tank semitrailer to lean to the right and begin to roll over. The truck driver's attempt to steer the combination unit away from the shoulder and into the right lane exacerbated the roll motion by reducing the curvature of the vehicle trajectory from 881 to 630 feet, as evidenced by visible weight-shift tire marks. Therefore, the NTSB concludes that the truck driver's quickly steering the combination unit from the right shoulder to the right lane contributed to the rollover.

The weight-shift marks indicated that the cargo tank semitrailer came near the edge of the pavement before it moved closer to the white painted solid line and rolled over. The combination unit struck the ground at an angle (relative to the travel lanes on the connection ramp), with the right-rear side of the semitrailer impacting the right shoulder and the right-front side of the semitrailer and truck-tractor landing diagonally across the right lane. The dark tire imprints on the right shoulder and in the right lane indicate where the sidewalls of the right outboard tires on the semitrailer and truck-tractor's drive axles struck the ground (see figure 20).

Figure 20. Tire imprints in the right lane and on the shoulder indicating where the combination unit rolled over onto its right side. (Source: Indiana State Police.)

During the rollover sequence, the truck-tractor's fifth wheel plate attached to the kingpin at the front of the cargo tank semitrailer separated from the slide rail bracket fastened to the rear of the truck-tractor. After decoupling, the trajectory of the truck-tractor and the front of the cargo tank semitrailer shifted away from the centerline toward the right shoulder, with each unit sliding independently on its right side toward the right guardrail. The truck-tractor struck and rebounded from the right guardrail before coming to rest on the connection ramp south of the I-465 overpasses. The front head of the cargo tank penetrated the W-beam guardrail at an approximately 20° angle before striking the I-465 bridge footing and completely displacing one of seven concrete bridge pier columns supporting the I-465 southbound overpass.

The impact resulted in a breach of the head and shell, which provided a portal for compressed liquefied petroleum gas to escape, form a vapor cloud, ignite, and erupt into a fireball. The remaining kinetic energy and swift expulsion of liquefied petroleum gas caused the cargo tank semitrailer to advance forward and rotate counterclockwise. The cargo tank eventually came to rest on its left side, with its front head near the southbound I-465 bridge footing and the rear bumper close to the railroad tracks located west of the connection ramp (see figure 21).

Figure 21. Final rest position of cargo tank semitrailer. (Source: Indiana State Police.)

The lateral acceleration required to shift the CG far enough outward to create weight-shift marks, lift the inside wheels off the ground, and induce the untripped rollover was not solely caused by the speed at which the truck driver negotiated the left curve on the ramp but also by the excessive, rapid steering wheel inputs made during the evasive maneuver; the vehicle instability resulting from traveling on a −2 percent cross slope; the side-to-side displacement of the partial bulk liquid load within the cargo tank; and the truck driver's decision to quickly return the combination unit from the right shoulder to the right lane.

2.2.1 Rollover Speed

The spot-speed study conducted by INDOT approximately 750 feet north of the westbound I-465 overpass shortly after the accident (November 2, 2009) showed that the 85th percentile speed for heavy trucks traveling on the ramp was 53 mph, slightly above the posted advisory speed of 50 mph. The Volvo driver indicated during a postaccident interview that he was not speeding on the ramp and could not estimate the combination unit's speed. The engine's electronic control module was destroyed in the postaccident fire, so limited objective information was available to accurately estimate the combination unit's speed at rollover. As an alternative means of estimating the combination unit's speed at rollover, NTSB investigators analyzed information collected during the postaccident examination of the truck-tractor and performed computer simulations.

NTSB investigators used a sawtooth curve chart and data sheet obtained from Navistar International Corporation to determine the range of speeds at which the truck-tractor could travel when the transmission was engaged in ninth gear, as observed during the postaccident inspection.[156] The data sheet, which provides speed calculations for the truck-tractor in each gear of the 10-speed transmission, with a Caterpillar C13 diesel engine operating at approximately 1,522–2,100 rpm, revealed that the accident truck-tractor was capable of traveling 47–65 mph with the transmission in ninth gear. Operating the engine at a lower speed of 1,200 rpm, as recommended by the engine manufacturer, would extend the speed range of the truck-tractor in ninth gear to a lower limit of 38 mph (see table 8).[157]

Table 8. Speed range of truck-tractor in ninth gear.

Engine Operating Range	Transmission Gear	Engine RPM	Speed (mph)
Navistar	9	1522–2100	47–65
Caterpillar	9	1200–2100	38–65

The NTSB conducted a vehicle dynamics study to investigate the propensity of a truck-tractor semitrailer to roll over while traveling on a paved shoulder with a −2 percent cross slope and, moreover, to determine whether the wide speed range calculated in ninth gear (38–65 mph) could be narrowed. Using *TruckSim*[158] software, NTSB staff performed computer simulations to determine the rollover speed of a truck-tractor semitrailer negotiating a steady-state curve with a constant radius of 700, 800, and 881 feet. The three different curve radii were selected to replicate the nominal curve radius of the connection ramp (881 feet) and the reduced instantaneous radius of trajectory curvature when the combination unit rolled over (800 and 700 feet). For each of the three curve radii selected, the simulations also considered a truck-tractor semitrailer traveling on a surface similar to the measured superelevation of the

[156] The travel speed of a vehicle in each transmission gear depends upon (and can be predicted by) engine speed.

[157] *On-Highway Diesel Engine with ACERT Technology* <http://www.cat.com/cda/files/2202661/7/LEHT8892-00.pdf>, accessed April 30, 2011.

[158] *TruckSim* is a software tool used for simulating and analyzing the dynamic behavior of medium-to-heavy trucks, buses, and articulated vehicles.

travel lanes on the ramp (+8 percent) and right shoulder (−2 percent) and the effective superelevation when the combination unit was partially on the right shoulder and the right lane of the connection ramp (0 percent).

The nine iterations computed the combination unit's rollover speed when optimally driven along a curve by an ideal simulated driver and the speed at which the combination unit's inside trailer wheels would lift off the ground. In each case, the semitrailer's inside wheels were the first to lift off the ground. The simulations indicated that the maximum speed at which a truck-tractor semitrailer combination unit could negotiate a curve with a radius of 881 feet and +8 percent superelevation without rolling over was 77 mph. The maximum speed without wheel lift was 73 mph, which was lowered to 66 mph when the effective superelevation was changed from +8 to 0 percent and to 55 mph when the nominal radius of the curve was reduced to 700 feet.

The simulations did not take into account the additional lateral acceleration generated by rapid steering inputs or the resulting side-to-side displacement of the partial bulk liquid load in the cargo tank. Under those conditions, the combination unit's maximum speed before wheel lift may have been less than 55 mph.[159] Therefore, the NTSB concludes that the combination unit's speed at the onset of rollover may have been near the posted advisory speed limit.

2.2.2 Driver Fatigue

NTSB investigators examined whether fatigue played a role in the accident. The examination included reviewing the 72-hour reconstruction of the truck driver's activities, which was developed by interpreting *Qualcomm* vehicle position history data, shipping documents, and information provided by the driver about when he slept. The truck driver indicated that he generally went to bed at home about 11:00 p.m. and awakened about 7:00 a.m. He stated that he did not have difficulty falling asleep but did awaken once or twice at night to use the bathroom. His self-reported sleep quality at home on a 1 to 5 scale (with "1" being quite tired and "5" fully alert) was 5, higher than the 4 he reported when he slept in the truck-tractor. The driver said he occasionally took a nap in the sleeper berth (usually in the afternoon) when he was away from home driving the combination unit.

Investigators were able to estimate the driver's off-duty time, which was assigned whenever the driver was not on duty loading (supported by shipping documents) or when the combination unit (according to vehicle position history data) was stationary.[160] The driver's time available for sleep, or sleep opportunity, will necessarily be less than his off-duty time due to

[159] A spot-speed study of the connection ramp directly north of the I-465 westbound overpass conducted on November 2, 2009, found that the 85th percentile speed was 56 mph for passenger cars and 53 mph for heavy trucks.

[160] On-duty status was assigned according to shipping documents produced when the driver loaded the combination unit at the loading terminal and estimated when the cargo tank was unloaded at a delivery location. Driving status was assigned when the combination unit traveled away from or returned to the loading terminal. The only off-duty time assigned was on October 21, when the combination unit was stationary from 5:30–9:00 a.m. in Mexico, Indiana, before traveling to the loading terminal in Lebanon.

other normal daily activities such as eating, bathing, and socializing. However, investigators were not able to determine the driver's activities and their duration during his off-duty time. Furthermore, the actual sleep obtained by the driver, a subset of the sleep opportunity, was also unknown.

Investigators examined the possibility of driver fatigue using the driver's off-duty time, which represents a maximum sleep opportunity for the driver. Two sleep schedules were analyzed because it was not known whether the driver slept during each off-duty period (schedule 1 in table 9) or just during the one off-duty period that encompassed the longer night sleep (schedule 2). The first sleep schedule assumes that the truck driver slept 0.75–3.5 hours daily when he went off duty, providing him with a maximum of 9.25–11 hours of sleep opportunity each day. The second sleep schedule provided the driver with a maximum of 6.0–8.25 hours of sleep opportunity each day.

Table 9. Time available for truck driver to rest.

Date	Time Awake	Long Sleep (start)	Total Work Time* (hours)	Maximum Sleep Opportunity Schedule 1 (hours)	Maximum Sleep Opportunity Schedule 2 (hours)
October 19	7:00 a.m.	1:00 a.m.	9.75	9.5	6.0
October 20	7:00 a.m.	10:15 p.m.	15.25	11.0	6.75
October 21	5:00 a.m.	12:00 a.m.	14.5	9.25	8.25
October 22	8:15 a.m.	—	2.4	—	—

* Includes on-duty time spent loading, unloading, and driving.

Factors that can lead to an accident from loss of alertness due to driver fatigue include the duration of the last sleep, elapsed time awake, time of day, and known sleep disorders. Based on the first sleep schedule, the truck driver had a maximum of 9.25 hours of sleep opportunity the night before the accident and was awake the following day for approximately 2.4 hours before the accident occurred at approximately 10:38 a.m. The second sleep schedule provided the truck driver an average of 7.0 hours of sleep opportunity each day, which was an average of 2.91 hours less than the first sleep schedule and 1.25–2 hours less sleep for 2 nights than the 8 hours that he customarily received at home. Research measuring the effects of different amounts of nightly time in bed (3, 5, 7, or 9 hours) on the subsequent performance (cognitive tasks and simulated driving) of bus and truck drivers holding a valid CDL[161] showed that across 7 consecutive days of testing, driver performance in the 7-hour group (averaging 6.28 hours of actual sleep, slightly less than population norms) was measurably poorer than driver performance in the 9-hour group (averaging 7.93 hours of actual sleep, within normal limits). The results of this study suggest that commercial drivers, including the AmeriGas/PTI truck driver, may not be able to adapt to, or compensate for, even mild reductions in total sleep time. Further, although the driver's maximum sleep opportunity on the second sleep schedule the night before the accident was 8.25 hours, a

[161] T. Balkin and others, *Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance*, DOT contract DTFH61-94-Y-00090, Report No. DOT-MC-00-133 (Silver Spring, Maryland: Walter Reed Army Institute of Research, 2000).

length the driver reported that he normally slept, research has found that 2 full nights of sleep is required to obtain a near or full recovery from protracted sleep loss or sleep restriction.[162]

The truck driver did not comply with the sleeper berth provision and exceeded the 14-hour limit within hours-of-service regulations,[163] maintained an irregular sleep/wake schedule by rising earlier one day than the next, and remained awake the day before the accident (on the second sleep schedule) for 19 hours. An arduous work schedule is one of the most highly predictive underlying factors associated with long-distance truck drivers falling asleep at the wheel.[164]

To summarize, because of inconsistencies with the truck driver's reported sleep, the NTSB constructed two possible sleep schedules. Under the first sleep schedule, the driver's performance was unlikely affected by fatigue but may have been affected by other factors, such as distraction or inattention. However, under the second sleep schedule, the driver may have been fatigued. Therefore, the NTSB concludes that there was insufficient information available to determine whether the truck driver was fatigued.

The truck driver did not meet regularly with a supervisor or report to a company-operated terminal. Consequently, he worked independently, setting his own hours within the delivery schedule assigned by a dispatch office in Houston, Texas. A review of the truck driver's work/rest schedule indicated that it differed daily and was inconsistent with sound sleep management practices. The truck driver's decisions about when and how long to sleep may be indicative of similar choices being made by other AmeriGas/PTI drivers.

In this accident, the truck driver violated Federal regulations (49 CFR Part 395) by either splitting sleep periods or not resting at least 8 consecutive hours in the sleeper berth on 2 consecutive nights before the accident. Additionally, after conducting a detailed review of the truck driver's reported hours, comparing entries made in the driver's handwritten logbook with shipping documents and *Qualcomm* vehicle position history data, NTSB investigators discovered five false log entries and hours-of-service violations on 3 separate days during the weeks before the accident.

Surveys conducted for the *Cargo Tank Roll Stability Study* consistently identified driver fatigue and inattention as major contributors to rollover accidents. Information from the Trucks Involved in Fatal Accidents (1999–2003) and GES (2000–2004) databases revealed that

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[162] a) A. Smiley and R. Heslegrave, *A 360 Hour Recovery Period for Truck Drivers; Synopsis of Current Scientific Knowledge*, TP 13035E (Ottawa, Canada: Transport Canada, Transportation Development Centre, 1997). (b) D.F. Dinges and others, "Cumulative Sleepiness, Mood Disturbance, and Psychomotor Vigilance Performance Decrements During a Week of Sleep Restricted to 4–5 hours Per Night," *Sleep,* vol. 20, no. 4 (1997), pp. 267–277. (c) S. Vespa and others, "Study of Commercial Vehicle Driver Rest Periods and Recovery of Performance in an Operational Environment," *Third International Conference on Fatigue and Transportation, Institute for Research in Safety and Transport, Murdoch University, February 9–13, 1998, Fremantle, Western Australia*.

[163] Title 49 CFR Part 395 stipulates that property-carrying commercial drivers may not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour limit. Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

[164] A.T. McCartt and others, "Factors Associated With Falling Asleep at the Wheel Among Long-Distance Truck Drivers," *Accident Analysis & Prevention,* vol. 32, no. 4 (2000), pp. 493–504.

inattention was a factor in 12–14 percent of rollover accidents involving cargo tank motor vehicles. One countermeasure that motor carriers can implement to minimize the risk of fatigue-related accidents is a *fatigue management program*, the key components of which include organizational commitment; education; medical screening and treatment; scheduling; and a strategy for implementing, monitoring, and evaluating the program. The North American Fatigue Management Program, currently under development and anticipated to be completed by 2012, is a collaborative effort by the FMCSA, Canadian regulators, and industry associations to reduce fatigue-related accidents by creating the components necessary to manage commercial driver fatigue.

The NTSB issued the following recommendations associated with fatigue management to the FMCSA after its investigation of a 2009 multi-vehicle rear-end accident[165] resulting in 10 passenger vehicle occupant fatalities:

> Create educational materials that provide current information on fatigue and fatigue countermeasures and make the materials available in different formats, including updating and redistributing your truck-driver-focused driver fatigue video; make the video available electronically for quicker dissemination; and implement a plan to regularly update the educational materials and the video with the latest scientific information and to regularly distribute them. (H-10-8)

> Require all motor carriers to adopt a fatigue management program based on the North American Fatigue Management Program guidelines for the management of fatigue in a motor carrier operating environment. (H-10-9)

NTSB Safety Recommendations H-10-8 and -9 are currently classified “Open—Await Response.”

A fatigue management program should include, at a minimum, an accurate method of verifying hours-of-service records and disseminating information on sleep physiology, effect of altering sleep/wake cycles, accumulated sleep debt, sleep management, sleep disorders, and fatigue countermeasures. A recent study examining the effect of such programs on driver fatigue found that drivers experienced improvements in subjective sleep quality and in the sleep achieved during on-duty days when a fatigue management program was implemented.[166] As noted earlier, when asked by NTSB investigators, AmeriGas Propane, L.P., management indicated that the company does not have a formal fatigue management program.

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[165] *Truck-Tractor Semitrailer Rear-End Collision Into Passenger Vehicles on Interstate 44, Near Miami, Oklahoma, June 26, 2009,* Highway Accident Report NTSB/HAR-10/02 (Washington, DC: National Transportation Safety Board, 2010).

[166] A. Smiley and others, *Effects of Fatigue Management Program on Fatigue in the Commercial Motor Carrier Industry* (Ottawa, Canada: Transportation Development Centre, Transport Canada and Federal Motor Carrier Safety Administration, 2009).

Such programs have been recognized by the NTSB,[167] the FMCSA,[168] and the motor carrier industry[169] as a valuable and effective safety tool for reducing incidents from commercial driver fatigue. The NTSB concludes that AmeriGas Propane, L.P., drivers would be less likely to violate hours-of-service regulations and make better informed choices about sleep if the company implemented a fatigue management program.

2.3 Cargo Tank Rollover Prevention

Cargo tank motor vehicles represent approximately 6 percent of large trucks[170] yet account for 31 percent of *all* fatal commercial truck rollover accidents.[171] The *Cargo Tank Roll Stability Study* examined data from the *Large Truck Crash Causation Study (LTCCS)*[172] and found that cargo tank motor vehicles were more prone to rollover while negotiating a curve (57.1 percent) than all heavy trucks (40.1 percent). Therefore, the NTSB maintains that a holistic approach involving commercial drivers, dispatchers, carrier management, manufacturers, and highway design engineers working together to prevent cargo tank motor vehicle rollovers is an effective strategy for reducing hazardous materials releases. Measures discussed in the following sections include:

- Developing and implementing a comprehensive *rollover prevention program*;
- Equipping cargo tank motor vehicles with stability control systems;
- Making design and manufacturing changes to improve the rollover threshold of cargo tank motor vehicles;
- Minimizing the effect of partial loads on the rollover threshold of cargo tank motor vehicles, particularly when evasive maneuvers are executed; and
- Addressing the reduced effective superelevation through changes in cross slope on curve sections of high-speed highways.

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

[168] *Pilot Test of Fatigue Management Technologies*, Report Number FMCSA-RT-05-002 (Washington, DC: Federal Motor Carrier Safety Administration, 2005).

[169] For further information, see "Hours of Service Listening Session: MCSAC Briefing" <http://mcsac.fmcsa.dot.gov/documents/HOS%20Listening%20Session%20Summary%20V1.ppt>, accessed April 30, 2011.

[170] *Vehicle Inventory and Use Survey*, 2002 Economic Census (Washington, DC: U.S. Department of Commerce, December 2004).

[171] "Tank Truck Drivers: This Sign's for You!" *Safety News*.

[172] The LTCCS contains a nationally representative sample of 967 large-truck fatal and injury crashes that were investigated in 2001–2003 at 24 sites in 17 states. For further information, see *Report to Congress on the Large Truck Crash Causation Study*, Report Number MC-R/MC-RRA (Washington, DC: Federal Motor Carrier Safety Administration, March 2006).

2.3.1 Rollover Prevention Programs

Rollover threshold has been defined as the maximum value of lateral acceleration required to bring a vehicle to the point of initiating roll instability.[173] Rollover threshold for a five-axle articulated vehicle combination unit occurs when the inside wheels of the semitrailer begin to lift off the ground as the combination unit negotiates a curved path. The basic measure of vehicle roll stability is *static rollover threshold*, which is expressed as lateral acceleration in gravitational units (*g*).[174] The typical rollover threshold of a fully loaded five-axle cargo tank motor vehicle is 0.35 *g* for a semitrailer carrying petroleum and 0.26 *g* for a semitrailer with cryogenic[175] product.[176] Drivers usually maneuver cars, light trucks, vans, and sport-utility vehicles below 0.2 *g*,[177] which is well below the calculated rollover threshold of 0.8–1.2 *g* for passenger vehicles. The wide range of maneuvering capability that allows passenger vehicle drivers to recover when errors are made, such as traveling too fast around a curve or introducing a rapid steering input, is not available to commercial drivers because the rollover threshold of loaded heavy trucks extends occasionally into the "normal" maneuvering range and well within the "emergency" maneuvering capability of the vehicle,[178] particularly when rapid, evasive steering maneuvers are executed. Therefore, the NTSB concludes that laden cargo tank motor vehicles provide little tolerance for operator error.

Leaders from three of the largest propane retailers, including AmeriGas Propane, L.P., identified better driver training as the foremost solution for reducing the 120–150 yearly rollovers involving single-unit cargo tank trucks that transport liquefied petroleum gas.[179] Training has been provided to "program" drivers not to jerk the steering wheel or attempt to overcorrect when the wheels of the vehicle move off the road.

The rollover segment of the *Vehicle Incident Prevention Training* program provided by AmeriGas Propane, L.P., to its commercial drivers primarily consisted of seven PowerPoint slides containing images and information about the basic considerations for preventing the rollover of cargo tank motor vehicles. The training, which was completed by the accident truck driver on August 15, 2008, emphasized the importance of not "swerving" because it could result in the instability and untripped rollover of a cargo tank motor vehicle. In response to a question on the post-training test about what action should be avoided if an animal darts onto the road, the truck driver correctly responded "swerve." However, contrary to the training he had received to avoid "swerving" to prevent rollovers, the truck driver executed an excessive, rapid, evasive

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[173] UMTRI-83-25.

[174] C.B. Winkler and R.D. Ervin, *Rollover of Heavy Commercial Vehicles*, UMTRI-99-19 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1999).

[175] Cryogenic liquids are liquefied gases such as nitrogen, natural gas, oxygen, argon, and methane that are kept in a liquid state at temperatures from -150 to -453° F.

[176] UMTRI-99-19.

[177] AASHTO guidelines for highway curve design result in lateral accelerations as high as 0.17 *g* at the posted advisory speed.

[178] UMTRI-99-19.

[179] "Tipping Point: Bobtail Rollover Frequency Concerns Prompt Push for New Training Remedies," *LPGas* magazine, June 1, 2010.

steering maneuver during this accident in response to becoming aware of a passenger vehicle's horn in an adjacent lane.

The truck driver indicated during a postaccident interview with NTSB investigators that he had not received training for preventing or recognizing rollovers, although employee records showed he had attended the *Vehicle Incident Prevention Training* program in August 2008, just over a year before the accident. The NTSB concludes that the rollover training received by the truck driver was not effective in preventing this accident.

Approximately 66 percent of cargo tank rollovers involve drivers with 10 or more years of driving experience.[180] The *Cargo Tank Roll Stability Study* found the main training challenge facing the cargo tank industry was trying to modify human performance by motivating drivers to remain alert and not become distracted. The *Cargo Tank Roll Stability Study* also found that although more "hands on" training using driving simulators has proven cost-effective by reducing training time, no demonstrated business model exists for incorporating simulators for small carriers; further, no long-term studies have been conducted to validate the benefits of simulator training for rollover prevention.

Rollover training should not be limited to commercial drivers but also include action that can be taken by management to reduce schedule-related demands, minimize delivery of loads with partially filled compartments, and identify strategic steps that could be taken to improve the roll stability of existing and newly manufactured cargo tank motor vehicles. The *Cargo Tank Roll Stability Study* concluded the leading factor for increasing or decreasing cargo tank rollover risk is the dispatcher, who can control the operational demands to comply with tight delivery schedules that often pressure drivers to travel at excessive speeds or drive when drowsy. Dispatchers now more commonly have access to real-time information that can be used to monitor hours-of-service records and vehicle position history data to identify drivers who may be fatigued or driving faster than posted speed limits.

Similar to the *Heavy Vehicle Rollover Prevention Program* initiated in Australia,[181] rollover prevention programs should include, as a minimum, a detailed and informed discussion about rollover dynamics using truck models and written policies that identify the roles of—and reasonable measures to be taken collaboratively by—drivers, dispatchers, and management for preventing cargo tank motor vehicle rollovers. These policies should specifically clarify motor carrier actions to reduce the operational demands that may inadvertently be imposed on drivers and contribute to rollover accidents, and stipulate initiatives for improving the roll stability of cargo tank motor vehicles.

The NTSB concludes that although a rollover prevention program will not eliminate all rollovers due to driver errors, it can be effective for identifying ways for cargo tank motor vehicle drivers and management to work collaboratively to prevent rollover accidents. The NTSB recommends that the FMCSA work with PHMSA, as appropriate, to develop and disseminate guidance that will assist hazardous materials carriers in implementing

[180] "Tank Truck Drivers: This Sign's for You!" *Safety News*.

[181] *Heavy Vehicle Rollover Prevention Program*, VicRoads, Australia <http://www.vicroads.vic.gov.au/truckrollover>, accessed May 1, 2011.

comprehensive cargo tank motor vehicle rollover prevention programs, including the active participation of drivers, dispatchers, and management through training, loading practices, delivery schedules, and acquisition of equipment.

2.3.2 Stability Control Systems

Simulations were conducted during the *Cargo Tank Roll Stability Study* using Vehicle Dynamics Analysis, Non-Linear (VDANL) software[182] to compare the overall probability of a rollover crash *with* and *without* tractor-based RSC in combination with a two-axle cargo tank semitrailer. The analysis examined 126 specific events with dynamic characteristics found to precede a rollover crash, as identified during a DOT-sponsored field operational test. The simulations found that rollover crash probability was reduced with a tractor-based RSC system.[183] The simulation analysis estimated that a tractor-based RSC system could prevent approximately 53 percent of *untripped* rollovers resulting from excessive speed in a curve.

It was not possible to determine whether stability control systems could have prevented this specific accident due to the absence of information as a result of the truck-tractor's engine electronic control module being destroyed in the fire. However, simulations conducted by the NTSB using circumstances similar to the accident indicated that an RSC system has the potential to prevent rollovers by applying the service brakes when the lateral acceleration of a simulated vehicle exceeds 0.3 *g*.

Research has found the effectiveness of ESC and RSC in reducing rollover and loss of control accidents can vary depending on the crash scenario. The combined effectiveness rates of ESC installed on class 8 truck-tractors was found to be greater (28–36 percent) than for RSC (21–30 percent).[184] A 2009 DOT study involving tractor-semitrailers found that more overall safety benefits were provided with ESC than with RSC; 106 fewer fatalities and 4,384 fewer injuries would be expected to occur if all existing five-axle tractor-semitrailers in the United States were outfitted with ESC systems.[185] The NTSB concludes that a stability control system on the combination unit may have prevented this accident.

The NTSB recommended, as a result of its investigation of a 2009 bus rollover in Dolan Springs, Arizona,[186] that NHTSA develop performance standards and ultimately require that all newly manufactured buses with a GVWR greater than 10,000 pounds be equipped with stability control systems. Separate rulemakings may be required to equip all commercial motor vehicles

[182] VANDL Systems Technology, Inc., Hawthorne, California <http://www.stisimdrive.com/our-solutions/associated-products/vdanlatrade.html#tvm>, accessed May 10, 2011.

[183] Simulations were used during the *Cargo Tank Roll Stability* study because (as reported in DOT-HS-811-437) statistical analysis of heavy commercial vehicles using real-world accident data has not been feasible due to ESC and RSC being relatively new technologies that were implemented primarily as optional safety features.

[184] *Effectiveness of Stability Control Systems for Truck Tractors*, Traffic Safety Factors, DOT-HS-811-437 (Washington, DC: National Highway Traffic Safety Administration, January 2011).

[185] J. Woodrooffe and others, *Safety Benefits of Stability Control Systems for Tractor-Semitrailers*, DOT-HS-811-205 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2009).

[186] NTSB/HAR-10/01.

with a GVWR greater than 10,000 pounds with such systems because some vehicles have hydraulic brakes and others have pneumatic brakes, which use different components and approaches to modulate, maintain, and release the pressurized fluid or air sent to the foundation brakes to prevent wheel lockup. Therefore, the NTSB recommends that NHTSA develop stability control system performance standards for all commercial motor vehicles and buses with a GVWR greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system; and, once the performance standards have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a GVWR greater than 10,000 pounds. As a result of these new recommendations to NHTSA, the NTSB reclassifies Safety Recommendations H-10-5 and -6 "Closed—Superseded."

The NTSB concludes that, given the long service life of cargo tanks, 25–50 years could pass before all cargo tank trailers would be equipped with stability control systems. While it is feasible to retrofit trailers with an RSC system, it is not practical to fully integrate sensors and internal communication systems on single-unit trucks and truck-tractors. Consequently, the NTSB recommends that the FMCSA require all in-use cargo tank trailers with a GVWR greater than 10,000 pounds to be retrofitted with an RSC system.

2.3.3 Vehicle Design

Although several aspects of transporting hazardous materials on public roads are covered by Federal regulations, no current regulations address optimizing the roll stability of cargo tank motor vehicles. In the absence of requirements, there has been little improvement in the roll stability of cargo tank motor vehicles in the United States. Meanwhile, several countries have developed procedures, such as testing rollover propensity using a tilt table or conducting dynamic tests on a closed track, to objectively quantify and evaluate the roll stability of newly manufactured cargo tank motor vehicles. The NTSB concludes that the absence of regulatory guidance in the United States has discouraged proactive measures to improve the roll stability of cargo tank motor vehicles during the design and manufacturing process.

NTSB investigators used crash data from the *Cargo Tank Roll Stability Study*, extracted from the GES, to determine how many rollovers could be prevented annually, on average, by equipping truck-tractors with an RSC system, lowering CG height by 3 inches, and increasing track width by 6 inches. GES crash data for 1999–2004 indicated that an average 1,265 cargo tank rollovers occurred annually, with approximately 702 (55.5 percent) of these involving a truck-tractor in combination with a cargo tank semitrailer.[187] Of the 702 average annual rollovers involving cargo tank semitrailers, approximately 84 (12 percent) could be prevented by lowering the CG height 3 inches and approximately 119 (17 percent) by increasing the track width by 6 inches. An estimated one of every four cargo tank semitrailer rollovers could be prevented (27 percent) by both nominally lowering the CG height 3 inches and increasing the track width 6 inches. The relative effects and rollover prevention rate of these vehicle modifications and those that may be obtained by a tractor-based RSC, as determined by commercially available vehicle simulation software, are shown in table 10.

[187] *Cargo Tank Roll Stability Study*, table 2-8, p. 17.

Table 10. Estimated annual reduction in cargo tank semitrailer rollover accidents.

Vehicle Improvements[a]	Annual Rollover Reduction	Rollover Prevention Rate
Install tractor-based RSC system to reduce untripped rollovers (traveling too fast in a curve)	37	5%
Lower CG height 3 inches to reduce tripped and untripped rollovers	84	12%
Increase track width[b] 6 inches to reduce tripped and untripped rollovers	119	17%
Reduce CG height 3 inches and increase track width 6 inches[c] to reduce tripped and untripped rollovers	189	27%

[a]Estimates assume that all truck-tractors are equipped with an RSC system and all cargo tank semitrailers have had their CG height lowered 3 inches and/or track width increased 6 inches. Analyses to quantify the safety benefits of improving roll statiblity by lowering CG height and increasing track width were performed using DOT 406 cargo tanks. Results of similar analyses using other DOT specification cargo tanks may differ.

[b]No data exist to quantify the proportion of cargo tank semitrailers with increased track width, which has been estimated at 10–30 percent. Analyses performed to estimate the rollover prevention rate for increasing track width 6 inches were based on all existing cargo tanks having a standard (and not a wider) track width. Consequently, the prevention rate calculated for equipping cargo tank semitrailers with increased track width may be less than 17 percent.

[c]The rollover prevention rate for lowering the CG height 3 inches and increasing track width 6 inches is slightly less than the combined total because of the decreasing slope in the relationship between rollovers per million miles of travel and rollover threshold of heavy trucks, as developed from historical accident data.

The authors of the *Cargo Tank Roll Stability Study* emphasized that improving the roll stability of cargo tank motor vehicles, by lowering CG height and increasing track width, was the only approach that would reduce tripped and untripped rollovers because the rollover involvement of heavy trucks is strongly related to their rollover threshold. Although design improvements for increasing the roll stability of cargo tank motor vehicles have been found cost beneficial, such improvements have been slow to gain market share because of a small cost premium and thus their benefit has not been widely appreciated.[188] The safety benefits of concept cargo tank semitrailers that were unveiled in the 1980s, featuring improved roll stability and an additional axle to increase the GVWR by approximately 10 percent, did not lead to widespread changes in the design and manufacture of cargo tank motor vehicles.[189,190]

In summary, the NTSB concludes that the roll stability of cargo tank motor vehicles can be improved significantly by two design considerations: maximizing track width and selecting several available options for lowering CG height. Both of these design improvement strategies are utilized today.

Performance-Based Standards. The success of performance-based standards depends on empirically establishing a link between performance measures and accident risks.[191] NHTSA has effectively linked the rollover risk of sport-utility vehicles and other high CG vehicles to their static stability factor, the measurement of a vehicle's resistance to rollover, which led to

188 *Cargo Tank Roll Stability Study*.

189 L.A. Botkin, "Proposed Tri-Axle Tank Trailer Improves Stability and Productivity," *Modern Bulk Transporter*, September 1983.

190 B. Klingenberg, G. Rossow, and R. Jacobsen, *FACT—The Freightliner/Heil Advanced Concept Truck*, Technical Paper No. 892462 (Warrendale, Pennsylvania: SAE International, 1989).

191 *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles*, Special Report 267 (Washington, DC: Transportation Research Board, 2002).

design changes and improvements in the geometric stability and rollover resistance of those vehicles.[192] In the case of cargo tank motor vehicles, no additional data are required to establish a link between the risks associated with high CG vehicles that are prone to rollover and the release of hazardous materials. A performance-based roll stability standard for all cargo tank motor vehicles transporting hazardous materials in the United States was previously recommended by UMTRI.[193] The NTSB maintains that a regulation establishing minimum operational requirements for cargo tank motor vehicles may direct attention toward the efforts necessary for heavy truck and cargo tank manufacturers to build rollover-resistant cargo tank motor vehicles. The NTSB concludes that although manufacturers have the ability to improve the roll stability of cargo tank motor vehicles, little incentive exists for making improvements. Therefore, the NTSB recommends that NHTSA establish comprehensive minimum rollover performance standards, based on the least stable condition operated, for all cargo tank motor vehicles with a GVWR greater than 10,000 pounds. Further, the NTSB recommends that NHTSA, once the performance standards have been developed, require that all newly manufactured cargo tank motor vehicles with a GVWR greater than 10,000 pounds comply with the performance standards.

2.3.4 Partial Loads

A partial liquid load has the potential to roll up the side of the tank and shift the CG as a vehicle negotiates a curve or if rapid steering movements are introduced. Assuming all other factors that could affect the stability of a vehicle remain constant, the rollover thresholds of cargo tank motor vehicles with fill levels of 80 and 100 percent would not differ significantly while negotiating a steady-state curve.[194] However, during a transient maneuver,[195] the lateral displacement of a partially filled tank introduces the added dimension of dynamic effects, which can cause bulk liquid to be displaced in one direction and then the other with an amplitude (resulting from a quick succession of steering inputs) that is twice the level of the steady-state amplitude.[196] Consequently, when a rapid, evasive steering maneuver occurs, the potential for rollover of a cargo tank with a fill level of 80 percent can be greater, despite a lower CG height, than for a cargo tank with a fill level of 100 percent.[197]

In this accident, the fill level of the cargo tank with 9,001 gallons of liquefied petroleum gas was approximately 78 percent by volume, which resulted in approximately 23 inches of void space between the top surface of the product (fill level) and the uppermost interior surface of the tank. Evaluating the dynamic effect of the sloshing and surging of liquefied petroleum gas within the MC331 cargo tank and its contribution to the rollover of the combination unit after the rapid, evasive steering maneuver was executed is beyond the capabilities of commercially available

[192] M.C. Walz, *Trends in the Static Stability Factor of Passenger Cars, Light Trucks, and Vans*, Report No. DOT HS 809-868 (Washington, DC: National Highway Traffic Safety Administration, 2005).

[193] UMTRI-85-35/2.

[194] In a steady state curve, the steering wheel is maintained in a relatively constant position.

[195] In a transient maneuver, such as when a double lane change is quickly executed, the steering wheel is turned rapidly in one direction and then quickly reversed at an equal steer angle in the opposite direction.

[196] C.B. Winkler and others, *Rollover of Heavy Commercial Vehicles*, Research Report No. RR-004 (Warrendale, Pennsylvania: SAE International, 2000).

[197] Research Report No. RR-004.

vehicle simulation software. Although more advanced simulations are possible, data for validating a model of fluid sloshing and surging are not available, and a more precise description of the actual vehicle motion would be required to evaluate the effect of sloshing.

The NTSB has issued at least two recommendations to the Bureau of Motor Carrier Safety (BMCS, predecessor to the FMCSA) to address the instability that can result from the lateral and longitudinal displacement of bulk liquid in partially filled cargo tanks:

> In cooperation with affected industries, as represented by the Tank Truck Technical Council, conduct an investigation designed to resolve the overturn stability problems created by liquid surging of partially loaded tank-truck combinations. The ultimate objective of such a research program should be the promulgation of Federal regulations to limit the effects of surge to a specific degree. Such regulations might be based on acceptable liquid cargo outage and/or dampening requirements, consistent with safe tank truck operations. (H-72-45) [198]
>
> In cooperation with the Tank Truck Technical Council, investigate the overturn stability problem created by liquid cargo surging in tank-truck combinations. The ultimate objective of such an investigation should be the promulgation of Federal regulations to specifically limit the effects of surge. (H-73-24)[199]

The BMCS responded to Safety Recommendation H-72-45 by stating it would not issue special permits for cargo tank semitrailers pending research that was to be conducted by the National Bureau of Standards. Safety Recommendation H-72-45 was classified "Closed—Acceptable Action" on January 1, 1980. The BMCS responded to Safety Recommendation H-73-24 by indicating it would determine whether to initiate rulemaking to address the surging of partial loads transported by cargo tanks after reviewing the results of a NHTSA study on the handling of trucks and buses to be completed in March 1974. In June 1980, the BMCS issued an *On Guard* bulletin to raise driver awareness of the instability of partial loads. Safety Recommendation H-73-24 was classified "Closed—Acceptable Action" on September 26, 1980.

The Truck Trailer Manufacturers Association has long expressed concern about the practice of partial loading of cargo tank motor vehicles, stating in a 1980 technical bulletin that "a partially downloaded cargo tank will be less stable under cornering and braking conditions than an ordinary liquid tank loaded to its normal capacity."[200] Cargo tank manufacturers have also expressed concern, as reported during the August 2010 NTSB public hearing, about the

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[198] *Tank-Truck Combination Overturn Onto Volkswagen Microbus Followed by Fire, U.S. Route 611, Moscow, Pennsylvania, September 5, 1971*, Highway Accident Report NTSB/HAR-72/06 (Washington, DC: National Transportation Safety Board, 1972). Safety Recommendation H-72-45 was reiterated in *Transport Company of Texas, Tractor-Semitrailer (Tank) Collision With Bridge Column and Sudden Dispersal of Anhydrous Ammonia Cargo, I-610 at Southwest Freeway, Houston, Texas, May 11, 1976*, Highway Accident Report NTSB/HAR-77/01 (Washington, DC: National Transportation Safety Board, 1977).

[199] *Propane Tractor Semitrailer Overturn and Fire, U.S. Route 501, Lynchburg, Virginia, March 9, 1972*, Highway Accident Report NTSB/HAR-73/03 (Washington, DC: National Transportation Safety Board, 1973).

[200] *MC 307 Tank Vehicles*, Technical Bulletin 81 (Alexandria, Virginia: Truck Trailer Manufacturers Association, June 16, 1980).

practice of partially loading cargo tanks, explaining to motor carriers via letter the limitations of partially loaded cargo tank motor vehicles.

The *Cargo Tank Driver Rollover Prevention Video* developed by the FMCSA, PHMSA, and industry partners cautions drivers that sloshing can move the liquid sideways too suddenly and too strongly, causing a cargo tank motor vehicle to roll over. Additional strategies for reducing the number of cargo tank motor vehicle rollovers that result from the sloshing and surging of bulk liquid include specifying or retrofitting vehicles with high roll stiffness suspensions, subdividing the tank into separate compartments, and installing transverse and longitudinal baffles to impede the fore/aft and lateral movement of product.

Although a great deal is known about the mechanics of sloshing liquids in transportation tanks, fluid mechanics is exceedingly complex and slosh motions are difficult to generalize when wave amplitudes become severe.[201] While several studies have been conducted to learn more about the stability of cargo tank motor vehicles, few, if any, have included performing dynamic tests on a closed track to quantify the effect of partial liquid loads on the roll stability of cargo tank semitrailers. The NTSB concludes that the directional stability and rollover threshold of cargo tank motor vehicles can be degraded by the sloshing and surging of partial liquid loads. Therefore, the NTSB recommends that NHTSA evaluate the effect of emergency maneuvers on the sloshing and surging of bulk liquids that have various densities over a range of partially filled levels in a DOT specification cargo tank. The NTSB further recommends that, if the results of the evaluation warrant action, NHTSA establish and implement performance standards for mitigating the sloshing and surging of bulk liquids in all newly manufactured cargo tank motor vehicles with a GVWR greater than 10,000 pounds.

2.3.5 Cross-Slope Break

The most detrimental effect of cross-slope break traversals is the lateral acceleration generated when a vehicle migrates from the travel lane fully onto the shoulder. If the lateral acceleration is great enough, loss of directional control can occur directly because of the lack of available skid resistance at the tire/road interface or indirectly because of intolerable centrifugal forces that may cause a driver to become apprehensive and take inappropriate actions (hard braking or excessive steer input).

An unpublished 1983 FHWA report contained the results of a study that evaluated the dynamic effects of centerline crowns when passing maneuvers were conducted on tangent roadway sections with passenger cars and loaded and empty truck-tractor combinations and single-unit trucks.[202] The simulations produced vehicle dynamic responses of 0.28–0.34 *g* for cross slopes of 2 percent for all vehicle types. The findings indicated that cross slopes should be kept to a minimum on high-speed highways. These results were consistent with simulation-based analyses conducted by the NTSB that revealed a high CG vehicle would be significantly less stable on a shoulder with a −2 percent cross slope than on a travel lane with an 8 percent cross

[201] UMTRI-85-35/2.

[202] J.C. Glennon and others, *HVOSM Studies of Highway Centerline Crowns, Technical Report*, Contract No. DOT-FH-11-9575, unpublished, August 1983.

slope. Therefore, the NTSB concludes that the transition from a positive to a negative cross slope as the combination unit moved laterally from the right lane onto the shoulder significantly decreased the speed at which the combination unit involved in this accident could negotiate the curve without rolling over.

The effect of cross-slope breaks on the roll stability of heavy trucks has not been fully evaluated. The results of the limited FHWA study that examined the dynamic response of cross-slope break traversals on highway curves was based on simulations performed with a passenger car, not articulated truck-tractor semitrailers.[203] NCHRP Report 505 indicated that the 2001 AASHTO Green Book criteria for cross-slope breaks and vertical clearances appeared to be appropriate for the current truck fleet; however, the report also acknowledged that no further data were found in the literature to address questions on the sensitivity of heavy trucks to cross-slope break traversals. Furthermore, the FHWA confirmed in a September 3, 2010, memorandum that it did not have adequate data to establish an appropriate cross-slope break for heavy trucks.[204] The same assessment was noted during the August 2010 NTSB public hearing, when a question was asked about FHWA research regarding the effect of cross-slope breaks on the safe operation of heavy commercial vehicles. The NTSB concludes that the guidance on cross-slope break in the current AASHTO publication *A Policy on Geometric Design of Highways* does not take into account low-stability heavy trucks that are susceptible to rollover, such as cargo tank motor vehicles with a high CG.

The NTSB believes that more information is needed on heavy truck rollover characteristics relative to cross-slope break traversals. Therefore, the NTSB recommends that AASHTO work with the FHWA to evaluate vehicle design characteristics specific to the rollover thresholds of heavy trucks, including those having cargo tanks, and use the information obtained to develop best practices in highway design that will mitigate the increased rollover risk caused by reduced effective superelevation through changes in cross slope that high CG commercial vehicles experience when they migrate onto the shoulder while negotiating curve sections of high-speed highways. The NTSB also recommends that AASHTO incorporate the findings of this evaluation in *A Policy on Geometric Design of Highways and Streets.* Further, if the results of the heavy vehicle design evaluation warrant such action, the NTSB recommends that the FHWA work with AASHTO to develop and implement best practices to assist state transportation agencies in identifying existing locations where cross-slope breaks pose a rollover hazard, placing an emphasis on those roadways having high volumes of heavy truck traffic, and develop appropriate strategies for mitigating the hazard. The NTSB further recommends that, until these best practices have been developed and disseminated, the FHWA provide information to state transportation agencies about the safety risks associated with cross-slope breaks and their potential for increasing the rollover propensity of commercial vehicles that have a high CG.

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[203] J.C. Glennon, T.R. Neuman, R.R. McHenry, and B.G. McHenry, *HVOSM Studies of Cross-Slope Breaks on Highway Curves*, DOT-FH-11-9575 (Washington, DC: U.S. Department of Transportation, July 1981).

[204] Associate Administrator for Safety, Federal Highway Administration, memorandum (regarding design considerations for prevention of cargo tank rollovers) to Directors of Field Services, Division Administrators, and Federal Land Engineers, September 3, 2010, p. 2

The NTSB addressed highway geometry in its 1994 investigation of a rollover accident involving a cargo tank semitrailer.[205] The investigation determined that cargo tank motor vehicles that are susceptible to rollover should be considered when designing cross sections and horizontal curves. As such, the NTSB recommended that AASHTO:

> Add a cargo tank to the design vehicle in the AASHTO *A Policy on Geometric Design of Highway and Streets*. (H-95-39)

In its response to Safety Recommendation H-95-39, AASHTO indicated the development of a cargo tank as a design vehicle would not address rollover issues because the Green Book's design vehicles are used for assessing two-dimensional aspects of highway design using a minimum centerline turning radius, out-to-out track width (overall distance across the axle from the outboard edge of right tire to the outboard edge of left tire), wheelbase, and path of the inner-rear tire. Due to the Green Book's limitations for evaluating rollover issues and because the NTSB believes that the new recommendations address the intent of Safety Recommendation H-95-39, this recommendation is classified "Closed—Reconsidered."

The collision between the cargo tank and bridge pier column in this accident both breached the tank and displaced the outermost bridge pier column supporting the southbound I-465 overpass. In the sections that follow, the NTSB examines the availability of statistical data for evaluating the accident performance of DOT specification cargo tanks and the adequacy of bridge pier protection guidelines.

2.4 Crashworthiness of DOT Specification Cargo Tanks

2.4.1 Cargo Tank Breach

In this accident, the lower half of the front tank head was deformed inward by impacting the bridge pier column, initiating a breach. The breach, which began as a fracture of the cargo tank, generally followed a fillet weld around the perimeter of the right mounting pad attaching the bottom of the tank to the upper coupler assembly. The front head of the tank then rebounded forward, as evidenced by 180° rear-facing folds at the front ends of the left and right mounting pads (see figure 22). During the forward rebound, the tank head broke free from the mounting pads, causing shell material to overlay the folds at the end of the mounting pads. The tank head rebounded approximately 3 inches forward from the left mounting pad and 8 inches forward from the right mounting pad.

[205] NTSB/HAR-95/02.

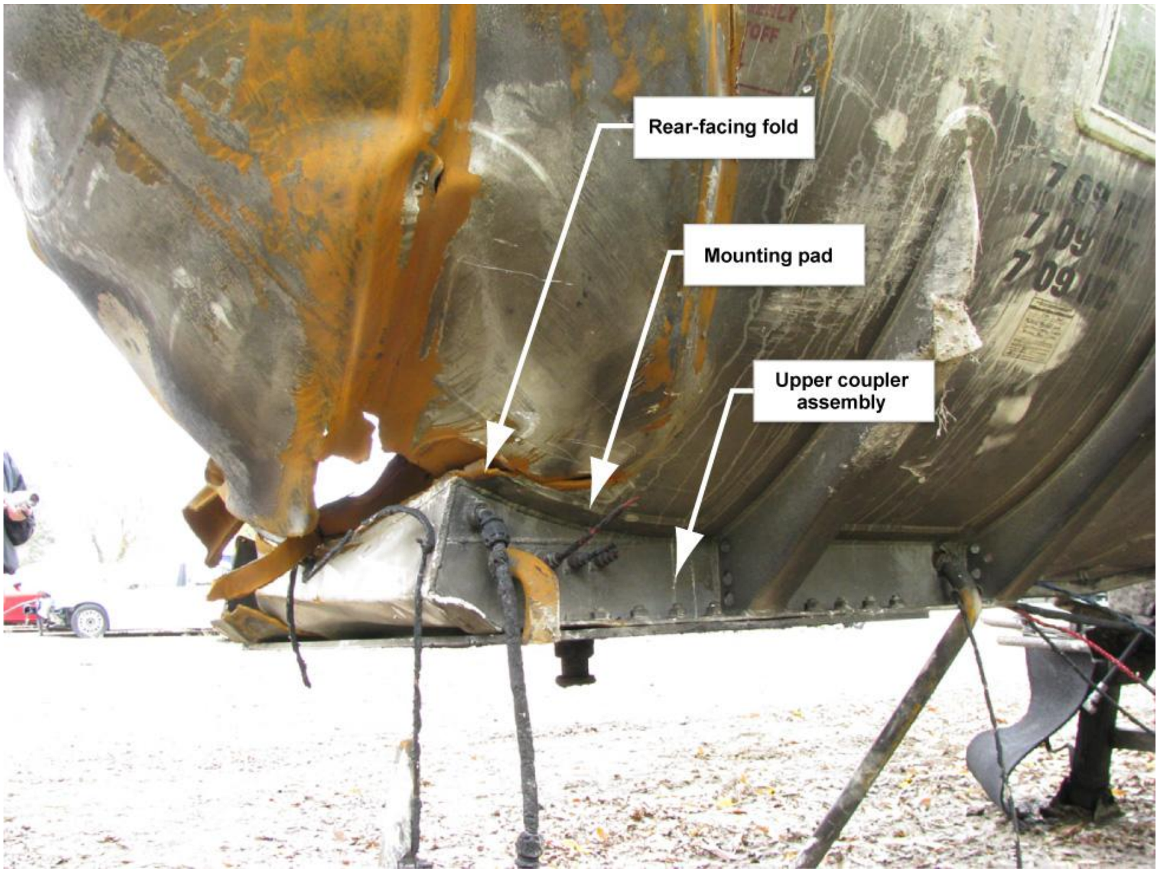

Figure 22. Mounting pad and rear-facing fold above upper coupler assembly.

The largest breach in the tank was a vertically oriented 20- by 29-inch opening at the right side of the head/shell interface, which was formed as the crack progressed from the front of the head. Two large petal-shaped flaps of shell material were peeled outward and forward and aft of the opening; this deformation was caused by pressure loading on the interior front head of the tank. Additional damage from the force of the surging liquefied petroleum gas was seen in the forward deformation of both interior transverse baffles, in which the baffles apparently reduced some of this force. The severe deformation of the baffle panels would not be expected to occur from normal transport operations.[206] The NTSB therefore concludes that the large opening at the right side of the head/shell interface was caused by internal pressure within the tank and forward surging of liquefied petroleum gas after the tank struck the bridge pier column.

2.4.2 Population of Cargo Tanks by DOT Specification

A basic requirement for evaluating the accident performance of DOT specification cargo tanks (such as the MC331) is access to data that can be used to quantify both the involvement of those tanks in reportable incidents and the in-service population of those same tanks. While the approximate number of DOT specification cargo tanks involved in accidents may be obtained

[206] Comments by representatives affiliated with the Mississippi Tank Company and AmeriGas/PTI.

from the Hazardous Materials Information System (HMIS) or other databases, there is limited access to accurate information on the population of cargo tanks by DOT specification. For example, the most precise number of petroleum-hauling DOT 406 cargo tank semitrailers cited in the *Cargo Tank Roll Stability Study* appeared to be somewhere between 10,648–60,003 units.

When asked at the August 2010 NTSB public hearing, a PHMSA official acknowledged that they did not know the total number of cargo tanks by DOT specification that were currently in service.[207] Further, PHMSA indicated that data analyses for evaluating the performance of DOT specification cargo tanks could be enhanced if the population of cargo tanks by DOT specification were available. The NTSB concludes that the absence of a requirement for motor carriers to periodically provide the number of cargo tanks by DOT specification limits the ability to perform accurate trend analyses.

The limited information currently available for PHMSA to quantify the distribution of cargo tanks by DOT specification differs considerably, for example, from information that can be accessed by the Association of American Railroads (AAR) about tank cars used for transporting bulk liquids by rail. The AAR has used the Universal Machine Language Equipment Register (UMLER) equipment management information system as the industry's central repository for registered railroad and intermodal equipment since 1968. The UMLER system is updated in real time and capable of tracking equipment status, ownership, and inspection history and providing the particular fleet profile.

The population of cargo tanks by DOT specification could be obtained by modifying the *Hazardous Materials Registration Statement* (DOT Form F 5800.2) administered by PHMSA or the *Motor Carrier Identification Report* (MCS-150) administered by the FMCSA. Although the MCS-150 requires carriers to report the classes of hazardous materials transported and the number of cargo tank single-unit trucks and trailers that are owned and leased, no obligation exists to provide the DOT specification, age, or carrying capacity of cargo tanks. Consequently, arrangements could be made to revise the MCS-150 form to regularly require all intrastate and interstate hazardous materials carriers to provide basic information about a cargo tank motor vehicle's manufacture date, carrying capacity, DOT specification, and other pertinent information for conducting risk assessments. Therefore, the NTSB recommends that the DOT require all intrastate and interstate hazardous materials carriers to submit annually the number and types of DOT specification cargo tanks that are owned or leased in addition to data displayed on the specification plates of such tanks and, if necessary, modify the appropriate database to accept additional data fields.

2.4.3 Cargo Tank Head Protection (MC331)

The NTSB determined that the heads on the accident tank were approximately 30 percent thicker than necessary to meet design and ASME code requirements. A statistical review of DOT HMIS database information by NTSB investigators indicated that the majority of releases of liquefied compressed gases from cargo tanks involve leaks from damaged hoses, valves, pipes, and fittings. Despite the inability to normalize these statistics because of uncertainty in the

[207] Testimony delivered by Charles H. Hochman, Director, Office of Hazardous Materials Technology, on August 4, 2010, at NTSB public hearing concerning the Indianapolis rollover accident.

distribution of DOT specification cargo tanks, the risk of catastrophic releases from breaches of MC331 heads appears relatively low compared to other DOT specification cargo tanks, with one fatality in the past 10 years. While MC330/331 cargo tanks represent approximately 15 percent of the national fleet of cargo tank semitrailers, they sustained—according to 1999–2009 HMIS data—0.5 percent of tank shell and head breaches in rollover accidents.[208]

PHMSA takes the position that the limited number of catastrophic releases from MC331 cargo tank head breaches provides insufficient justification for taking further measures to increase the crashworthiness of these structures. The strong negative cost-benefit analysis cited in the 2001 cargo tank crashworthiness study[209] continues to discourage PHMSA from advancing any requirement for supplemental protection of the front heads of MC331 cargo tanks. There is also opposition to the additional cost of equipping cargo tanks with energy-absorbing material and to the estimated 4,376 pounds of weight needed to protect the front head, which would increase the number of individual shipments and potentially result in more accidents because of greater accident exposure for delivering an equivalent amount of hazardous materials.

2.4.4 Cargo Tank Crash Performance

Federal regulations associated with the structural integrity of DOT specification cargo tanks require design calculations for the tank shell and heads to account for the load resulting from the design pressure in combination with the dynamic pressure of a longitudinal deceleration.[210] The regulations, however, do not consider the magnitude of accident impact forces imposed on the external surface of DOT specification cargo tanks. Accordingly, while current regulatory requirements account for stresses imposed from a 2 *g* or equivalent force generated by the longitudinal surge of bulk liquid impacting the interior tank head during an abrupt stop, there is no consideration for stresses imposed when accident impact forces are applied to the tank's external structure. PHMSA and industry panelists at the August 2010 NTSB public hearing maintain that this standard is still applicable today because a 2 *g* longitudinal deceleration force generated by product surge represents an extreme condition that could not be achieved by a hard brake application. However, the 2 *g* longitudinal deceleration does not represent all potential impact accident scenarios. For example, a cargo tank initially moving at 60 mph and decelerating at 2 *g* would come to a stop in 1.4 seconds after traveling a distance of 60 feet. In contrast, if a cargo tank traveling at 60 mph were to strike an immovable object and come to a stop by crushing the front head of the tank over a distance of 4 feet, the average deceleration would be 30 *g*, and the tank would come to a stop in less than 0.1 second.

Specification MC331 cargo tanks are required to be designed to transport compressed liquefied gases under high internal tank pressures that are significantly greater than the dynamic force generated during a 2 *g* deceleration. Consequently, the 2 *g* standard does not affect the design and construction of MC331 cargo tanks but does affect other DOT specification cargo

[208] Testimony delivered by cargo tank manufacturers (population estimates for DOT specification cargo tanks) and PHMSA (HMIS data) on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

[209] *Further Work to Improve Crashworthiness of Front Head of MC331 Cargo Tank Motor Vehicles*.

[210] Title 49 CFR 178.338-3(d), Structural Integrity, and 49 CFR 178.345-8, Accident Damage Protection, Specifications for Packaging.

tanks that transport hazardous materials. The NTSB concludes that performance standards for impacts to the external surfaces of all DOT specification cargo tanks, under varying accident conditions, would provide objective guidance for regulators and cargo tank manufacturers in identifying appropriate designs and protective systems for mitigating the release of hazardous materials.

Statistical analysis of accident data provides a starting point for determining which DOT specification tanks are more likely to release product during rollover accidents. A review of additional information—such as the DOT specification of cargo tanks, detailed accident description, tank damage, and type of object that struck the tank—would be instrumental in identifying specific measures to protect cargo tanks and prevent the release of product after rollover accidents. For example, the higher number of shipments carried by DOT specification cargo tanks that transport petroleum may account for their greater frequency of rolling over and such tanks' thin-wall aluminum shell construction may account for their greater risk of releasing hazardous materials than other DOT specification cargo tanks transporting bulk liquid hazardous materials. A statistical analysis of reportable incidents, for instance, may identify DOT specification tanks that were vulnerable to abrasion. Additionally, modeling impact forces and testing may identify a solution or the development of protective devices for mitigating damage that could result in the release of hazardous materials.

The current 2 *g* longitudinal deceleration standard should be supplemented by accident impact performance standards that provide guidance about how structures could withstand significant impacts under varying accident conditions without the release of hazardous materials. Such performance standards would be more meaningful in predicting the performance and safety of DOT specification cargo tanks in accident situations than the current longitudinal 2 *g* deceleration standard. Therefore, the NTSB recommends that PHMSA conduct a comprehensive analysis of all available accident data on DOT specification cargo tanks to identify cargo tank designs and the associated dynamic forces that pose a higher risk of failure and release of hazardous materials in accidents; and, once such cargo tanks have been identified, study the dynamic forces acting on susceptible structures under varying accident conditions and develop performance standards to eliminate or mitigate these risks. Further, the NTSB recommends that, once the performance standards have been developed, PHMSA require that all newly manufactured cargo tanks comply with the performance standards.

2.5 Protection of Bridge Pier Columns

A W-beam guardrail was installed during the connection ramp's original construction in 1970 to prevent vehicles from colliding with the bridge pier columns that supported the westbound and southbound I-465 overpasses. Guidance at that time for selecting roadside barriers called for installing a W-beam guardrail to contain and redirect errant passenger vehicles traveling south on the ramp.[211] The W-beam guardrail was not upgraded to a higher performance barrier in 1992, when the I-465 overpasses were rehabilitated and widened and the guardrail was lengthened at select locations, nor during a 1997 pavement resurfacing project.

[211] *Location, Selection and Maintenance of Highway Guardrails and Median Barriers*, NCHRP Report No. 54 (Washington, DC: Highway Research Board, National Cooperative Highway Research Program, 1968).

The 1989 AASHTO *Roadside Design Guide*—which may have been considered in determining whether to upgrade the W-beam guardrail—contained subjective factors but no objective warrants. Even if INDOT had believed in 1997 that the W-beam guardrail needed upgrading, no objective warrants were contained in the 1996 AASHTO *Roadside Design Guide* (second edition) to justify upgrading the W-beam guardrail to a higher performance barrier; further, the 1994 AASHTO *LRFD Bridge Design Specifications* only applied to new and replacement of existing bridges, not resurfacing projects. Essentially, the *Roadside Design Guide* provides guidance for protecting occupants from harm by redirecting vehicles away from bridge pier columns, which differs from the *LRFD Bridge Design Specifications*, which were created to protect bridge pier columns from vehicle impacts.

As evidenced by the Indianapolis connection ramp, where the level of protection from a roadside barrier had not changed in 40 years, the upgrading of "existing" roadside barriers is generally not high on the list of priorities competing for limited safety program funds. In contrast, if a new bridge overpass were built on I-465 today, a 42-inch concrete barrier (and not a W-beam guardrail) would be required, per the AASHTO *LRFD Bridge Design Specifications*, to protect the bridge pier columns, which are located approximately 14 feet from the edge of the traveled way and within the 30-foot clear zone. Therefore, the NTSB concludes that the proximity of the I-465 overpass bridge pier columns to the travel lanes on the connection ramp made them more vulnerable to damage resulting from a heavy vehicle collision. However, given the circumstances of this accident—with the combination unit vehicle not upright but on its right side, the angle of impact between the barrier and front head of the tank greater than 15°, and the spherical shape and robustness of the front of the tank—it is possible that even a 42-inch concrete continuous barrier may not have been able to redirect the combination unit back into the travel lane and protect the bridge pier column from a high-speed, heavy-vehicle impact.

Under current FHWA policy, the upgrade of existing roadside barriers to protect bridge pier columns can be accomplished through planned highway improvements or a rational documented policy developed by the states for determining when upgrades are necessary. Major highway improvements include construction of new bridges and replacement of existing bridges; major reconstruction projects; and resurfacing, rehabilitation, or restoration projects.

Prior to the accident, approximately 150 linear feet of W-beam guardrail on the connection ramp was replaced on October 27, 2008, and approximately 225 linear feet of damaged W-beam guardrail on the left and right sides of the ramp was replaced on October 5, 2009. INDOT's maintenance section determines how damaged guardrail is replaced,[212] which in the majority of cases will be with the same type of guardrail that was there before the damage occurred. The INDOT maintenance section consults with the INDOT design section on a case-by-case basis to determine whether a guardrail should be upgraded at high-accident locations. The INDOT design section typically evaluates guardrail replacement as part of a planned project, such as the upgrade of roadside barriers or median barriers along a stretch of interstate.

[212] INDOT becomes aware of the thousands of locations in the state where guardrail is damaged through annual maintenance reviews, weekly drive inspections, damage notifications following accidents, and calls from the public.

2.5.1 Past Accident Investigations

The need to identify and assess existing bridges that could be vulnerable to impact by a heavy commercial vehicle was identified following the NTSB's 1993 investigation of an overpass collapse in Evergreen, Alabama.[213] In this accident, a tractor with a bulk-cement-tank semitrailer left the paved road, traveled along the embankment, overran a guardrail, and collided with a supporting bridge pier column of an overpass. Two spans of the overpass collapsed onto the semitrailer and the southbound lanes of the interstate. An automobile and another tractor-semitrailer, also southbound, then collided with the collapsed bridge spans. The cement-tank truck driver sustained serious injuries; the drivers of the other two vehicles were killed. The NTSB determined that the bridge collapse, which occurred after the semitrailer collided with and demolished the north column, was a combined result of nonredundant bridge design, the proximity of the column bent to the road, and the lack of protection for the column bent from a high-speed, heavy-vehicle collision. The identification and evaluation of bridges that are vulnerable to high-speed, heavy-vehicle collisions and subsequent collapse was discussed in the report, resulting in the following recommendation to the FHWA:

> Request States to identify and assess bridges that are vulnerable to collapse from a high-speed heavy-vehicle collision with their bridge columns and develop and implement countermeasures to protect the structures. (H-94-5)

In response to Safety Recommendation H-94-5, the FHWA indicated that a program to retrofit all existing structures that may be vulnerable, or slightly vulnerable, to heavy-vehicle collisions with bridge pier columns should not be undertaken at the expense of other improvements that may be more effective and efficient in terms of reducing accidents. Furthermore, the FHWA advised the states in an April 12, 1995, memorandum to evaluate initiatives as part of a comprehensive program for improving bridge safety, noting that it would be inappropriate to bypass the bridge management processes by singling out one type of mitigation action for implementation. Because the FHWA intended to encourage the states to use the LRFD requirements pertinent to pier design and protection of structures on Federal-aid projects, which the states later began to use, and because these requirements can also be utilized to evaluate the vulnerability of existing bridges, Safety Recommendation H-94-5 was classified "Closed—Acceptable Alternate Action" on October 7, 1997.

One year after the Evergreen accident, a truck-tractor cargo-tank semitrailer loaded with 9,200 gallons of liquefied petroleum gas drifted across the left lane onto the left shoulder, struck a guardrail, and collided with a bridge pier column that supported an overpass.[214] The tractor and the semitrailer separated and the front head of the tank fractured, releasing the liquefied petroleum gas, which vaporized and ignited. The NTSB investigation of the accident found that the design of the highway geometries and appurtenances, which did not accommodate the protection of the bridge pier columns by an errant heavy vehicle, increased the bridge's vulnerability to collapse. As a result of its investigation, the NTSB issued two recommendations to the FHWA:

[213] *Tractor-Semitrailer Collision With Bridge Columns on Interstate 65, Evergreen, Alabama, May 19, 1993*, Highway Accident Report NTSB/HAR-94/02 (Washington, DC: National Transportation Safety Board, 1994).

[214] NTSB/HAR-95/02.

> Require that highway geometric design and traffic operations of the National Highway System be based on heavy-truck operating characteristics. (H-95-32)
>
> Conduct research with cargo tanks (80,000 pounds) to evaluate the safety performance of roadside barriers and highway geometrics, such as embankment sideslopes and ditches, and change the standards accordingly. (H-95-33)

In response to these recommendations, the FHWA prepared and circulated a resource document entitled *Supplemental on Safe Accommodation of Heavy Vehicles on U.S. Highways*, dated October 8, 2004, containing references to truck characteristics in NCHRP 505,[215] which was distributed to its resource centers, field offices, and Federal lands highway divisions. The supplemental document was also sent to all members of the AASHTO Technical Committee for Roadside Safety, with a suggestion to incorporate the information in the document into the next edition of the *Roadside Design Guide*. Because these actions met the intent of Safety Recommendation H-95-33, to raise each state's level of awareness concerning the continuing need to weigh the likelihood and consequences of large truck crashes at selected highway locations when new construction or reconstruction projects are being considered, this recommendation was reclassified "Closed—Acceptable Action" on April 1, 2005. The other recommendation issued to the FHWA, Safety Recommendation H-95-32, was reclassified "Closed—Acceptable Alternate Action," on April 1, 2005, although the NTSB emphasized that the full intent of the recommendation had not been met and that there was still concern that the protection of bridge pier columns would be an issue in future investigations.

After the Indianapolis accident, on September 3, 2010, the FHWA sent a memorandum to the directors of field services, division administrators, and Federal land engineers, along with copies of the same *Supplemental on Safe Accommodation of Heavy Vehicles on U.S. Highways* document that was distributed in 2004. In the memorandum, the FHWA restated its position that, although crashes involving cargo tank motor vehicles can be catastrophic, they remain relatively rare and generally occur at unpredictable locations.[216] The FHWA again encouraged geometric improvements at identified, predicted, or probable problem locations rather than advocating system-wide reconstruction to geometric standards above and beyond those recommended in the AASHTO *Policy on Geometric Design of Highways and Streets* (Green Book). The FHWA also submitted a proposal to AASHTO in October 2010 to consider funding an NCHRP research project[217] for developing risk-based guidelines for designing or shielding bridge pier columns from heavy truck impacts. The 30-month project, estimated to cost $500,000, was approved by AASHTO in April 2011.

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[215] *Review of Truck Characteristics as Factors in Roadway Design*, NCHRP Report No. 505 (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2003).

[216] FHWA memorandum regarding design considerations for prevention of cargo tank rollovers (September 3, 2010), p. 1.

[217] NCHRP Research Problem Statement, *Guidelines for Design and Shielding of Bridge Piers,* Project Number 2012-C-03.

2.5.2 Risk Assessment

Bridges without two specific attributes—redundancy and continuity—are at higher risk of failure due to pier column impacts.[218] *Redundancy* means that alternate load paths are available when a portion of a structure fails. In this accident, one of the outside columns collapsed. However, the I-465 southbound bridge structure was supported by seven columns, so even though the accident removed the outside column, the structure remained standing because six columns were still carrying the load. *Continuity* means that the bridge beams are continuous over the top of the pier columns, allowing the redistribution of loads in the superstructure from one beam to another. In some older bridge structures, the joints are placed over the pier columns, resulting in a superstructure that is not continuous. With such bridge structures, if the bridge pier columns deflect (move in a different direction) as a result of an impact, the beams will also deflect and be more likely to collapse. The bridge in this accident had continuous beams that did not deflect when the outside pier column was removed by the cargo tank semitrailer. Thus, although the right guardrail failed to redirect or prevent the combination unit from impacting the bridge pier column, the ability of the I-465 overpass to remain standing after impact indicates that consideration was taken when the bridge was designed to ensure that the integrity of the structure would be maintained and not compromised when struck by a heavy commercial vehicle. The NTSB therefore concludes that the bridge structure's existing redundancy and continuity prevented the southbound I-465 overpass from collapsing after the cargo tank semitrailer collided with and displaced the outside bridge pier column.

It is not feasible to expect that all inadequate roadside barriers will be replaced or upgraded through planned highway improvements. Accordingly, a risk assessment should be performed to identify high-risk interchanges and prioritize bridges in terms of vulnerability to collapse if struck. The risk assessment would examine key pier protection factors such as the bridge's redundancy, continuity, and distance of bridge pier columns from the edge of the traveled way. It would also take a tiered approach, first looking at locations with no redundancy, no continuity, and bridge pier columns close to the edge of the traveled way. Targeting the most unsafe locations would be more focused and strategic than attempting to retrofit all existing structures that may be vulnerable, or slightly vulnerable, to heavy-vehicle impacts.

The NTSB therefore recommends that the FHWA work with AASHTO to develop guidance for a bridge pier protection program that will allow state transportation agencies to conduct risk-based assessments of bridges located within highway interchanges. At a minimum, the program should consider each structure's redundancy, continuity, and the distance of bridge pier columns from the edge of traveled ways. Additionally, consider traffic volumes, traffic type, and the percentage of commercial vehicles transporting bulk liquid hazardous materials in identifying and prioritizing initiatives for preventing vulnerable bridges at high-risk interchanges from collapsing if struck or otherwise damaged by a heavy vehicle. Once the guidance for a bridge pier protection program has been developed, the NTSB recommends that the FHWA require that it be applied to bridges that are vulnerable to collapse if struck by a heavy vehicle.

[218] Testimony delivered by the AASHTO Chair of the Technical Committee for Guardrail and Bridge Rail on August 4, 2010, at the NTSB public hearing concerning the Indianapolis rollover accident.

3. Conclusions

3.1 Findings

1. The weather did not contribute to the accident.

2. There was no evidence of mechanical defects or preexisting damage to the combination unit and cargo tank.

3. The truck driver was adequately licensed and familiar with both the route and driving the combination unit.

4. The truck driver's performance was not impaired by alcohol or any of the prescription, over-the-counter, or illicit drugs for which he was tested following the accident.

5. There was no evidence that the truck driver was distracted by his cellular telephone immediately before the accident.

6. Neither the staged bilateral knee replacement surgery nor the general health of the truck driver caused or contributed to the accident.

7. The emergency response was timely and adequate.

8. The truck driver's excessive, rapid, evasive steering maneuver triggered the subsequent accident sequence.

9. The truck driver's quickly steering the combination unit from the right shoulder to the right lane contributed to the rollover.

10. The combination unit's speed at the onset of rollover may have been near the posted advisory speed limit.

11. There was insufficient information available to determine whether the truck driver was fatigued.

12. AmeriGas Propane, L.P., drivers would be less likely to violate hours-of-service regulations and make better informed choices about sleep if the company implemented a fatigue management program.

13. Laden cargo tank motor vehicles provide little tolerance for operator error.

14. The rollover training received by the truck driver was not effective in preventing this accident.

15. Although a rollover prevention program will not eliminate all rollovers due to driver errors, it can be effective for identifying ways for cargo tank motor vehicle drivers and management to work collaboratively to prevent rollover accidents.

16. A stability control system on the combination unit may have prevented this accident.

17. Given the long service life of cargo tanks, 25–50 years could pass before all cargo tank trailers would be equipped with stability control systems.

18. The absence of regulatory guidance in the United States has discouraged proactive measures to improve the roll stability of cargo tank motor vehicles during the design and manufacturing process.

19. The roll stability of cargo tank motor vehicles can be improved significantly by two design considerations: maximizing track width and selecting several available options for lowering center of gravity height.

20. Although manufacturers have the ability to improve the roll stability of cargo tank motor vehicles, little incentive exists for making improvements.

21. The directional stability and rollover threshold of cargo tank motor vehicles can be degraded by the sloshing and surging of partial liquid loads.

22. The transition from a positive to a negative cross slope as the combination unit moved laterally from the right lane onto the shoulder significantly decreased the speed at which the combination unit could negotiate the curve without rolling over.

23. The guidance on cross-slope break in the current American Association of State Highway and Transportation Officials publication *A Policy on Geometric Design of Highways* does not take into account low-stability heavy trucks that are susceptible to rollover, such as cargo tank motor vehicles with a high center of gravity.

24. The large opening at the right side of the head/shell interface was caused by internal pressure within the tank and forward surging of liquefied petroleum gas after the tank struck the bridge pier column.

25. The absence of a requirement for motor carriers to periodically provide the number of cargo tanks by U.S. Department of Transportation specification limits the ability to perform accurate trend analyses.

26. Performance standards for impacts to the external surfaces of all U.S. Department of Transportation specification cargo tanks, under varying accident conditions, would provide objective guidance for regulators and cargo tank manufacturers in identifying appropriate designs and protective systems for mitigating the release of hazardous materials.

27. The proximity of the Interstate 465 overpass bridge pier columns to the travel lanes on the connection ramp made them more vulnerable to damage resulting from a heavy vehicle collision.

28. The bridge structure's existing redundancy and continuity prevented the southbound Interstate 465 overpass from collapsing after the cargo tank semitrailer collided with and displaced the outside bridge pier column.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the excessive, rapid, evasive steering maneuver that the truck driver executed after the combination unit began to encroach upon the occupied left lane. Contributing to the rollover was the driver's quickly steering the combination unit from the right shoulder to the right lane, the reduced cross slope of the paved right shoulder, and the susceptibility of the combination unit to rollover because of its high center of gravity. Mitigating the severity of the accident was the bridge design, including the elements of continuity and redundancy, which prevented the structure from collapsing.

4. Recommendations

As a result of its investigation of this accident, the National Transportation Safety Board makes the following recommendations:

4.1 New Recommendations

To the U.S. Department of Transportation:

Require all intrastate and interstate hazardous materials carriers to submit annually the number and types of U.S. Department of Transportation specification cargo tanks that are owned or leased in addition to data displayed on the specification plates of such tanks and, if necessary, modify the appropriate database to accept additional data fields. (H-11-1)

To the Federal Motor Carrier Safety Administration:

Work with the Pipeline and Hazardous Materials Safety Administration, as appropriate, to develop and disseminate guidance that will assist hazardous materials carriers in implementing comprehensive cargo tank motor vehicle rollover prevention programs, including the active participation of drivers, dispatchers, and management through training, loading practices, delivery schedules, and acquisition of equipment. (H-11-2)

Require all in-use cargo tank trailers with a gross vehicle weight rating greater than 10,000 pounds to be retrofitted with a rollover stability control system. (H-11-3)

To the Pipeline and Hazardous Materials Safety Administration:

Work with the Federal Motor Carrier Safety Administration, as appropriate, to develop and disseminate guidance to assist hazardous materials carriers in implementing comprehensive cargo tank motor vehicle rollover prevention programs, including the active participation of drivers, dispatchers, and management through training, loading practices, delivery schedules, and acquisition of equipment. (H-11-4)

Conduct a comprehensive analysis of all available accident data on U.S. Department of Transportation specification cargo tanks to identify cargo tank designs and the associated dynamic forces that pose a higher risk of failure and release of hazardous materials in accidents. Once such cargo tanks have been identified, study the dynamic forces acting on susceptible structures under varying accident conditions and develop performance standards to eliminate or mitigate these risks. (H-11-5)

Once the performance standards in Safety Recommendation H-11-5 have been developed, require that all newly manufactured cargo tanks comply with the performance standards. (H-11-6)

To the National Highway Traffic Safety Administration:

Develop stability control system performance standards for all commercial motor vehicles and buses with a gross vehicle weight rating greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system. (H-11-7) *This safety recommendation supersedes H-10-5.*

Once the performance standards from Safety Recommendation H-11-7 have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-8). *This safety recommendation supersedes H-10-6.*

Establish comprehensive minimum rollover performance standards, based on the least stable condition operated, for all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-9)

Once the performance standards in Safety Recommendation H-11-9 have been developed, require that all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds comply with the performance standards. (H-11-10)

Evaluate the effect of emergency maneuvers on the sloshing and surging of bulk liquids that have various densities over a range of partially filled levels in a U.S. Department of Transportation specification cargo tank. (H-11-11)

If the results of Safety Recommendation H-11-11 warrant action, establish and implement performance standards for mitigating the sloshing and surging of bulk liquids in all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-12)

To the Federal Highway Administration:

Work with the American Association of State Highway and Transportation Officials to evaluate vehicle design characteristics specific to the rollover thresholds of heavy trucks, including those having cargo tanks. Use the information obtained to develop best practices in highway design that will mitigate the increased rollover risk caused by reduced effective superelevation through changes in cross slope that high center of gravity commercial vehicles experience when they migrate onto the shoulder while negotiating curve sections of high-speed highways. (H-11-13)

If the results of the evaluation in Safety Recommendation H-11-13 warrant such action, work with the American Association of State Highway and Transportation Officials to develop and implement best practices to assist state transportation agencies in identifying existing locations where cross-slope breaks pose a rollover hazard, placing an emphasis on those roadways having high volumes of heavy truck traffic, and develop appropriate strategies for mitigating the hazard. (H-11-14)

Until the best practices in Safety Recommendations H-11-13 and -14 have been developed and disseminated, provide information to state transportation agencies about the safety risks associated with cross-slope breaks and their potential for increasing the rollover propensity of commercial vehicles that have a high center of gravity. (H-11-15)

Work with the American Association of State Highway and Transportation Officials to develop guidance for a bridge pier protection program that will allow state transportation agencies to conduct risk-based assessments of bridges located within highway interchanges. At a minimum, the program should consider each structure's redundancy, continuity, and the distance of bridge pier columns from the edge of traveled ways. Additionally, consider traffic volumes, traffic type, and the percentage of commercial vehicles transporting bulk liquid hazardous materials in identifying and prioritizing initiatives for preventing vulnerable bridges at high-risk interchanges from collapsing if struck or otherwise damaged by a heavy vehicle. (H-11-16)

Once the guidance for a bridge pier protection program as described in Safety Recommendation H-11-16 has been developed, require that it be applied to bridges that are vulnerable to collapse if struck by a heavy vehicle. (H-11-17)

To American Association of State Highway and Transportation Officials:

Work with the Federal Highway Administration to evaluate vehicle design characteristics specific to the rollover thresholds of heavy trucks, including those having cargo tanks. Use the information obtained to develop best practices in highway design that will mitigate the increased rollover risk caused by reduced effective superelevation through changes in cross slope that high center of gravity commercial vehicles experience when they migrate onto the shoulder while negotiating curve sections of high-speed highways. Also, incorporate the findings in the American Association of State Highway and Transportation Officials publication *A Policy on Geometric Design of Highways and Streets.* (H-11-18)

If the results of the evaluation in Safety Recommendation H-11-18 warrant such action, work with the Federal Highway Administration to develop and implement best practices to assist state transportation agencies in identifying existing locations where cross-slope breaks pose a rollover hazard, placing an emphasis on those roadways having high volumes of heavy truck traffic, and develop appropriate strategies for mitigating the hazard. (H-11-19)

Work with the Federal Highway Administration to develop guidance for a bridge pier protection program that will allow state transportation agencies to conduct

> risk-based assessments of bridges located within highway interchanges. At a minimum, the program should consider each structure's redundancy, continuity, and distance of bridge pier columns from the edge of traveled ways. Additionally, consider traffic volumes, traffic type, and the percentage of commercial vehicles transporting bulk liquid hazardous materials in identifying and prioritizing initiatives for preventing vulnerable bridges at high-risk interchanges from collapsing if struck or otherwise damaged by a heavy vehicle. (H-11-20)

4.2 Previously Issued Recommendations Reclassified in This Report

The National Transportation Safety Board classifies the following previously issued recommendations:

- Safety Recommendation H-95-39 to the American Association of State Highway and Transportation Officials is classified "Closed—Reconsidered" in the "Cross-Slope Break" section of this report's Analysis.
- Safety Recommendations H-10-5 and -6 to the National Highway Traffic Safety Administration are classified "Closed—Superseded" in the "Stability Control Systems" section of this report's Analysis.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Adopted: July 26, 2011

5. Appendixes

Appendix A

Investigation and Public Hearing

Investigation

The National Transportation Safety Board was notified of the Indianapolis, Indiana, accident on October 22, 2009. An investigative team responded from the Washington, D.C.; Gardena, California; and Arlington, Texas, offices. Groups were established to investigate human performance; motor carrier operations; hazardous materials; structural integrity of cargo tanks; and highway, vehicle, and survival factors. No Board Member traveled to the accident scene.

Parties to the investigation were the Federal Highway Administration (FHWA), Indiana Department of Transportation (INDOT), Lawrence Township Fire Department, Indiana State Police, Mississippi Tank Company, and AmeriGas Propane, L.P.

Public Hearing

The NTSB held a public hearing on this accident August 3–4, 2010, in Washington, D.C. NTSB Chairman Deborah A.P. Hersman presided over the hearing, and NTSB staff participated as members of a Board of Inquiry. Six technical panels composed of subject matter experts participated. Three panels explored the capability and limitations of electronic stability control systems, role of driver training and testing, and feasibility of vehicle design improvements for reducing cargo tank motor vehicle rollovers. Three other panels examined the prevalence and cause-effect relationship between excessive cross-slope break and roll stability of heavy commercial vehicles with a high center of gravity, guidelines for protecting the bridge pier columns of vulnerable bridges at high-speed interchanges, and measures to improve the crashworthiness of cargo tanks for mitigating the unintentional release of hazardous materials.

NTSB investigators were members of a technical panel that asked questions of the subject matter experts. Additional questions were asked by the parties to the public hearing and the Board of Inquiry. Parties to the hearing included the U.S. Department of Transportation (DOT), the Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), the National Highway Traffic Safety Administration (NHTSA), and the Pipeline and Hazardous Materials Safety Administration (PHMSA); INDOT; and National Tank Truck Carriers (NTTC), AmeriGas Propane, L.P., Mississippi Tank Company, and Truck Trailer Manufacturers Association.

Witnesses who participated at the hearing included representatives of the following organizations: the DOT, FHWA, FMCSA, NHTSA, and PHMSA; Connecticut Department of Motor Vehicles, INDOT, and the Ohio and Texas Departments of Transportation; and Battelle, Meritor WABCO Vehicle Control Systems, Bendix Commercial Vehicle Systems LLC, Haldex Commercial Vehicle Systems, Inc., Trimac Transportation System, All State Career School, Commercial Vehicle Training Association, Praxair, Inc., Groendyke Transport, Inc., Vanasse Hangen Brustlin, Inc., Walker Group Holdings, LBT, Inc., Mississippi Tank Company, and RLT, Inc.

Appendix B

Improvements to Connection Ramp

Before Accident

Measurements of the connection ramp obtained after the accident revealed that the cross-slope break between the right southbound lane and right shoulder varied from 8.08–10.75 percent. The concrete bridge pier column impacted by the semitrailer was offset from the W-beam guardrail by approximately 6 feet (see figure B-1).

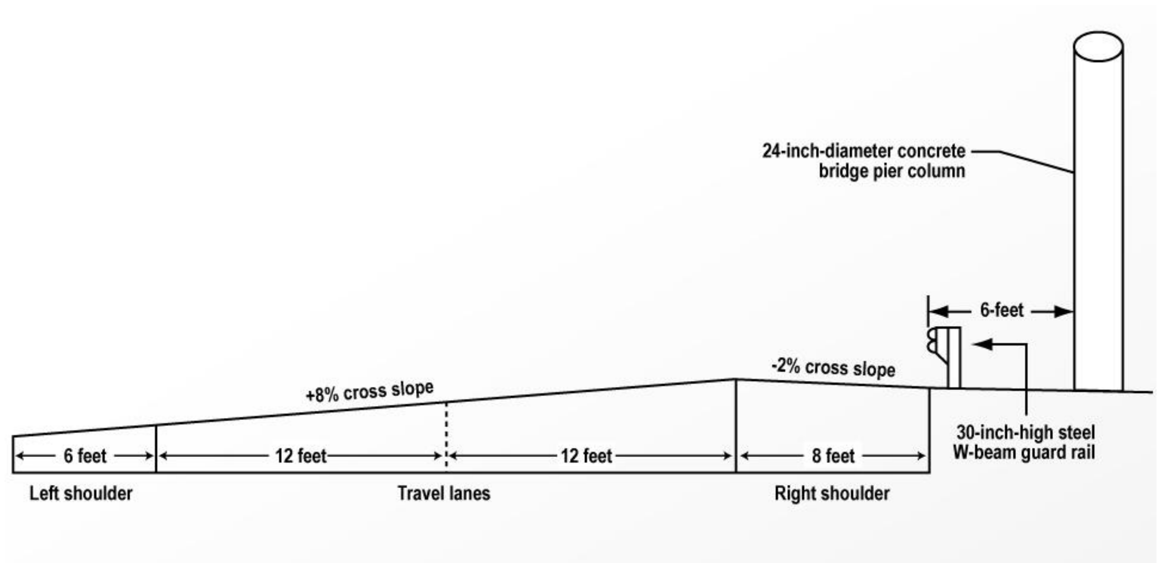

Figure B-1. Cross-slope break and bridge pier column protection (before improvements).

After Accident

Following the accident, the Indiana Department of Transportation installed a 32-inch-high temporary barrier before improvements were made to the Interstate 465 (I-465) connection ramp to modify the cross-slope break and enhance the protection of the bridge pier columns supporting the I-465 overpasses. As shown in figure B-2, the right shoulder was reconstructed after the accident to change the superelevation from a −2 percent cross slope that sloped downward from left to right (in the direction of travel) to a +4 percent cross slope that sloped upward from left to right (in the direction of travel). This alteration allowed the right shoulder to slope upward in the same direction as the travel lanes and changed the cross-slope break from 10 percent (at the time of the accident) to 4 percent. A slotted drain pipe was constructed on the right shoulder to drain stormwater runoff from the travel lanes. In addition, a permanent 45-inch-high concrete barrier and moment slab was constructed approximately 4 feet[1]

[1] The actual distance varied from 3.7–4.8 feet depending on the location of the bridge pier columns.

from the bridge pier columns that support the southbound I-465 overpasses, extending approximately 290 feet along the right shoulder. The barrier construction began on August 5, 2010, and was completed October 21, 2010, at a cost of $277,343.

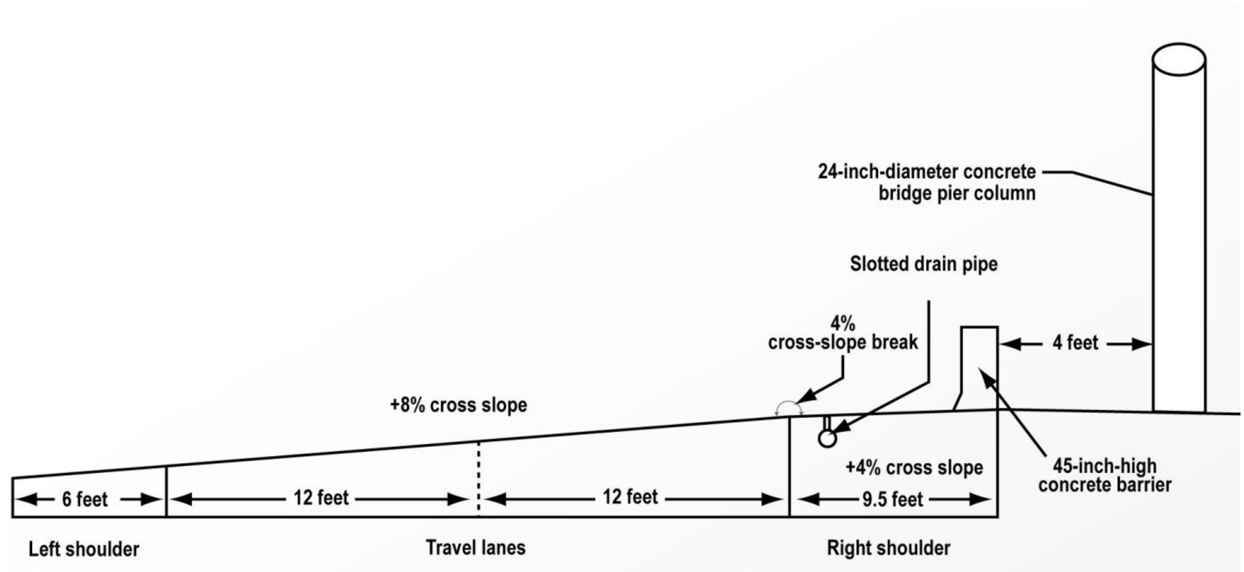

Figure B-2. Cross-slope break and bridge pier column protection (after improvements).

Planned Improvements

The twin bridges that carry the westbound and southbound lanes of I-465 over the connection ramp will be replaced as part of a new I-69 and I-465 interchange project planned to begin within 5 years. The new ramp will carry three lanes instead of two lanes, with a ramp-to-ramp merge area located immediately north of the overpass. If bridge pier columns are part of the new design and located within the 30-foot clear zone, bridge pier protection will conform to current American Association of State Highway and Transportation Officials guidance in the *AASHTO LRFD [Load and Resistance Factor Design] Bridge Design Specifications*.

Appendix C

Outdoor Advertising Signs

Federal law requires that all real property, including air space, within right-of-way boundaries be devoted exclusively to public highway purposes (23 *Code of Federal Regulations* [CFR] 1.23). State highway departments are responsible for ensuring that the right-of-way is free of all public and private installations, facilities, or encroachments. Although exceptions exist, any agreement for outdoor advertising signs entered into by a state must conform to Federal advertising policy and standards (Federal-Aid Highway Act of 1958, section 12). Further, the *Manual on Uniform Traffic Control Devices* (MUTCD) forbids the use of signs on the right-of-way as an advertising medium; guide and information signs are intended solely for traffic control and navigation (section 1A-1, 1988 edition). One notable exception is signage covered by the Highway Beautification Act, which allows advertising on the right-of-way using logo signs and, to a limited degree, in rest areas.

Two high-rise outdoor advertising signs are located near the accident location, with one sign approximately 60 feet north of Interstate 465 (I-465) and the other approximately 60 feet south of I-465. The signs were damaged by the postaccident fire but later restored. Current plans for future reconstruction of the I-69/I-465 interchange, expected to occur within the next 5 years, will require the removal or relocation of the sign on the south side of I-465 but not the sign on the north side.

The sign north of I-465 was directly in the line of sight of vehicles entering the curved portion of the ramp. The accident truck driver indicated during a postaccident interview with NTSB investigators that there were no external distractions and he did not notice the outdoor advertising sign.

The two signs are located on a railroad right-of-way owned by the Hoosier Heritage Port Authority, a nonprofit organization established to preserve Indiana railroad history. The Indiana Department of Transportation (INDOT) approved permits for the signs on October 5, 2005. INDOT indicated that because the outdoor advertising signs are not on INDOT right-of-way, but on a right-of-way owned by the railroad that traverses through the interchange, the agency did not believe it had a legal basis to deny the permits.[1]

The Federal Highway Administration (FHWA) is investigating the circumstances surrounding the permit approvals. The FHWA's Indiana Division Office is working with INDOT to trace the information provided on the permit application.[2] The FHWA is also attempting to determine (a) why the outdoor advertising signs were installed in 1999 before the permits were approved, and (b) why the current multifamily residential zoning surrounding this area does not allow outdoor advertising signs. INDOT is also attempting to determine whether the information

[1] INDOT e-mail to the NTSB (August 19, 2010).

[2] FHWA Office of Real Estate Services e-mail to the NTSB (October 18, 2010).

contained on the permit application is correct, to include determining whether the zoning within the vicinity of the signs in 1999 was commercial, as stipulated on the permit application. False statements on a permit are grounds for permit revocation and removal of the billboard.