# Motorcoach Median Crossover and Collision With Sport Utility Vehicle Hewitt, Texas February 14, 2003

## Highway Accident Report

NTSB/HAR-05/02

PB2005-916202
Notation 7727A

National Transportation Safety Board
Washington, D.C.

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Adopted July 12, 2005

National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

**National Transportation Safety Board. 2005.** ***Motorcoach Median Crossover and Collision With Sport Utility Vehicle, Hewitt, Texas, February 14, 2003.*** **Highway Accident Report NTSB/HAR-05/02. Washington, DC.**

**Abstract:** On February 14, 2003, about 9:59 a.m., central standard time, a 1996 Dina Viaggio motorcoach, operated by Central Texas Trails, Inc., and occupied by a driver and 34 passengers, was traveling northbound on Interstate 35 near Hewitt, Texas. The weather was overcast with reduced visibility due to fog, haze, and heavy rain. As the motorcoach approached the crest of a hill, the bus driver said he observed brake lights ahead of him and began to brake lightly. The bus driver said that as he moved from the right lane into the left lane, another vehicle ahead of the bus also moved over, so he braked harder and the rear of the bus skidded. The bus driver was unable to maintain control of the bus as it departed the left side of the roadway, crossed the grassy median, entered the southbound lanes, and collided with a 2002 Chevrolet Suburban sport utility vehicle (Suburban) occupied by a driver and two passengers. The motorcoach then overturned on its right side, rotated, and slid to final rest facing south against a concrete embankment on the side of the road. The Suburban rotated 180 degrees, began to climb the embankment, slid back down, and came to rest facing north and against the roof of the bus. Five motorcoach passengers, the Suburban driver, and one Suburban passenger sustained fatal injuries. The bus driver sustained serious injuries; the remaining passengers on the bus and in the Suburban sustained injuries ranging from minor to serious.

Major safety issues identified in this accident include: sight distance and speed as they relate to roadway design; roadway and tire friction interaction, particularly between commercial vehicle tires and wet pavement; the effect on vehicle stability of differing front and rear tire tread depths; and the need to better identify areas with a high risk of wet weather accidents and implement the necessary roadway improvements. As a result of this investigation, the National Transportation Safety Board makes recommendations to the Federal Highway Administration, the National Highway Traffic Safety Administration, the Federal Motor Carrier Safety Administration, and the Texas Department of Transportation.



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# Acronyms and Abbreviations

| | |
|---|---|
| **AASHTO** | American Association of State Highway and Transportation Officials |
| **ABS** | antilock braking system |
| **ASTM** | American Society for Testing and Materials |
| **CFR** | *Code of Federal Regulations* |
| **CVSA** | Commercial Vehicle Safety Alliance |
| **ECU** | electronic control unit |
| **FHWA** | Federal Highway Administration |
| **FMCSA** | Federal Motor Carrier Safety Administration |
| **FMCSRs** | *Federal Motor Carrier Safety Regulations* |
| **I-35** | Interstate 35 |
| **MCMIS** | Motor Carrier Management Information System |
| **MTMC** | Military Traffic Management Command |
| **NCHRP** | National Cooperative Highway Research Program |
| **NHTSA** | National Highway Traffic Safety Administration |
| **PMIS** | Pavement Management Information System |
| **psi** | pounds per square inch |
| **SafeStat** | Motor Carrier Safety Status Measurement System |
| **SAFETEA** | Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2003 |
| **SDM** | sensing diagnostic module |
| **Suburban** | 2002 Chevrolet Suburban sport utility vehicle |
| **Texas DPS** | Texas Department of Public Safety |
| **TxDOT** | Texas Department of Transportation |
| **WWARP** | Wet Weather Accident Reduction Program |

# Executive Summary

On February 14, 2003, about 9:59 a.m., central standard time, a 1996 Dina Viaggio motorcoach, operated by Central Texas Trails, Inc., and occupied by a driver and 34 passengers, was traveling northbound on Interstate 35 near Hewitt, Texas. The weather was overcast with reduced visibility due to fog, haze, and heavy rain. As the motorcoach approached the crest of a hill, the bus driver said he observed brake lights ahead of him and began to brake lightly. The bus driver said that as he moved from the right lane into the left lane, another vehicle ahead of the bus also moved over, so he braked harder and the rear of the bus skidded. The bus driver was unable to maintain control of the bus as it departed the left side of the roadway, crossed the grassy median, entered the southbound lanes, and collided with a 2002 Chevrolet Suburban sport utility vehicle (Suburban) occupied by a driver and two passengers. The right mirror of a southbound 1996 Chevrolet C1500 Z71 pickup truck, occupied by a driver, was also struck by the motorcoach. The motorcoach then overturned on its right side, rotated, and slid to final rest facing south against a concrete embankment on the side of the road. The Suburban rotated 180 degrees, began to climb the embankment, slid back down, and came to rest facing north and against the roof of the bus.

Five motorcoach passengers, the Suburban driver, and one Suburban passenger sustained fatal injuries. The bus driver sustained serious injuries; the remaining passengers on the bus and in the Suburban sustained injuries ranging from minor to serious. The pickup truck driver was not injured.

The National Transportation Safety Board determines that the probable cause of this accident was Texas's decision to set a speed limit on Interstate 35, in the vicinity of the accident, that did not take into account the roadway's limited sight distance or its poor conditions in wet weather; as a result, the bus driver was unable to detect the stopped vehicles as he approached the traffic queue and lost control of the motorcoach due to low pavement friction. Exacerbating the poor roadway conditions were the minimum tread depths on the motorcoach's drive axle tires and differing tread depths on its front and rear tires, both of which were allowed under the *Federal Motor Carrier Safety Regulations* but reduced the friction available to the motorcoach. Contributing to the severity of the accident were the lack of a temporary or permanent median barrier, which might have redirected the motorcoach or reduced the speed at which it crossed the median into the southbound lanes, and the lack of an occupant protection system for the motorcoach passengers.

Major safety issues identified in this accident include:

- Sight distance and speed as they relate to roadway design;
- Roadway and tire friction interaction, particularly between commercial vehicle tires and wet pavement;

- Effect on vehicle stability of differing front and rear tire tread depths; and
- Need to better identify areas with a high risk of wet weather accidents and implement the necessary roadway improvements.

As a result of this accident, the National Transportation Safety Board makes recommendations to the Federal Highway Administration, the National Highway Traffic Safety Administration, the Federal Motor Carrier Safety Administration, and the Texas Department of Transportation.

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# Factual Information

## Accident Narrative

On February 14, 2003, about 9:59 a.m., central standard time, a 1996 Dina Viaggio motorcoach, operated by Central Texas Trails, Inc., and occupied by a driver and 34 passengers, was traveling northbound on Interstate 35 (I-35) near Hewitt, Texas. The weather was overcast with reduced visibility due to fog, haze, and heavy rain. As the motorcoach approached the crest of a hill, the bus driver said he observed brake lights ahead of him and began to brake lightly. The bus driver said that as he moved from the right lane into the left lane, another vehicle ahead of the bus also moved over, so he braked harder and the rear of the bus skidded. The bus driver was unable to maintain control of the bus as it departed the left side of the roadway, crossed the grassy median, entered the southbound lanes, and collided with a 2002 Chevrolet Suburban sport utility vehicle (Suburban) occupied by a driver and two passengers. The right mirror of a southbound 1996 Chevrolet C1500 Z71 pickup truck, occupied by a driver, was also struck by the motorcoach. The motorcoach then overturned on its right side, rotated, and slid to final rest facing south against a concrete embankment on the side of the road. (See figures 1 and 2.) The Suburban rotated 180 degrees, began to climb the embankment, slid back down, and came to rest facing north and against the roof of the bus.

Five motorcoach passengers, the Suburban driver, and one Suburban passenger sustained fatal injuries. The bus driver sustained serious injuries; the remaining passengers on the bus and in the Suburban sustained injuries ranging from minor to serious. The pickup truck driver was not injured.

The bus driver told investigators that he reported for duty at 7:15 a.m. on the day of the accident and conducted a pretrip inspection of the accident bus, which he found to be in good mechanical condition. He departed Central Texas Trails in Waco, Texas, about 7:55 a.m., arriving at the Memorial Baptist Church in Temple, Texas, about 8:50 a.m. (See figure 3.) The driver loaded passengers onto the bus and departed for Dallas, Texas, about 9:31 a.m., where the church group was scheduled to attend a 1:00 p.m. concert. The driver stated that he was driving about 65 mph (the posted speed limit was 70 mph during the day) on I-35 when the intensity of the rain increased and he reduced his speed to about 60 mph. The driver and several passengers stated that visibility was about 1/2 mile due to the rain and fog. The driver said that traffic was light and proceeding normally and that he drove primarily in the right lane.

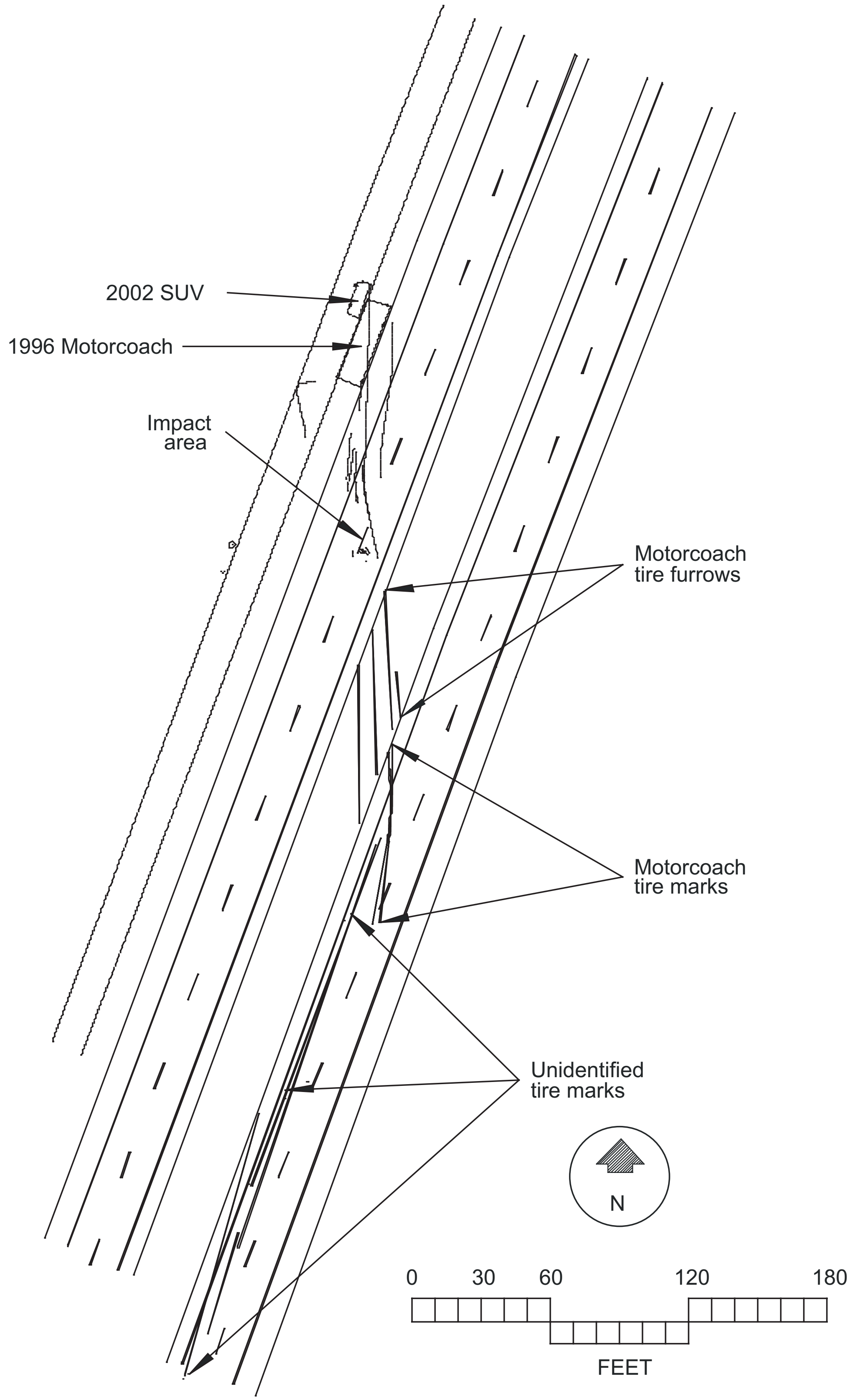



**Figure 1.** Accident scene. (Source: Texas Department of Public Safety)

**Figure 2.** Motorcoach postaccident position.

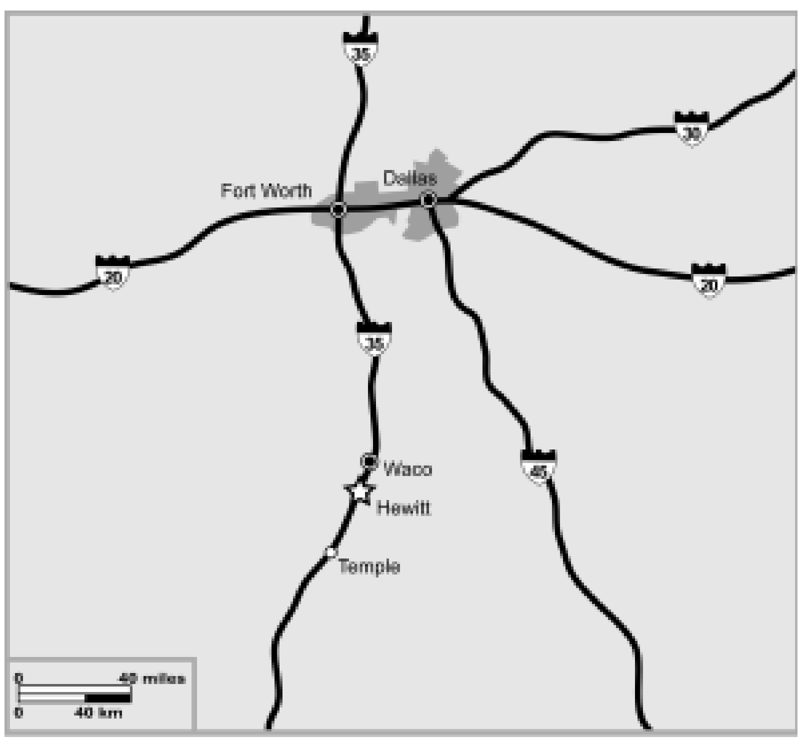



**Figure 3.** Accident location.

About 9:30 a.m., an accident had occurred on northbound I-35 at mile marker 328, causing traffic to back up on I-35. The backup extended to mile marker 326.3, where the 9:59 a.m. accident subsequently occurred.

The bus driver stated that he observed brake lights appearing in the traffic ahead. He believed at first that the brake lights indicated traffic was slowing, but as he got closer, he saw that the traffic had slowed almost to a complete stop or had stopped. He stated that he was in the right lane, where the queue was longer, so he decided to move into the left lane to avoid having to stop more quickly. He stated that he initially braked normally, slowed, and steered to the left, when another vehicle ahead also moved to the left, requiring the bus driver to brake harder. The rear of the bus then began to skid to the right. He said he reduced brake pressure and steered to the right to attempt to straighten the bus and regain control, but the bus continued to travel to the left into the median. (See figure 1.)

A witness traveling through the area just before the accident described the rain as being heavy, with visibility reduced to about 500 feet. This witness also stated that he saw brake lights as he crested the hill and that the queue of traffic was longer in the right lane, so he moved to the left lane to take advantage of the increased distance to stop. The witness also stated that he observed two trucks approach his vehicle from the rear. One was able to move to the right lane and come to a stop; the other ran off the road into the median, becoming mired in the mud.

Another witness described the rain as being “really hard.” He stated he could not see the stopped traffic until he reached the top of the hill on I-35. A witness in a business adjacent to I-35 showed investigators the location of the end of the traffic queue, which was about 350 feet north of the beginning of the motorcoach’s skid marks.

## Injuries

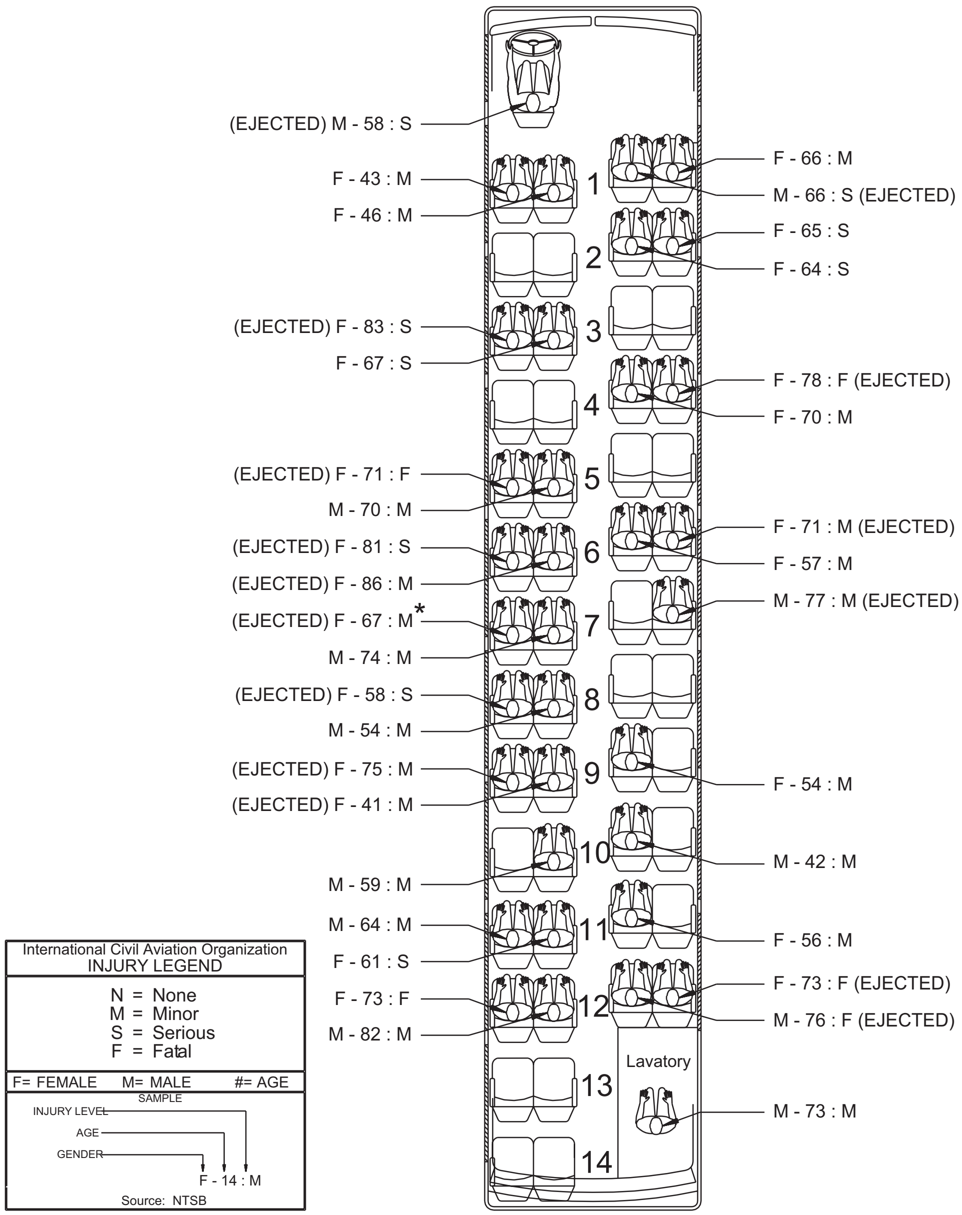
**Table 1.** Injuries.*

| | Motorcoach passengers | Motorcoach driver | Suburban passengers | Suburban driver | Pickup truck driver | Total |
|---|---|---|---|---|---|---|
| **Fatal** | 5 | 0 | 1 | 1 | 0 | 7 |
| **Serious** | 8 | 1 | 1 | 0 | 0 | 10 |
| **Minor** | 21 | 0 | 0 | 0 | 0 | 21 |
| **None** | 0 | 0 | 0 | 0 | 1 | 1 |
| **Total** | 34 | 1 | 2 | 1 | 1 | 39 |

*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 from the date the injury was received; results in a fracture of any bone (except simple fractures of the fingers, toes, or nose); causes severe hemorrhages, nerve, muscle, or tendon damage; involves any internal organ; or involves second or third degree burns, or any burns affecting more than 5 percent of the body surface.

## Survival Aspects and Emergency Response

The driver of the motorcoach was ejected during the rollover and sustained serious injuries. He was not wearing the available lap/shoulder belt. Fourteen passengers in the motorcoach were either fully or partially ejected; one was ejected out of the front window, and the rest were ejected or fell through the broken windows on the right side of the motorcoach as it rolled over. Four of the ejected passengers sustained fatal injuries, and four sustained serious injuries. (See figure 4.) None of the passenger seats had restraints.




*Passenger was readmitted to the hospital for treatment of injuries from a previous unrelated motor vehicle accident.

**Figure 4.** Seating diagram.

The right side of the motorcoach came to rest over a drainage ditch that was filled with 12 to 14 inches of rainwater (see figure 5), in which several of the ejected passengers were submerged. Witnesses said these passengers were assisted in keeping their heads above water until they could be extricated; in one instance, a rescuer gave a passenger a piece of tubing to use as a snorkel to breathe. Because autopsies were not performed,[1] it could not be determined whether the fatally injured passengers who were ejected died from their injuries or from drowning; the coroner found that all sustained blunt force trauma.

**Figure 5.** Drainage ditch filled with water beneath motorcoach.

Damage to the motorcoach's interior was minimal. The headrest on the seventh row, right aisle seat, was bent forward. The interior padding on many of the headrests on the aisle had worn away, such that the headrests consisted of only a metal pipe frame covered by fabric. (See figure 6.) The headrests on the window seats had 2.5 inches of foam rubber padding covering the metal pipe under the fabric. The manufacturer's service manual did not provide information regarding headrest padding.

[1] According to the coroner, autopsies were not performed out of respect for the religious beliefs of the families of the deceased.


**Figure 6.** Interior of headrest without padding.

Several passengers stated that they exited the bus through the roof hatch or slid out the windows and exited from under the motorcoach. Emergency personnel helped passengers exit the bus through the windshield, which shattered during the accident sequence.

The Suburban's dashboard was pushed rearward to within several inches of the front seats. (See figure 7.) The space between the passenger seating area in the rear and the front seat remained intact. (See figure 8.) The front airbags deployed during the accident. Emergency responders cut the lap/shoulder belts from the driver and two passengers during their extrication.

The Robinson Fire Department received the first 911 call at 9:59 a.m., followed by several calls to the Hewitt Fire Department and a motorist's notification to the Texas Department of Public Safety (Texas DPS) troopers investigating the other accident 2 miles north. The Robinson Fire Department arrived at 10:11 a.m., followed by the Hewitt Fire Department at 10:12 a.m., followed by Texas DPS troopers, Lorena Volunteer Fire Department and Woodway Volunteer Fire Department firefighters, Hewitt Police Department and Waco Police Department police officers, and McLennan County Sheriff's Department deputies. Police and fire department responders stated that their initial focus was on evacuating the bus, identifying and removing the injured from the interior, and partially raising the motorcoach with wooden blocks to stabilize it. Ambulances began to arrive about 10:17 a.m. Twelve ambulances transported 31 injured; 2 additional injured were airlifted by helicopter. The last transport occurred at 10:43 a.m.

**Figure 7.** Suburban front seating area damage.

**Figure 8.** Suburban rear passenger seating area.

## Driver Information

The 58-year-old bus driver held a valid Texas Class A Commercial Driver License with an expiration date of April 2, 2005. The driver also held a valid medical certificate issued January 14, 2003, with an expiration date of January 14, 2004. The driver had 23 years of experience driving commercial vehicles with no convictions or prior accidents. He had been working part-time or full-time as a driver for Central Texas Trails since 1980.

The bus driver's medical examination certificate was valid for 1 year, rather than the standard 2 years, because of the driver's chronic hypertension, according to the "Medical Examination Report for Commercial Driver Fitness Determination," which was completed by a physician. The driver was being treated and prescribed medications for his hypertension and osteoarthritis.[2] The driver told investigators that he used alcoholic beverages occasionally, was a nonsmoker, and did not use illicit drugs or abuse prescription medication. The driver's blood and urine were tested by the Texas DPS and the Civil Aeromedical Institute and found to be negative for alcohol and illicit or performance-impairing drugs. The driver reported that he was in good general health at the time of the accident. The driver was 5 feet 11 inches tall and weighed between 390 and 400 pounds. He reported that he snored; when the symptoms of sleep apnea were described to him, he denied experiencing any, other than snoring. He had never been screened for sleeping disorders.

The bus driver's 72-hour history, obtained during an interview with the driver, shows that he received 7.75 to 11 hours of sleep each of the 3 nights before the accident. He was off duty the 3 days before the accident. (See table 2.)

**Table 2.** Driver 72-hour history.

| Date | Time | Activity | Sleep |
|---|---|---|---|
| **February 11, 2003** | 12:00 a.m. – 2:00 a.m. | Went to bed | |
| **February 12, 2003** | 10:30 a.m. – 11:00 a.m. | Awoke | 8.5 – 11 hours |
| | 11:00 p.m. | Went to bed | |
| **February 13, 2003** | 8:00 a.m. | Awoke | 9 hours |
| | 10:00 p.m. | Went to bed | |
| **February 14, 2003** | 5:45 a.m. | Awoke | 7.75 hours |
| | 7:15 a.m. | Reported for duty | |
| | 7:55 a.m. – 8:50 a.m. | Driving | |
| | 8:50 a.m. – 9:31 a.m. | Loading passengers | |
| | 9:31 a.m. – 9:59 a.m. | Driving | |
| | 9:59 a.m. | Accident | |

[2] The driver was prescribed 300 mg Tiazac® (generic name: Diltiazem) daily for hypertension (high blood pressure) and 500 mg Nabumetone (generic) daily for osteoarthritis, a degenerative joint disease.

## Vehicle and Wreckage Information

### *Motorcoach*

The 1996 Dina Viaggio 1000 motorcoach was equipped with a Detroit Diesel Corporation Series 60 engine and an Allison Transmission HT-755 5-speed automatic transmission. The motorcoach had an odometer reading of 126,419 miles, which reflects the number of miles traveled with that odometer, and a hubometer[3] reading of 216,928 miles, which reflects the mileage traveled by the vehicle.[4] The engine was equipped with a model 765 Jacobs engine brake; the switch was in the off position during the postaccident inspection, and the bus driver said that the engine brake was not on at the time of the accident. The engine was also equipped with an electronic control module to control engine timing and conduct diagnostics; its recording capability was not activated. The bus had hydraulic power steering; inspection of this system revealed no defects. The suspension was also examined for defects, and, except for a missing bump stop[5] on the left-front suspension, none were found.

An examination of the brake system revealed some mild heat checking[6] on the inside surface of the drive axle brake drums. All brake pads were in good condition and free of excessive wear and anomalies, except for the left drive axle brake drum, which had axle grease contamination between the brake shoe and drum. All drums were round, and their diameters were within manufacturer's specifications. All brakes were found to be within adjustment limits. Testing determined that the pneumatic brake system delivered air pressure to all brake chambers as designed.

The motorcoach was equipped with a Bendix MC-30 Antilock Braking System (ABS) module for the drive (second) and tag (third) axles,[7] which was nonfunctional at the time of the accident. The steer axle was not equipped with an ABS module, and the motorcoach was not manufactured with ABS sensors on the drive axle.[8] The ABS module, when functioning and fully connected, could monitor wheel speed on four wheels and had two modulator valves; it had replaced an earlier model that could monitor wheel speed and modulate braking on the tag axle only. During a braking event, weight is shifted off a lightly loaded tag axle, preventing excessive tire wear.

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3 The hubometer is generally used by maintenance personnel to provide reference mileage for service of the axles, tires, and wheels.

4 Maintenance records did not indicate why the mileage difference exists; one possible explanation is that the speedometer/odometer was replaced.

5 The bump stop acts as a cushion to prevent contact between the upper control arm and the spring assembly in the event that the shock absorber is fully compressed.

6 Heat checking results in small cracks and possible bluing of the brake surface and is indicative of friction, resulting in heat amassing during braking. Mild heat checking is a normal condition for heavy vehicle brakes.

7 The front axle is the steer axle, the second axle is the drive axle, and the third axle is the tag axle. The tag axle is an undriven third axle used to distribute the weight at the rear of a motorcoach.

8 ABS was not required for this motorcoach because it was manufactured before March 1, 1998, the effective date for all motorcoaches to be equipped with ABS (49 CFR 393.55).

Postaccident testing of the ABS electronic control unit (ECU), which controls the operation of the ABS by monitoring system status, revealed 25 fault codes.[9] Thirteen entries[10] were recorded relating to wiring system shorts in the vehicle's wiring system and were not internal to the ABS ECU. Whenever the ABS ECU records five identical faults, no matter what the cause, the ABS is designed to shut down. At the time of the accident, 5 of the 13 entries related to the wiring system shorts were identical, rendering the ABS nonfunctional.[11]

**Tires.** The manufacturer-recommended tire pressures were 115 pounds per square inch (psi) for the steer axle and 95 psi for the drive and tag axles. Table 3 shows the tire inflation pressures and tread depths measured during the postaccident investigation (see figure 9).

**Table 3.** Motorcoach tire inflation pressures and tread depths.

| Tire | Inflation pressure (psi) | | Minimum tread depth (inches) | |
|---|---|---|---|---|
| | Actual | Recommended | Actual | Required |
| Left steer axle | 73 | 115 | 14/32 | 4/32 |
| Right steer axle | 94 | 115 | 15/32 | 4/32 |
| Outside left drive axle | 92 | 95 | 3/32 | 2/32 |
| Inside left drive axle | 87 | 95 | 2/32 | 2/32 |
| Outside right drive axle | 94 | 95 | 6/32 | 2/32 |
| Inside right drive axle | 90 | 95 | 5/32 | 2/32 |
| Left tag axle | 92 | 95 | 8/32 | 2/32 |
| Right tag axle | 92 | 95 | 5/32 | 2/32 |

The drive axle tires had been replaced in August 2001, when the hubometer read 144,175, indicating that they had been in use for 72,753 miles at the time of the accident. The steer axle tires had been replaced in January 2003 and had been in use for about 9,412 miles. The tag axle tires, which were replaced in August 2002, had been in use for 34,771 miles.

Federal regulations require that the tread depth for the front tires of motorcoaches be at least 4/32 inch and the tread depth for remaining tires be at least 2/32 inch.[12] This regulation has existed since 1969, when the FMCSRs were established. Commercial Vehicle

[9] A fault code identifies an anomaly in the ABS or in a system with which the ABS interfaces.

[10] The other entries were: comments, low battery voltage, tests when the vehicle is powered up, and a fault that occurred when the vehicle was on its right side after the accident.

[11] The nonfunctioning ABS, which could not have been detected by the driver, could have been detected during system maintenance.

[12] Title 49 CFR 393.75.

Safety Alliance (CVSA)[13] out-of-service criteria (sections 10(a)(1) and 10(b)(7)) state that a steer axle tire is out of service when the tread is worn to less than 2/32 inch in two adjacent tread grooves and that all other tires are out of service when the tread is worn to less than 1/32 inch in two adjacent tread grooves. The CVSA sets out-of-service criteria based upon the existence of imminent hazards, that is, a significant chance of a crash occurring. CVSA out-of-service criteria may differ from FMCSR criteria for the same items.[14]

**Figure 9.** Left drive axle tire treads.

**Damage.** During the accident sequence, the motorcoach was involved in multiple collisions. The first collision occurred when the vehicle crossed over the center median of I-35 and collided with the Chevrolet Suburban. Secondary impacts along the right side of the motorcoach occurred as both vehicles rotated while separating from each other and as the motorcoach rolled onto its right side and came in contact with the pavement. The most significant damage was to the right front of the motorcoach. The lower portion of the

[13] The CVSA is a nonprofit organization dedicated to improving commercial vehicle safety that comprises Federal, State, and Provincial government agencies and representatives from private industry in the United States, Canada, and Mexico. The CVSA establishes and maintains commercial vehicle safety operational standards and practices, inspection procedures, out-of-service criteria, and enforcement practices and penalties that provide for uniformity, compatibility, and reciprocity among CVSA member jurisdictions and industry partners.

[14] Conversation with Stephen Keppler, Director of Policy and Programs, CVSA, March 1, 2005.

passenger loading door was displaced to the rear about 30 inches. (See figure 10.) The impact also damaged the body panels and the frame support structures between the loading door and the front wheel opening, pushing the front wheel opening rearward 6 inches. From the front of the bus, the maximum deformation to the windshield frame was 33 inches rearward at the right-front corner.

**Figure 10.** Motorcoach damage.

### *Chevrolet Suburban*

The 2002 Chevrolet Suburban was examined by Safety Board investigators for mechanical factors that may have contributed to the Suburban driver's inability to avoid the accident. The inflation pressures for tires not damaged in the collision were near the manufacturer's recommended pressures.[15] The steering, suspension, and brake systems were examined, and, while damaged, no anomalies were found. The vehicle was equipped with a four-wheel ABS.

The Suburban also had a sensing diagnostic module (SDM), with the primary function of sensing changes in vehicle speed and determining when to deploy the vehicle's airbags. The SDM stores data for airbag deployment and near-deployment events. In this accident, the driver and passenger frontal airbags were deployed. The data retrieved from the SDM revealed that the driver's seatbelt was buckled. The SDM further indicated that 5

[15] The recommended pressure was 35 psi; the right-front tire was inflated to 34.5 psi and the right-rear tire, to 31.5 psi. The other two tires were deflated due to accident damage.

seconds[16] before the airbags' deployment, the Suburban was traveling 54 mph; about 2 to 3 seconds before the crash, the driver released the throttle and applied the brake; and less than 1 second before the crash, the Suburban's speed decreased to 40 mph. The SDM indicated that the Suburban experienced a longitudinal velocity change of about 48.9 mph over a period of 110 milliseconds.

The tires recommended for the Suburban were P265/70R16, which have a radius (distance from the center of wheel rotation to the ground) of 15.3 inches. The tires found on the Suburban were P285/50R20, which have a radius of 15.6 inches.

Damage to the Chevrolet Suburban encompassed the entire vehicle. The two primary areas of contact damage were to the left side of the front end and to the rear section of the roof panel. (See figure 11.) The maximum penetration to the front end was 68 inches. The left side of both axles had shifted rearward, with the greatest displacement to the front axle, which moved about 8 inches; the rear axle moved about 2 inches rearward. Near the end of the accident sequence, the right side of the motorcoach made contact with the roof panel of the Suburban. The vehicles came to rest with the motorcoach's roof panel against the right side of the Suburban. As a result of the contact, the left-rear corner of the Suburban's roof panel was crushed downward about 19 inches and was displaced to the left about 15 to 18 inches. It is unknown whether recovery or extrication efforts altered the measured damage from the original postcrash configuration.

**Figure 11.** Suburban damage.

[16] The SDM records and saves data only once per second. Therefore, even though the SDM indicated the speed 5 seconds before the accident, the speed may have been recorded anywhere between 5 and 6 seconds before the crash.

## Highway Information

The accident occurred on I-35 at mile marker 326.3 in McLennan County, Texas, approximately 5 miles south of the Waco city limit line. I-35 is a divided, two-way, four-lane urban principal arterial paved asphalt roadway bordered on either side by a two-way frontage road. A sloped Portland cement concrete wall separates the southbound lanes from the frontage road. The paved portion of both the north- and southbound roadways consists of one 10-foot-wide right (outside) shoulder, two 12-foot-wide travel lanes, and one 6-foot-wide left (inside) shoulder. The north- and southbound lanes are divided by a 28-foot-wide depressed earthen median, which did not contain a temporary or permanent barrier at the time of the accident. (See figure 12.) A crest vertical curve[17] consisting of a 1.965 percent foreslope (uphill) and a –3.826 percent downslope (downhill) is located south of the accident site. The crest of the curve occurs about 158 feet before the motorcoach's first skid mark.

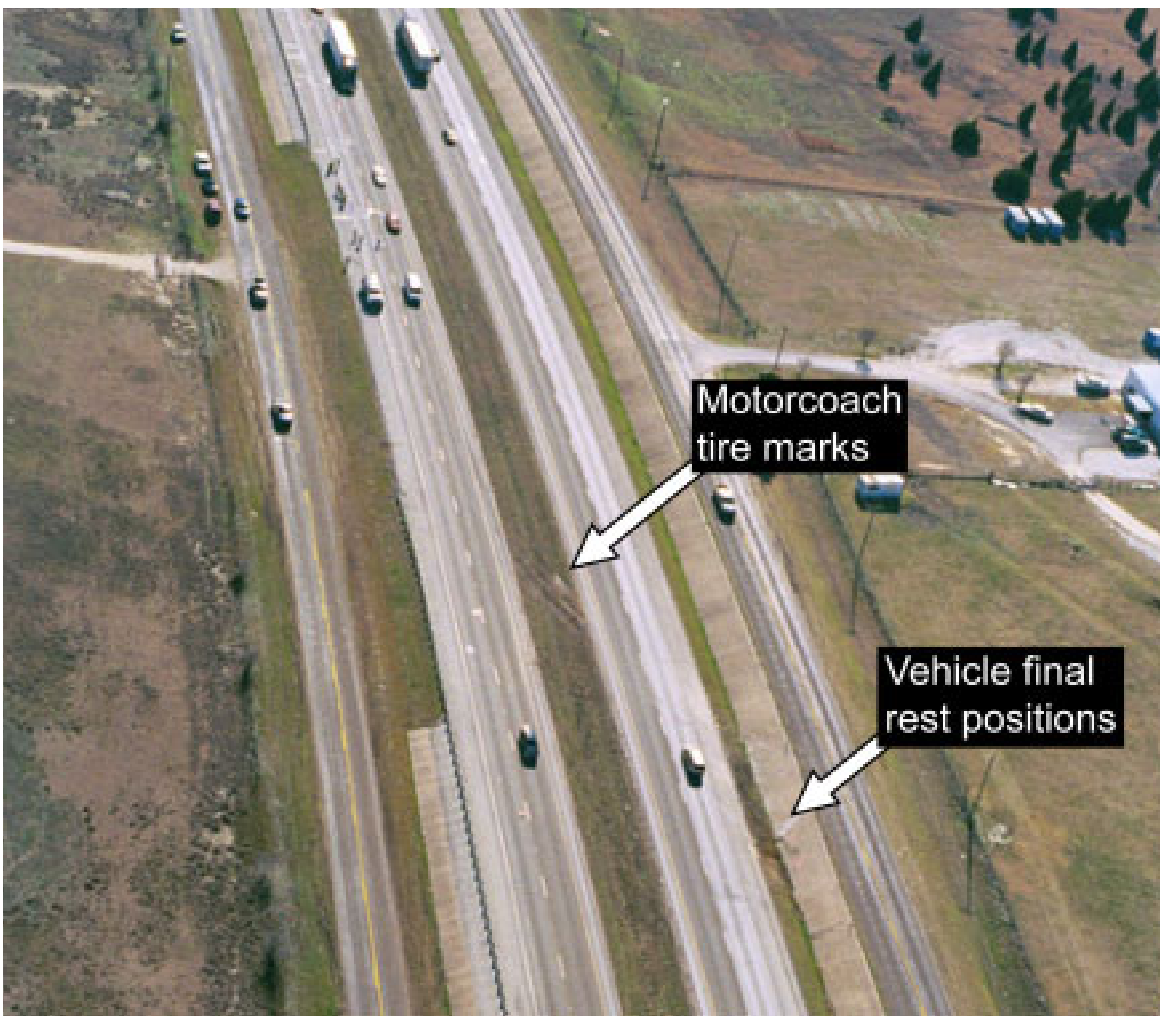


**Figure 12.** Accident location. (Source: Texas DPS)

[17] A crest vertical curve is a hill that provides a smooth transition from one roadway grade to another. The total length of the crest vertical curve was approximately 900 feet.

I-35 was first constructed in 1917[18] and expanded to a four-lane, divided highway in 1955. The horizontal alignment and vertical profile of the roadway have not changed since 1955, when the design speed was 60 mph. The most recent rehabilitation was completed in September 1992 and consisted of asphalt concrete repavement in the right lane of the southbound lanes and rut filling in the right lane of the northbound lanes. All north- and southbound lanes received microsurfacing.[19]

> **Pavement Surface Friction Characteristics**
>
> Pavement texture depth consists of ***microtexture***, the component for surface friction, and ***macrotexture***, the component for removing water to obtain better surface friction.
>
> The ***cross slope*** of a lane is the slope from the center of the lane (referred to as the crown) to the outer edge of the lane that allows water to run off the roadway.
>
> ***Ruts*** (or wheel paths) are depressions formed over time in pavement by traffic repeatedly traveling over the same path, compressing and wearing away the pavement. Water can collect in ruts, diminishing a roadway's surface friction.
>
> The ***coefficient of friction*** represents the frictional properties of the pavement. This number is used to evaluate the skid resistance of the pavement relative to other pavements and/or to evaluate the change in skid resistance of the pavement over time. The higher the coefficient of friction, the less likely a vehicle is to skid.
>
> The ***skid (or friction) number*** is equivalent to the coefficient of friction times 100.

Pavement texture depth ultimately determines most tire/road interactions, including wet friction, noise, splash and spray, rolling resistance, and tire wear. The pavement texture depth consists of *microtexture,* the component for surface friction, and *macrotexture,* the component for removing water to obtain better surface friction. For the area encompassing 0.5 mile north and south of the accident location, the average estimated macrotexture pavement depths ranged from 0.024 to 0.029 inch in the left lane and from 0.017 to 0.018 inch in the right lane. Research conducted in Great Britain concluded that the effect of texture depth on friction loss was greatest below depths of 0.028 inch.[20] The Texas Department of Transportation (TxDOT) conducted research in 1970 that suggests a 0.035-inch macrotexture pavement depth be used for design purposes.[21] Other research recommended minimum pavement texture depths of 0.040 inch[22] or 0.015 to 0.031 inch.[23]

The cross slope of the right lane ranged from approximately 1.70 percent to 1.85 percent at the accident site. The rut depth in the right lane was measured near the accident site and found to be between 0.40 to 0.42 inch in the left wheel path and 0.25 to 0.35 inch in the right wheel path.

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[18] Highway 2, as the road was originally called, was renamed U.S. 81 in 1932. In 1959, the road was designated I-35.

[19] Microsurfacing is a short-term improvement, generally lasting 5 to 6 years, in which a fine aggregate and cement mixture less than 0.25-inch thick is applied.

[20] P.G. Roe, A.R. Parry, and H.E. Viner, *High and Low Speed Skidding Resistance: The Influence of Texture Depth*, TRL Report 367 (United Kingdom: Transportation Research Laboratory, 1998) 1.

[21] Kenneth D. Hankins, Richard B. Morgan, Bashar Ashkar, and Paul R. Tutt, *The Degree of Influence of Certain Factors Pertaining to the Vehicle and the Pavement on Traffic Accidents Under Wet Conditions*, Research Study No. 1-8-69-133, Research Report 133-3F (Washington, DC: FHWA: September 1970) viii.

[22] Galloway and others, *Tentative Pavement and Geometric Design Criteria for Minimizing Hydroplaning*" FHWA-RD-75-11 (Washington, DC: FHWA, February 1975).

[23] Peter Elsenaar, J. Reichert, and Raymond Sauterey, *Pavement Characteristics and Skid Resistance*, U.S. Transportation Research Record No. 622 (Washington, DC: Transportation Research Board, 1976).

The speed limit on I-35 was 70 mph during the day and 65 mph at night. TxDOT conducted a speed study on February 17, 2003, and found that the 85th percentile speed was 74 mph during the day. The average daily traffic count for I-35, provided by TxDOT, was 63,000 vehicles for north- and southbound traffic in 2001. The most recent vehicle classification data were from 1999: 57.2 percent of the vehicles were passenger cars, 26.6 percent were single-unit trucks, 15.9 percent were tractor-semitrailers or double trailer combination vehicles, and 0.30 percent were buses.

Accident data for the area encompassing 5 miles north and south of the accident scene, including the frontage roads, were obtained from TxDOT. (See table 4.) About 16 percent of the accidents occurred on wet pavement while being exposed to precipitation about 2.35 percent of the days.[24] Ten fatal accidents occurred from 1996 through 2002: 3 median crossover accidents, 5 rear-end accidents, and 2 sideswipe accidents. The National Highway Traffic Safety Administration's (NHTSA's) General Estimate System and Fatality Analysis Reporting System indicate that approximately 11 percent of all accidents on the interstate highway system occur in wet weather. For the southern region of the United States, 12 percent of all accidents on the interstate highway system occur in wet weather.

**Table 4.** Accident data on I-35 in the vicinity of the accident.

| Accident year | Median crossover collision | | Rear-end collision | | Sideswipe collision | | Other | |
|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| **1996** | 2 | 0 | 12 | 1 | 6 | 0 | 37 | 10 |
| **1997** | 3 | 0 | 12 | 3 | 7 | 0 | 39 | 9 |
| **1998** | 5 | 1 | 18 | 1 | 6 | 1 | 51 | 8 |
| **1999** | 3 | 0 | 18 | 2 | 5 | 0 | 47 | 6 |
| **2000** | 4 | 2 | 10 | 0 | 6 | 1 | 53 | 18 |
| **2001** | 10 | 2 | 45 | 6 | 16 | 6 | 42 | 8 |
| **2002** | 7 | 0 | 36 | 5 | 15 | 5 | 17 | 12 |
| **Total** | 34 | 5 | 151 | 18 | 61 | 13 | 286 | 71 |

The FHWA requires that all States have a skid accident reduction program. To identify sites that are overrepresented in wet weather accidents, TxDOT established the Wet Weather Accident Reduction Program (WWARP) in 1999. In Texas, a site is considered to be overrepresented if it had five or more wet weather accidents in a 1/10-mile roadway segment in 1 year. Overrepresented segments are upgraded to improve the skid resistance of the roadway surface. The 2000 WWARP report did not indicate that I-35 in the vicinity of this accident had five or more accidents in the 1/10 mile surrounding the accident site. It did report 467 locations that had five or more accidents within 1/10 mile; 410 of these locations were in the districts with the highest populations (Austin, Dallas, Fort Worth, Houston, and San Antonio). These districts comprised 63 percent of the Texas population and covered 15 percent of Texas's land area.

[24] Office of the State Climatologist, Department of Atmospheric Sciences, Texas A&M University.

At the time of the accident, I-35 was part of an experimental project by TxDOT to evaluate the privatization of highway maintenance and operation. TxDOT's 5-year contract with Virginia Maintenance Services, Inc., which began on September 1, 1999, covered 876 lane miles from Johnson County, Texas, to Williamson County, Texas. As part of the contract, Virginia Maintenance Services was required to perform monthly condition assessments of the highway and conduct "all maintenance and repair required to
insure the highways are kept in their designed and constructed or updated condition."[25] The maintenance requirements further specified that no ruts be more than 0.5-inch deep.

TxDOT's Pavement Management Information System (PMIS) allows highway engineers to evaluate current pavement conditions, monitor trends over time, estimate pavement needs, analyze the impact of limited funding on current and future conditions, and fine-tune treatments.[26] PMIS scores roadways in five areas: distress, ride, condition, structural strength, and skid. For each category (except skid), the ratings range from A ("very good") to F ("very poor"). Skid ratings, which are numerical, are based on a standard deviation from the mean. Skid numbers between 36 and 99 are at the mean or above. Skid numbers between 13 and 20 are 1.0 to 1.5 standard deviations below the mean, and skid numbers between 1 and 12 are 1.5 standard deviations below the mean. Table 5 shows the PMIS ratings for I-35 in the accident area.

**Table 5.** PMIS ratings in the vicinity of the accident site.

| Fiscal year | Distress | Ride | Condition | Skid |
|---|---|---|---|---|
| **2000** | n/a | A | n/a | 12 |
| **2001** | A | A | A | n/a |
| **2002** | A | A | A | 13 |
| **2003** | A | B | A | n/a |
| Note: TxDOT did not provide PMIS structural strength data. The variation between skid numbers could be due to a variation in the position of the skid trailer during testing, seasonal and weather variation, measurement error, slight speed differences, or temperature. | | | | |

Before the accident, TxDOT planned to conduct improvements on I-35 from August 2003 to January 2004 using Federal funds. The improvements, which did occur, consisted of the installation of a 42-inch-high permanent concrete median barrier 4 feet from the edge of the northbound left lane.[27] TxDOT resurfaced the lanes in both directions in the vicinity

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[25] Special Specification, Item 7219, "Total Maintenance and Operation of Highway," Contract Nos. 6044-92-001 and 6045-71-001, Article 5—Scope of Work, 5-18.

[26] Texas Department of Transportation, Construction Division, Materials and Pavements Section, *Managing Texas Pavements, Basic Concepts and Data Interpretation for TxDOT's Pavement Management Information System (PMIS)* (Austin, Texas: TxDOT, 2002) 9.

[27] The American Association of State Highway and Transportation Officials (AASHTO) recommends that a barrier be considered for sites with a median width of less than 30 feet and an average daily traffic count greater than 30,000, as was the case at the accident location. AASHTO, *Roadside Design Guide 2002* (Washington, DC: AASHTO, 2002).

of the accident site between January and May 2005 and plans to expand I-35 to six lanes or more to accommodate growing traffic demands beginning in 2010. According to TxDOT, the complete reconstruction of I-35, including geometric changes to its vertical profile and the flattening some of the crest vertical curves, would be considered after 2010.

## Meteorological Information

Waco Regional Airport, approximately 10 miles north-northwest of the accident site, reported visibility of 10 miles in thunderstorms at 9:51 a.m. on the day of the accident. At 10:25 a.m., visibility was 2 miles in thunderstorms with heavy rain and mist. Rain had begun at 10:02 a.m., with 0.12 inch falling in 23 minutes. At 10:37 a.m., visibility was 4 miles in thunderstorms, heavy rain, and mist, with a total of 0.20 inch of precipitation in the last hour.

At 10:15 a.m., McGregor Executive Airport, approximately 7 miles west of the accident site, reported 2 miles visibility and 0.19 inch of precipitation in the previous 19 minutes. At 10:36 a.m., McGregor Executive Airport reported 3 miles visibility with thunderstorms beginning at 10:25 a.m. and 0.39 inch precipitation having fallen since 9:36 a.m.

The National Weather Service Weather Surveillance Radar—1988 Doppler, located at the Dallas-Fort Worth Forecast Office, approximately 67 miles north of the accident site, showed a large band of echoes[28] moving northeast at 45 knots across the area of the accident site about 9:59 a.m. At that time, the rainfall ranged from "very heavy" to "intense" with an estimated rainfall rate of 1.10 to 2.49 inches per hour for the 12 minutes that the heavy echoes were over the accident site. The total precipitation accumulation in the hour preceding 9:59 a.m. in the immediate vicinity of the accident site was 0.25 to 0.50 inch.

## Operational Information

### *Central Texas Trails*

The motorcoach was owned by Central Texas Trails of Waco, Texas, an interstate, for-hire passenger carrier. The majority of Central Texas Trails's business was charter service, although the company had four scheduled intrastate runs from Waco to Dallas, San Antonio, Tyler, and Lampasas. Central Texas Trails also regularly served as a subcontractor to another company in providing shuttle service for Fort Hood military base in Texas and for the news media during Presidential visits to Crawford, Texas.

[28] The echoes are interpreted as reflecting the type and rate of precipitation.

Central Texas Trails had 9 full-time drivers and 19 part-time drivers. The company participated in a drug and alcohol testing program as required by Federal regulations.[29] Records indicated that one Central Texas Trails employee failed a controlled substance test in 2002 and was terminated. Records further indicated that Central Texas Trails held driver meetings three times a year in 2001 and 2002 to discuss safety and operational issues. The accident driver attended all meetings.

The fleet consisted of 19 motorcoaches that were maintained by a full-time mechanic and three assistants. According to company records, Central Texas Trails conducted maintenance every 12,000 miles or when a driver reported a problem. The company also maintained a maintenance file for each motorcoach as required by the Federal Motor Carrier Safety Administration (FMCSA).[30] In 2002, Central Texas Trails reported traveling 75,000 miles in interstate operation and 1,062,000 miles in intrastate operation.

The FMCSA's Motor Carrier Management Information System (MCMIS)[31] reported that in the 24 months preceding this accident, Central Texas Trails had been involved in two tow-away accidents with no injuries or fatalities.[32] The MCMIS report also indicated 24 driver and vehicle roadside inspections with no out-of-service violations in the preceding 24 months.

Central Texas Trails had received a satisfactory rating in its most recent Federal compliance review on September 13, 1993. The FMCSA conducted a postaccident compliance review that also resulted in a satisfactory rating. In the postaccident review, the FMCSA inspector noted that Central Texas Trails had no recordable crashes because FMCSA policy[33] excludes intrastate accidents from the rating process. The FMCSA inspector wrote that if the three accidents in the 24 months preceding the review (the two tow-away accidents reported in MCMIS and this accident) had been included in the compliance review, Central Texas Trails would have received an unsatisfactory rating in the accident factor and a conditional rating overall.

Before January 26, 1996, Central Texas Trails was an approved passenger carrier for the Military Traffic Management Command (MTMC).[34] Two inspections conducted for MTMC on October 4, 1994, and November 21, 1995, revealed "less than adequate safety management controls to ensure continued compliance in support of safe operations" and specifically cited lack of a preemployment drug test, missing charter information, falsified records of duty status, and a high percentage of out-of-service vehicles. Central

[29] Title 49 CFR 382.

[30] Title 49 CFR 396.3.

[31] The MCMIS contains information on the safety fitness of commercial motor carriers subject to the FMCSRs.

[32] The MCMIS does not specify whether crashes are interstate or intrastate. Both crashes were identified by Central Texas Trails as occurring during intrastate operation.

[33] FMCSA memorandum "Exclusion of Intrastate Violations from the Safety Rating Process," April 19, 2002, and FHWA memorandum "Collection of Intrastate Noncompliance Information During Safety and Compliance Reviews," October 2, 1991.

[34] Now the Surface Deployment and Distribution Command.

Texas Trails was disqualified and removed from MTMC's list of approved carriers. However, this action did not prevent Central Texas Trails from operating or from being qualified under FMCSA regulations.[35]

### *Federal Motor Carrier Safety Administration*

The Motor Carrier Safety Act of 1984 directed the U.S. Secretary of Transportation to establish procedures to determine the safety fitness of commercial motor vehicle owners and operators engaging in interstate and foreign commerce. Subsequently, the Federal Highway Administration (FHWA)[36] established safety fitness standards and developed a method for determining whether a carrier has adequate management controls to ensure acceptable compliance with the safety requirements. As a result of the Motor Carrier Safety Act of 1990 and a 1997 rulemaking, the FHWA modified the original methodology.

Six factors (see table 6) provide the basis for determining a carrier's safety rating, that is, the degree to which the carrier is in compliance with the FMCSRs and therefore meets the Federal safety fitness standard. Each factor is rated satisfactory, conditional, or unsatisfactory, except the accident factor, which is rated either satisfactory or unsatisfactory. A satisfactory rating means the carrier has not violated any acute regulations[37] or shown a pattern of noncompliance with critical regulations[38] for that factor. A conditional factor means the carrier has violated one acute regulation or has a pattern of noncompliance with critical regulations. An unsatisfactory rating means the carrier has violated two or more acute regulations or has a pattern of noncompliance with two or more critical regulations. Factor 6, the accident factor, is based on the number of recordable accidents[39] in relation to the carrier's annual mileage. An accident rate below 1.5 per million miles is considered satisfactory;[40] anything higher is rated as unsatisfactory for the accident factor.

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[35] In 2004, the Safety Board issued Safety Recommendations H-04-20 and -21 to the FMCSA and MTMC to share information regarding motor carrier ratings. (For further information, see National Transportation Safety Board, *Motorcoach Run-off-the-Road and Overturn, Victor, New York, June 23, 2002,* Highway Accident Report NTSB/HAR-04/03 [Washington, DC: NTSB, 2004]). Because the agencies plan to share compliance audits, both recommendations were classified "Closed—Acceptable Action." (For further information, see appendix B.)

[36] Before the FMCSA was established on January 1, 2000, the Office of Motor Carriers, which was part of the FHWA, had responsibility for motor carrier safety.

[37] Acute violations of the FMCSRs or hazardous materials regulations demand immediate corrective action regardless of the motor carrier's overall safety posture (for example, requiring or permitting the operation of a vehicle declared out of service before repairs are made) (49 CFR 385, Appendix B II (b)).

[38] Critical violations indicate deficiencies in the motor carrier's management controls (for instance, requiring or permitting a driver to drive after having been on duty for 15 hours) (49 CFR 385, Appendix B II (b)).

[39] The FMCSA defines a recordable accident as an occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in a fatality, bodily injury, or a vehicle incurring disabling damage that requires it to be towed from the scene (49 CFR 390.5).

[40] For a carrier operating within 100-air-mile radius, then, according to the FMCSRs, an acceptable accident rate is 1.7 per million miles.

**Table 6.** Motor carrier safety rating factors.

| Factor | Applicable FMCSRs or other criterion |
|---|---|
| Factor 1—General | Parts 387 and 390 |
| Factor 2—Driver | Parts 382, 383, and 391 |
| Factor 3—Operational | Parts 392 and 395 |
| Factor 4—Vehicle | Parts 393 and 396 |
| Factor 5—Hazardous Materials | Parts 171, 177, 180, and 397 |
| Factor 6—Accident | Recordable preventable rate |

The rating for the first five factors and the accident rate (number of recordable accidents per million miles traveled in the 12 months before the compliance review) are entered into a rating table, which is used to establish the motor carrier's overall safety rating (see table 7). Each of the six factors receives equal weight.

**Table 7.** Motor carrier safety rating table.

| Number of unsatisfactory ratings | Number of conditional ratings | Resultant safety rating |
|---|---|---|
| 0 | 2 or less | Satisfactory |
| 0 | more than 2 | Conditional |
| 1 | 2 or less | Conditional |
| 1 | more than 2 | Unsatisfactory |
| 2 or more | 0 | Unsatisfactory |

In 1991, the FHWA's Office of Motor Carriers (FMCSA's predecessor) issued a memorandum requiring inspectors to indicate whether violations or accidents occur during interstate or intrastate operations. The FHWA stated it should enforce interstate violations only, leaving the enforcement of intrastate violations to the States. However, according to the memorandum, both interstate and intrastate violations would be recorded and considered in determining a motor carrier's overall safety rating.

On April 19, 2002, the FMCSA issued a memorandum modifying the 1991 policy allowing intrastate data to affect a motor carrier's overall safety rating, stating that the FMCSA's "safety rating process shall only incorporate data over which it has jurisdiction; the FMCSA has jurisdiction over motor carriers that operate a commercial motor vehicle in interstate commerce." Further,

> Any violation discovered on a trip in intrastate commerce, except for violations that fall under FMCSA jurisdiction as mentioned above,[[41]] shall not be included in the Federal rating process. All intrastate violations discovered should continue to be recorded on the CR [compliance review] to identify what area(s) of the carrier's operation may require further review by our State counterparts. In addition to violations in intrastate trips, recordable crashes or out-of-service vehicle inspections discovered to have occurred during an intrastate trip, or on a trip between two points in a foreign country, must be left out of the calculation of the carrier's safety rating.

In an August 1, 2002, letter to the FMCSA, the CVSA expressed concern about excluding intrastate violations from the rating process and requested that the interpretation be rescinded. The FMCSA responded on September 3, 2002, that the policy change could not be rescinded for legal reasons.[42] The FMCSA did note that intrastate accident and safety-related data are used to assign Motor Carrier Safety Status Measurement System (SafeStat) scores, which identify and prioritize motor carriers for on-site compliance reviews and roadside inspections.

The Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2005 (SAFETEA), which authorizes Federal surface transportation programs for highways, highway safety, and transit for a 6-year period, was passed by Congress on July 29, 2005. Section 4114 requires the FMCSA to include accident and inspection records of owners and operators for both interstate and intrastate trips when determining the safety fitness of motor carriers.

## Tests and Research

### *I-35 Pavement Friction*

To determine the water flow and the coefficient of friction[43] that the motorcoach may have experienced at the time of the accident, pavement friction testing was conducted. At the request of Safety Board investigators, TxDOT flooded the pavement surface where the accident occurred using a hose near the crown of the road. The water flowed down the left and right wheel paths of the right lane. The water did not drain off the pavement, and the ruts became flooded.

[41] These violations relate to drug and alcohol use and testing, commercial driver's license, financial responsibility, and hazardous materials.

[42] With the passage of the Transportation Equity Act of the 21st Century, which allows the FMCSA to place carriers with an unsatisfactory rating out of service, the FMCSA's rating program has changed from an informational tool to an enforcement tool. Because of this, FMCSA counsel concluded that the agency cannot rate carriers on the basis of accidents and inspections falling outside of the agency's jurisdiction. The FMCSA does not have jurisdiction over wholly intrastate operations.

[43] A coefficient of friction represents the frictional properties of the pavement. This number is used to evaluate the skid resistance of the pavement relative to other pavements and/or to evaluate the change in skid resistance of the pavement over time. The higher a friction number, the less likely a vehicle is to skid.

Pavement friction tests were conducted at 50 mph for the treaded tire and 40 mph for the smooth tire for 1 mile on either side of the accident site in accordance with American Society for Testing and Materials (ASTM) Standard E274-97.[44] The resulting coefficients of friction can be found in table 8.

**Table 8.** I-35 Coefficients of friction.

| | Smooth tire (0/32-inch tread depth) | | | | Treaded tire (12/32-inch tread depth) | | | |
|---|---|---|---|---|---|---|---|---|
| | **Right lane, right wheel path** | **Right lane, left wheel path** | **Left lane, right wheel path** | **Left lane, left wheel path** | **Right lane, right wheel path** | **Right lane, left wheel path** | **Left lane, right wheel path** | **Left lane, left wheel path** |
| **Range of friction numbers for 2 miles surrounding accident location** | 0.12 to 0.36 | 0.14 to 0.37 | 0.29 to 0.53 | 0.41 to 0.61 | 0.42 to 0.56 | 0.44 to 0.51 | 0.59 to 0.72 | 0.60 to 0.65 |
| **Average friction number at accident location** | 0.16 | 0.20 | 0.36 | 0.47 | 0.48 | 0.48 | 0.64 | 0.63 |

## *Tire Friction Testing*

In addition to determining the friction of motorcoach tires on a wet roadway under conditions similar to those at the time of the accident, investigators also determined the difference in friction values for the newer tires on the front axle and the worn tires on the drive axle. Testing was conducted at General Dynamics Company Tire Research Facility[45] under the direction of Safety Board investigators. The tires tested were the left- and right-front tires and the four drive axle tires from the accident motorcoach. Testing was conducted at three water depths: 0.02 inch, the depth of water at which the pavement friction testing is conducted; 0.11 inch, the estimated depth of the water as it flowed along the roadway at the accident site; and 0.19 inch, based on the heavy rainfall, which may have caused more water to have accumulated in the ruts. The pavement frictions used to calibrate the General Dynamics equipment were the pavement friction testing wet pavement friction numbers for a smooth tire in the right wheel path of the right lane (0.16), obtained in on-scene testing. Table 9 shows the resulting longitudinal and lateral coefficients of friction at which the tires began to slide. See appendix C for complete tire friction test results.

[44] This widely used testing method utilizes a measurement representing the steady-state friction force on a locked test wheel (a full-scale automobile tire) as it is dragged over a wetted pavement surface under constant load and at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement. The water depth on the wet pavement is estimated to be 0.02 inch. The ASTM standard specifies 40 mph, but 50 mph was used in Safety Board testing to more closely replicate the accident speed.

[45] In 2005, the facility where the testing took place was sold by General Dynamics and is now Calspan Corporation.

**Table 9.** Tire friction test results at 60 mph.

| Tire | Average tread depth* (inches) | Water depth (inches) | Longitudinal sliding coefficient of friction | Lateral maximum coefficient of friction |
|---|---|---|---|---|
| Left front | 15/32 | 0.02 | - | - |
| | | 0.11 | 0.27 | 0.46 |
| | | 0.19 | - | - |
| Right front | 15/32 | 0.02 | 0.30 | 0.61 |
| | | 0.11 | 0.29 | 0.54 |
| | | 0.19 | 0.28 | 0.46 |
| Left outer drive | 4.56/32 | 0.02 | - | - |
| | | 0.11 | 0.12 | 0.23 |
| | | 0.19 | - | - |
| Left inner drive | 4.06/32 | 0.02 | 0.15 | 0.30 |
| | | 0.11 | 0.12 | 0.24 |
| | | 0.19 | 0.10 | 0.16 |
| Right outer drive | 7.18/32 | 0.02 | - | - |
| | | 0.11 | 0.12 | 0.26 |
| | | 0.19 | - | - |
| Right inner drive | 7.93/32 | 0.02 | 0.16 | 0.31 |
| | | 0.11 | 0.13 | 0.24 |
| | | 0.19 | 0.12 | 0.20 |

*The average tread depth measured by General Dynamics varied slightly from that measured by investigators on scene, owing to the smallness of the measurements and to differences in measuring technique (General Dynamics measured the tread depth of the entire tire and averaged the numbers; Safety Board investigators used the CVSA's technique of measuring the minimum tread depth).

### *Sight Distance*

According to AASHTO,

> Sight distance is the length of roadway ahead that is visible to the driver. The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path."[46]

Using the formula recommended by AASHTO to calculate available sight distance, the calculated available sight distance on I-35 on the approach to the accident site was 732 feet, based on a 7.5-foot driver eye height,[47] a 2.0-foot object height,[48] and the measured slopes (foreslope and downslope) of the crest vertical curve.

A witness who was in a business next to the interstate indicated to investigators the location of the end of the queue, which was then measured to be about 350 feet beyond the beginning of the skid marks left by the motorcoach. Postaccident measurements taken by

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[46] AASHTO, *A Policy on Geometric Design of Highways and Streets,* Fourth Edition (Washington, DC: AASHTO, 2002) 110.

[47] The driver eye height of 7.5 feet from the ground (that is, the position of the driver's eye while seated in the motorcoach) was measured by investigators on scene.

[48] A 2.0-foot object height is used when calculating available sight distances. From *A Policy on Geometric Design of Highways and Streets,* 127.

Safety Board investigators indicate that, from a distance of 767 feet, a motorcoach driver could see a 4-foot-high vehicle stopped in the right lane of the interstate at the approximate end of the traffic queue. (See figure 13.) This sight distance, as measured, did not take into account limitations in visibility due to the hard rain falling at the time of the accident.


**Figure 13.** Sight distance to approximate end of traffic queue available to motorcoach driver in right lane.

The stopping sight distance, according to AASHTO, is the sum of the distance traversed from the instant the driver detects an object to the instant the brakes are applied and the distance required to stop once braking begins. The formula for calculating stopping sight distance is based on passenger car operation and does not explicitly consider truck (or motorcoach) operation. AASHTO's guidelines suggest a 3.5-foot driver eye height, a 2.0-foot object height, a 2.5-second brake reaction time, and a 0.34 coefficient of friction, resulting in a stopping sight distance of 570 feet at 60 mph (the design speed of I-35) and 730 feet at 70 mph (the daytime speed limit on I-35).

### *Simulation*

Safety Board staff conducted a simulation[49] of the accident to determine the dynamics of the motorcoach, its interaction with the Suburban, the drivers' potential steering input, and the braking and speed of the vehicles. The simulation used data collected on scene, including the vehicles' tire marks, the points of impact between the vehicles and their final rest positions, data from the Suburban's SDM, and a modeling of the tire forces based on tire testing at the accident scene and at General Dynamics.

The tires on the bus were modeled as commonly available commercial tires, with a dry slide friction value[50] of 0.48. The tires' frictional characteristics were modified to produce friction levels similar to those determined during the tire testing. The surface friction values were modeled based on the on-scene pavement friction testing conducted in both the right and left lanes.

The simulation indicated that the motorcoach was probably traveling about 61.2 mph as it reached the crest of the hill, and the driver had to provide a slight right steering input to maintain a straight course on the roadway.[51] In the simulation, when the driver began to apply the brakes, the motorcoach had traveled 256 feet before the skid marks began, and the simulation indicated the driver might have applied 15 pounds of brake force. About 1.4 seconds later, the driver probably began to steer to the left such that the steering wheel was at 180 degrees in about 0.7 second. The simulation further showed that this steering was held for about 0.45 second, followed by the driver steering right at a rate of 180 degrees per half second until the wheel was steered right about 450 degrees (1.25 turns), just before impact with the Suburban. The simulation also indicated that just after the driver began to turn the wheel back to the right (about 0.15 second), he quite likely increased the brake pressure to 35 pounds as he was traveling across the left lane and into the median.

In the simulation (as in the accident), the motorcoach struck the left-front corner of the Suburban, causing the Suburban to rotate about 100 degrees. As the vehicles became disengaged in the simulation, the motorcoach began to roll onto its right side, probably striking the top left-rear corner of the Suburban. The Suburban spun out from under the motorcoach and then probably traveled off the roadway and up the concrete wall adjacent to the roadway. After disengaging from the Suburban, the simulation indicated that the motorcoach rolled onto its right side and slid about 68.7 feet. The Suburban then most likely traveled back down the wall, turned, and slid into the motorcoach's roof. The

[49] Software used for the simulation included the Human Vehicle Environment (HVE) system, Simulation Model Non-linear (SIMON), Engineering Dynamics Corporation Vehicle Simulation Model (EDVSM), Engineering Dynamics Corporation General Analysis Tool (EDGEN), Engineering Dynamics Corporation Simulation of Automobile Collisions (EDSMAC4), and AutoCad.

[50] Slide friction is the friction value at which longitudinal slip occurs (that is, a tire stops rotating and slides on a surface, leaving behind a skid mark or tire mark) during a test at a given load and speed on a particular surface. The tires used in the model had a slide value of 0.48 at 40 mph and 6,625 pounds.

[51] The right steer was needed to counteract the tendency for the drive axle tires to slip as the bus slowed going up the hill. In the simulation, the bus had to be slowed to follow the physical evidence and could have slowed due to the rain becoming harder, increased water in the ruts, a perceived slipping of the tires, or in reaction to the traffic ahead.

simulation indicated that at the initial point of collision, the motorcoach was probably traveling about 40 mph in a northwesterly direction, and the Suburban was probably traveling 33 mph in a southerly direction.[52] The total change in velocity for the motorcoach was about 16 mph and for the Suburban, about 57.8 mph, according to the simulation. The Suburban's longitudinal change in velocity was 51.3 mph in the simulation, which is fairly close to the change in velocity measured by the Suburban's SDM (48.8 mph). The SDM can only record 0.15 second of deceleration data postaccident, and a review of the deceleration data from the SDM indicates that the Suburban may not have reached its maximum change in velocity before the SDM stopped recording. The simulation showed that the maximum deceleration of the Suburban was 46.8 g, and the maximum deceleration of the motorcoach was 7.6 g.

The simulation was rerun to determine the effect of the tire tread depth. In this case, the drive and tag axle tires were given the same tread depth as the right-front tire (15/32 inch), and the driver's steering and braking inputs remained the same. The motorcoach's rear tires never locked during braking and steering (in the original simulation they did lock), which allowed the tires to maintain a higher level of friction, approaching the peak lateral and longitudinal values for the tires. The motorcoach crossed the left lane and turned right on the shoulder and into the median until it traveled parallel to the roadways in the median. The bus did not travel into the southbound lanes.

### *Other Pavement Information*

**National.** Historically, the States have resisted the FHWA's efforts to set a minimum frictional quality standard for commercial vehicle and passenger car tires. Each State is unique in terms of frictional standards for highway functional classifications, climatic conditions, liability considerations, and available aggregate material used in pavements; thus, the minimum frictional quality standards for passenger car tires on wet pavement can vary widely among the States. Most States have minimum frictional quality standards for passenger car tires on wet pavement and no standards for commercial vehicle tires on wet pavement. Although the FHWA does not set a minimum frictional quality standard for interstate highways, each State must have standards for pavement design and construction with specific provisions for high skid resistance values. States must also have programs for correcting locations with low skid resistance and high or potentially high accident rates.[53] The FHWA issued a Technical Advisory, *Skid Accident Reduction Program*,[54] on December 23, 1980, which provided guidance to the States for conducting wet weather accident location studies in order to "identify locations with high incidence of wet weather accidents, determine corrective measures, and take appropriate actions in a timely and systematic manner."[55] While the advisory states that several methods can be used to conduct wet weather accident location studies, only one method is presented.

[52] The SDM indicated the Suburban was traveling about 40 mph 1 second before the collision, so, with continued braking, the Suburban likely was traveling about 33 mph at the time of the collision.

[53] Title 23 CFR 1204.4.

[54] U.S. Department of Transportation, Federal Highway Administration, *Skid Accident Reduction Program*, Technical Advisory T5040.17 (Washington, DC: FHWA, 1980).

[55] Technical Advisory T5040.17.

The guidelines currently used by AASHTO for skid-resistant pavement design date from 1976. These guidelines have not been updated to reflect changes in vehicle or tire characteristics, data collection, traffic flow, construction techniques, materials, and other factors that affect pavement surface characteristics. To update the guidelines, the National Cooperative Highway Research Program (NCHRP)[56] is developing a "Guide for Pavement Friction" (project 1-43) that identifies technologies, processes, and practices suited for designing and constructing pavements with acceptable frictional characteristics. The project, which will be considered for adoption by AASHTO, is expected to be completed in October 2005.

The FHWA initiated the Truck Pavement Interaction research program in the 1980s to develop advanced methods and technologies that would allow a better understanding of the interactions between heavy vehicles, climate, and pavements.[57] The research primarily focuses on pavement performance and damage mitigation, not on the interaction between truck tires and pavement.

**States.** Each State has its own method of determining whether a roadway's friction is a factor in wet weather accidents or has fallen to such a level that the roadway needs to be repaved. For instance, the Illinois Department of Transportation has developed categorical rating guidelines that provide tentative guidance regarding the accident potential of a range of friction values (see table 10).

**Table 10.** Illinois Department of Transportation categorical rating guidelines.[58]

| Range of friction number | Tentative guidelines |
|---|---|
| Friction number (treaded) of 30 or lower<br>**OR**<br>Friction number (smooth) of 1 through 15 | Friction may be a factor contributing to wet weather accidents. |
| Friction number (treaded) higher than 30 **AND**<br>Friction number (smooth) of 16 through 25<br>**OR**<br>Friction number (treaded) of 31 through 35 **AND**<br>Friction number (smooth) higher than 25 | Uncertain whether friction is a factor contributing to wet weather accidents. |
| Friction number (treaded) higher than 35 **AND**<br>Friction number (smooth) higher than 25 | Friction may not be a factor contributing to wet weather accidents. |

[56] The NCHRP conducts research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. This program, which was established in 1962, is administered by the Transportation Research Board and sponsored by member departments of AASHTO (that is, individual State departments of transportation) in cooperation with the FHWA.

[57] For further information, see <www.tfhrc.gov/pavement/truck/tech2.htm>.

[58] Joliet, Illinois, highway accident investigation, January 26, 2001, NTSB docket number HWY-01-FH-012.

The States also set their own thresholds for permissible rut depths.[59] For example, Indiana considers ruts above 0.25 inch to be "severe." Arizona classifies ruts less than 0.25 inch as "low," ruts between 0.25 and 0.50 inch as "medium," and ruts over 0.50 inch as "high." Washington State considers ruts less than 0.25 inch to be "very good," ruts between 0.25 and 0.33 inch to be "good," ruts between 0.33 and 0.50 inch to be "poor," and ruts greater than 0.50 inch to be "very poor."[60]

## Recommendation History

The Safety Board has issued numerous recommendations on tire tread depth, roadway friction requirements, and motorcoach crashworthiness, as well as a recommendation on the use of military motor carrier inspections. For more information on these recommendations, see appendix B.

[59] The FHWA has no defined severity levels for rut depths. For further information, see <www.tfhrc.gov/pavement/ltpp/reports/03031/01.htm>.

[60] For further information, see <www.fhwa.dot.gov/infrastructure/asstmgmt/pms08.htm>.

# Analysis

This analysis first identifies the factors and conditions that the Safety Board was able to exclude as neither causing nor contributing to the accident. It then provides a brief overview of the accident events, followed by a discussion of major safety issues, to include sight distance and speed as they relate to roadway design; roadway and tire friction interaction, particularly between commercial vehicle tires and wet pavement; the effect on vehicle stability of differing front and rear tire tread depths; and the need to better identify areas with a high risk of wet weather accidents and implement the necessary roadway improvements.

## Exclusions

The bus driver stated he slept normally the 3 days before the accident, receiving 7 to 9 hours of sleep each night. The driver stated that he snored; however, when the other symptoms of sleep apnea were described, he denied experiencing such symptoms. At the time of the accident, the driver had been on duty for 2 hours, 45 minutes, during which he had driven for about 1 hour, 25 minutes, with 28 of those minutes immediately before the accident.

Blood and urine specimens collected from the driver after the accident were negative for alcohol and illicit or performance-impairing drugs. The specimens were positive for Diltiazem (the generic name for Tiazac®), a prescribed medication for hypertension that has been approved by the Federal Aviation Administration for use by civilian pilots. The driver was overweight and was being treated for hypertension and osteoarthritis, neither of which, when under control, as in this case, would affect his driving performance. The driver held a valid medical certificate. The Safety Board concludes that the driver was neither fatigued nor under the influence of alcohol or performance-impairing drugs, and, although severely overweight and suffering from hypertension, had no medical conditions that contributed to the accident.

The first responders arrived about 12 minutes after the accident. All of the injured were removed from the bus and transported within 44 minutes of the accident. The Safety Board concludes that the emergency response was timely.

Based on measurements taken at the scene, the bus driver had a maximum of 767 feet to see the stopped vehicles ahead. The heavy rain may have reduced visibility even further, but a precise distance is unknown.[61] The simulation indicated that the driver may have begun braking 2.5 seconds before he reached about 35 pounds of brake force, at

[61] With rainfall as heavy as was recorded at the time of the accident, visibility may have been less than 1/4 mile and could have approached 0 feet.

which time the drive wheels likely locked (the tires would have started sliding) and began to skid. (See figure 14.) Given the speed of the motorcoach, the distance it would have traveled during perception and braking, and the sight distance available, the driver had about 2.0 to 2.3 seconds to detect the stopped traffic, decide what to do, and begin to brake. AASHTO utilizes a 2.5-second perception reaction time for all stopping sight distance calculations in its *A Policy on Geometric Design of Highways and Streets*, stating that "for approximately 90 percent of the drivers (in the Johansson and Rumar study)[62] a reaction time of 2.5 seconds was found to be adequate."[63] Thus, the driver reacted appropriately (his reaction was not delayed), especially given that the driver did not expect to stop on an interstate. Even had the rain not reduced the driver's visibility, he still would not have had enough time to react to the traffic ahead and safely stop the motorcoach. The Safety Board concludes that, based on the sight distance available to the driver and the time at which the driver began to apply the brakes and steer to avoid traffic ahead, his reaction was not delayed or impaired.

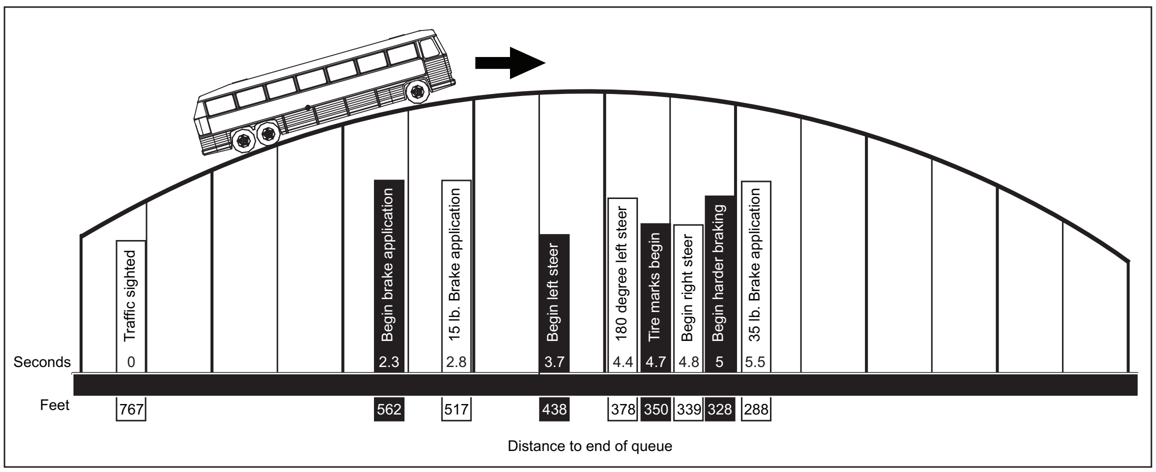


**Figure 14.** Time and distance available to bus driver.

The ABS installed on the motorcoach was connected to the tag axle tires primarily to prevent flat spotting (worn spots) on the tag axle tires. The ABS was not initially, or at the time of the accident, connected to the drive axle. Had the tag axle's ABS been operational, it would have had minimal effect on the dynamics of this accident because the majority of the motorcoach's braking capacity occurred at the drive and steer axles due to the size of those brakes and the weight distribution of the motorcoach.

[62] G. Johansson and K. Rumar, "Drivers' Brake Reaction Time," *Human Factors*, Vol. 13, No. 1 (Santa Monica, CA: Human Factors Society, 1971) 23-27.

[63] Daniel B. Fambro, Kay Fitzpatrick, Rodger J. Koppa, and Dale L. Picha, "Driver Perception—Brake Response in Stopping Distance Situations," Transportation Research Board, 1998 Annual Meeting (Washington, DC: Transportation Research Board, 1998).

## Accident Discussion

At the time of the accident, it was raining heavily, and the driver reported he had reduced the motorcoach's speed from 65 mph to about 60 mph. As the motorcoach approached the crest of a hill on northbound I-35, the driver stated that he noticed traffic ahead beginning to slow. He began to move from the right to the left lane to avoid the longer queue of traffic and applied his brakes. The driver stated that, at the same time, another vehicle also moved to the left ahead of him, requiring the motorcoach driver to provide more rapid steering input, followed by harder braking. As the motorcoach began to move to the left lane, the rear wheels of the bus began sliding and the motorcoach began rotating counterclockwise because of the reduced friction resulting from the low friction values of the highway and also the low tread depths on the drive axle tires. The simulation indicated that the bus driver rapidly turned the steering wheel to the right, probably to correct for the sliding, but that the available friction between the drive axle tires and the roadway was reduced such that the drive axle tires were unable to follow the steering maneuver and continued to slide forward and to the right, causing the motorcoach to rotate counterclockwise. The skid marks on the roadway and the path of the motorcoach as it crossed the median indicate that the steering maneuver was unsuccessful. After crossing the median, the motorcoach's right-front corner struck the left-front corner of a southbound Suburban.

The north- and southbound travel lanes were separated by 40 feet (shoulders and median), and the average daily traffic count in 2001 was 63,000 vehicles. AASHTO's *Roadside Design Guide*[64] recommends that the need for a median barrier be evaluated for median widths (distance between travel lanes) of 30 feet or greater and average daily traffic volumes of 30,000 vehicles or greater. At this location, a median barrier would be optional, based on AASHTO guidelines. TxDOT installed a median barrier in January 2004, over a year after the accident. Although median barriers are generally designed to prevent passenger vehicles from crossing a median, they can also help reduce the forward motion of larger vehicles upon impact. The Safety Board concludes that although a median barrier would not have prevented the motorcoach from leaving the travel lanes, it may have either redirected the motorcoach or slowed it significantly before entering the southbound lanes, possibly reducing the severity of the collision with the Suburban.

## Sight Distance

Traffic had backed up to and stopped at a location on the downslope of a hill on I-35. Because of the hill, the stopped traffic was obscured from the sight of approaching motorists. Using the AASHTO formula,[65] the sight distance available to the motorcoach approaching the crest vertical curve was 732 feet. Measurements taken during the on-scene investigation indicated that the sight distance available to the bus driver was 767

[64] *2002 Roadside Design Guide*, 6-2.

[65] *A Policy on Geometric Design of Highways and Streets,* 271.

feet.[66] The AASHTO formula is based on an object height of 2 feet, whereas on-scene testing used a minimum object height of 4 feet to represent a passenger car as the object being sighted by the bus driver, thus accounting for a longer available sight distance. Figure 15 shows the longest available sight distance calculated by the AASHTO formula in the right lane for the motorcoach and a passenger car, taking into account the vertical curve preceding the accident site. Investigators calculated the distance required to the stop motorcoach, using the coefficients of friction from the pavement friction tests (which

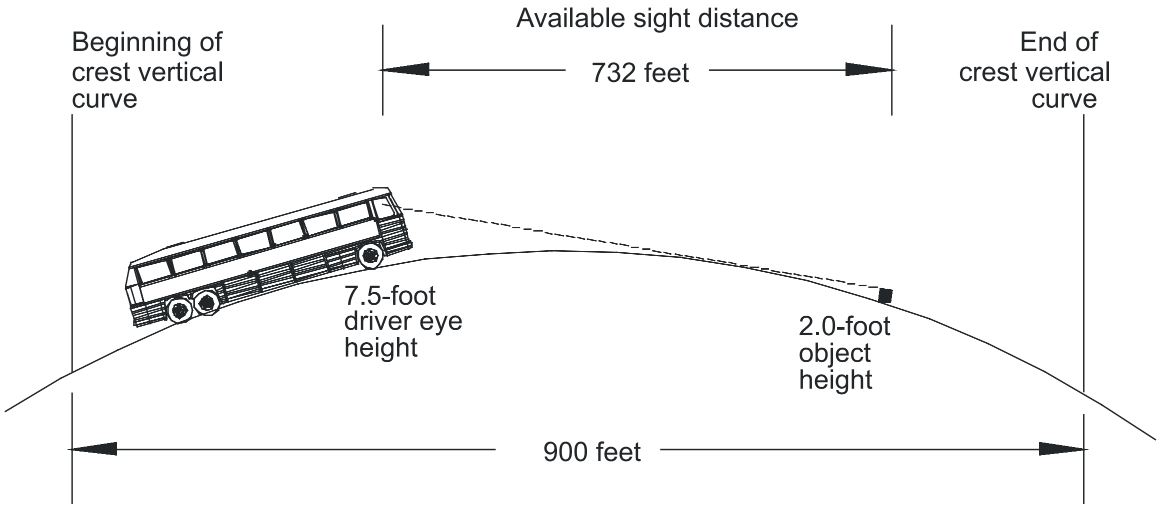


**Figure 15A.** Available sight distance for a motorcoach.

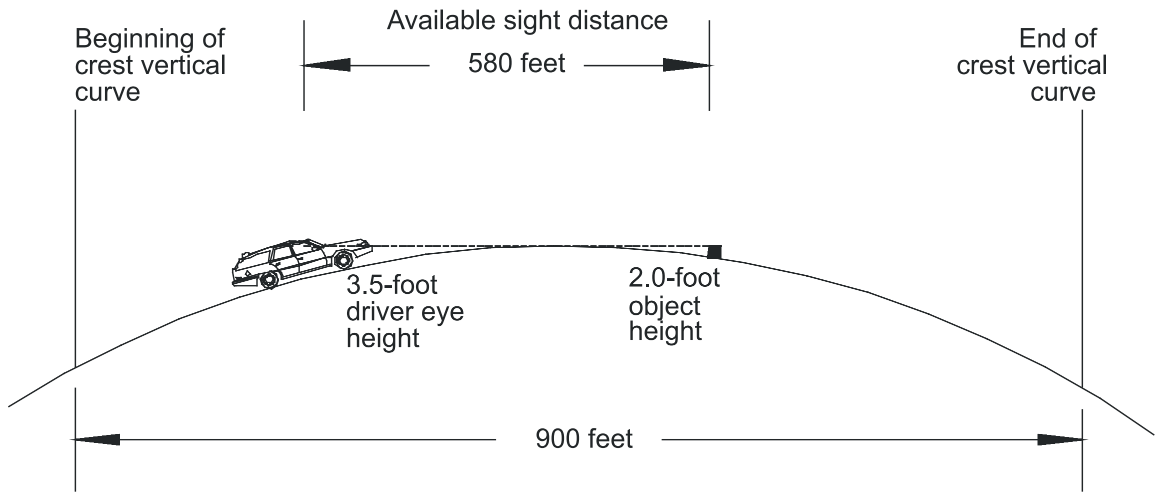


**Figure 15B.** Available sight distance for a passenger car.

[66] The AASHTO formula and this measurement did not take into account weather, which may have reduced the driver's visibility even further.

were on wet pavement) in the right lane. (See table 11.) Required stopping distances for the motorcoach ranged from 399 to 1,293 feet and for passenger cars from 335 to 962 feet, depending on speed and tire tread.

**Table 11.** Required stopping distance in the right lane.

| Vehicle type | Speed (mph) | Friction test | Calculated available sight distance (feet)* | Required stopping sight distance (feet) |
|---|---|---|---|---|
| Motorcoach | 50 | Smooth | 732 | 607 |
| Motorcoach | 60 | Smooth | 732 | 900 |
| Motorcoach | 70 | Smooth | 732 | 1,293 |
| Motorcoach | 50 | Treaded | 732 | 399 |
| Motorcoach | 60 | Treaded | 732 | 572 |
| Motorcoach | 70 | Treaded | 732 | 798 |
| Passenger car | 50 | Smooth | 580 | 481 |
| Passenger car | 60 | Smooth | 580 | 696 |
| Passenger car | 70 | Smooth | 580 | 962 |
| Passenger car | 50 | Treaded | 580 | 335 |
| Passenger car | 60 | Treaded | 580 | 466 |
| Passenger car | 70 | Treaded | 580 | 631 |

* Passenger cars have a reduced sight distance because the driver height is 4 feet lower. Calculations were based on the AASHTO formula for available sight distance.

As can be seen in table 11, the required motorcoach stopping distance in the right lane exceeds the available sight distance for smooth tires at speeds of 60 mph or greater. For a treaded tire, the required stopping distance is only exceeded at 70 mph or greater. The alignment of the roadway at the accident site, resulting in a vertical curve, combined with the low coefficients of friction on I-35 when the pavement is wet, created a situation in which vehicles may not have been able to avoid hitting traffic stopped on the roadway. I-35 was designed in 1955 with a 60-mph design speed. Since that time, the speed limit has been raised to 70 mph, yet the roadway geometry has remained the same, creating a potentially dangerous situation. The 85th percentile speed for traffic flow on I-35 in the vicinity of the accident was 74 mph, 14 mph over the original design speed. Thus, similar vehicles on the roadway may find it difficult to react in time to stop for traffic ahead, particularly in wet weather. The Safety Board concludes that the wet pavement at the accident site, combined with I-35's roadway geometry and speed limit exceeding the design speed, created a situation in which drivers may not have had enough time to react and come to an emergency stop on the interstate or to avoid a collision.

The Safety Board believes that TxDOT should inventory highway locations where poor vertical geometries, combined with low coefficients of friction and speeds greater than the design speed of the roadway, may create a situation in which traffic has inadequate stopping sight distance, and develop and implement a plan for repaving or other roadway improvements. The Safety Board believes that the FHWA should issue guidance to its field offices describing the inadequate stopping sight distance that could occur when poor vertical geometries exist at locations with low coefficients of friction and speeds higher than the design speed and work with the States to inventory such locations. The Safety Board also believes that once these locations have been identified, the FHWA should assist the States in developing and implementing a plan for repaving or other roadway improvements. The Safety Board will inform AASHTO of the inadequate stopping sight distances that could occur when poor vertical geometries exist at locations with low coefficients of friction and speeds greater than the design speed and ask that AASHTO encourage its members to rectify similar situations that may exist throughout the country.

The use of design speed was initiated in the 1930s, yet because design and operational criteria have changed over the years, many locations exist nationwide where the stopping distance may exceed the available sight distance. Members of the AASHTO Committee on Design have expressed concern that roadway operating speeds exceeding design speeds could lead to increased liability for the engineer or agency.[67] When these roadways were designed, a safety factor was often incorporated; thus, motorists may feel comfortable traveling at speeds greater than the roadway's design speed in good weather.[68] However, in poor weather, such as existed during this accident, it may be prudent to alert drivers of the condition. NCHRP Report 504 recommends that when a "safety concern exists at a location, appropriate warning or informational signs should be installed to warn or inform drivers of the condition."[69]

While drivers generally reduce their speed in rain by about 6 mph,[70] this may not be enough to compensate for the roadway geometry and wet pavement conditions. Before this accident, the bus driver was already traveling about 10 mph below the posted speed limit of 70 mph. As can be seen in table 11 earlier in this section, had the motorcoach been traveling at 50 mph, the required stopping distance for the motorcoach would have been less than the available sight distance, providing the driver with adequate time to react to the stopped traffic ahead. The Safety Board concludes that although the speed limit on I-35 was 70 mph and the design speed was 60 mph, the driver would have had to have been traveling 50 mph or less to avoid the collision or at least to have reduced its severity. Further, the Safety Board concludes that despite the safety factors that are incorporated into roadway design, roadways with speed limits exceeding their design speed can constitute a hazard in wet weather.

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[67] Kay Fitzpatrick, Paul Carlson, Marcus A. Brewer, Mark D. Wooldridge, and Shaw-Pin Miaou, *Design Speed, Operating Speed, and Posted Speed Practices*, NCHRP Report 504 (Washington, DC: Transportation Research Board, 2003) 16.

[68] Fitzpatrick and others, 80-81.

[69] Fitzpatrick and others, 84.

[70] Lin Zhang and Panos D. Prevedouros, "Motorist Perceptions on the Impact of Rainy Conditions on Driver Behavior and Accident Risk," Transportation Research Board, 2005 Annual Meeting (Washington, DC: Transportation Research Board, 2005).

Variable speed limit signs are one method of alerting drivers to reduce their speed in response to a potentially hazardous condition during poor weather. These signs display the posted speed limit during good weather, and, when weather conditions deteriorate, the posted speed limit is decreased. Over 1,300 Environmental Sensor Stations have already been deployed nationwide to provide transportation managers with information on current conditions, including atmospheric, pavement, subsurface, and water level conditions.[71] These data can be integrated with National Weather Service data to maximize the benefits from information posted on variable message signs. Road weather data may be used in automated motorist warning systems (such as variable speed limit signs) or sent to traffic management centers so that signs can be changed manually.

The Florida Department of Transportation, for example, installed a motorist warning system consisting of a flashing light mounted on a speed limit sign at an exit ramp where 69 percent of crashes occurred on wet pavement. Vehicle speeds and speed variances, as well as accidents, were reduced.[72] The New Jersey Turnpike Authority uses weather data to determine when to reduce speeds in inclement weather using variable speed limit signs, which have reduced inclement weather accidents.[73] The Washington State Department of Transportation uses speed management through the Snoqualmie Pass to inform motorists of reduced speeds due to inclement weather, including heavy rain and/or standing water on the roadway, thus increasing safety.[74]

Redesigning the roadway to eliminate locations where stopping distance exceeds available sight distance would be ideal; however, the Safety Board understands that roadway redesign can be costly. Variable speed limit signs based on current weather conditions could warn drivers to reduce their speed, thereby reducing their stopping distance below the available sight distance in adverse weather conditions. The Safety Board concludes that when redesigning a roadway for a higher design speed is not feasible, variable speed limit signs can be used as a countermeasure to reduce speeds and increase safety. The Safety Board believes that TxDOT should install variable speed limit signs or implement alternate countermeasures at locations where wet weather can produce stopping distances that exceed the available sight distance. The Safety Board also believes that the FHWA should issue guidance recommending the use of variable speed limit signs in wet weather at locations where the operating speed exceeds the design speed and the stopping distance exceeds the available sight distance. The Safety Board will inform AASHTO of the circumstances of this accident and of the benefits of using variable speed limit signs in wet weather at locations where the operating speed exceeds the design speed and where the stopping distance exceeds the available sight distance.

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[71] Paul Pisano, Brandy Hicks, Rudy Persaud, Lynette Goodwin, and Andy Stern, *An Overview of Federal Highway Administration Road Weather Management Program Activities*, 83rd Annual American Meteorological Society Meeting (Long Beach, CA: AMS, 2003). For further information, see <ams.confex.com/ams/pdfpapers/54831.pdf>.

[72] Lynette Goodwin and Paul Pisano, *Best Practices for Road Weather Management* (Washington, DC: FHWA, July 24, 2002) 8.

[73] Goodwin and Pisano, 26.

[74] Goodwin and Pisano, 50-51.

## Roadway/Tire Interaction

Investigators found a number of factors that contributed to the loss of available friction between the tires and the road in this accident, including low macrotexture pavement depths, rutting, and the low tread depths of the vehicle's drive axle tires. The right lane's cross slope, which testing indicated was not steep enough to properly drain the water off the pavement, exacerbated these problems. The sections that follow will discuss factors affecting roadway and tire interaction in more detail.

### *Macrotexture Pavement Depth*

The macrotexture, a roadway's surface roughness, affects how water is removed (drains) from the surface of the roadway. Macrotexture can have a great impact on surface friction; the higher the macrotexture, the greater the friction, particularly in wet weather. However, higher macrotexture depths can also increase road noise.

Currently, no national standards exist regarding acceptable or minimum macrotexture pavement depth; decisions concerning such matters are left to the States. Research conducted in Great Britain concluded that the effect of texture depth on loss of friction was found to be greatest below depths of 0.028 inch.[75] TxDOT conducted research in 1970 that suggests a 0.035-inch macrotexture pavement depth be used for design purposes.[76] Other research recommended minimum pavement texture depths of 0.040 inch[77]or 0.015 to 0.031 inch.[78] In the vicinity of the accident, the average macrotexture depths in the left and right lanes were 0.024 to 0.027 inch and 0.017 to 0.018 inch, respectively, well below the minimum levels recommended by TxDOT and others. As could be seen during the on-scene testing, water, when applied to the roadway, flowed down the left and right wheel paths and did not drain off the pavement. The Safety Board concludes that the low macrotexture depth at the accident site prevented proper drainage of the water from the roadway, allowing excessive water to remain on the road surface, which, in turn, contributed to its minimal frictional qualities.

### *Rut Depths*

While the low macrotexture pavement depths and the right lane's cross slope prevented water from being removed from the roadway surface at the accident site, the rutting found in the roadway contributed to the further accumulation of water during the rainstorm at the time of the accident. During a heavy rain, such ruts could become "full," resulting in water depths greater than the average tread depths of the motorcoach's

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[75] P.G. Roe, A.R. Parry, and H.E. Viner, *High and Low Speed Skidding Resistance: The Influence of Texture Depth*, TRL Report 367 (United Kingdom: Transportation Research Laboratory, 1998) 1.

[76] Kenneth D. Hankins, Richard B. Morgan, Bashar Ashkar, and Paul R. Tutt, *The Degree of Influence of Certain Factors Pertaining to the Vehicle and the Pavement on Traffic Accidents Under Wet Conditions*, Research Study No. 1-8-69-133, Research Report 133-3F (Washington, DC: FHWA: September 1970) viii.

[77] Galloway and others, *Tentative Pavement and Geometric Design Criteria for Minimizing Hydroplaning*" FHWA-RD-75-11 (Washington, DC: FHWA, February 1975).

[78] Peter Elsenaar, J. Reichert, and Raymond Sauterey, *Pavement Characteristics and Skid Resistance*, U.S. Transportation Research Record No. 622 (Washington, DC: Transportation Research Board, 1976).

drive axles. When water depth exceeds tire tread depth, water cannot be channeled out from beneath the tires, reducing the friction available between the tire and the roadway surface.

Although the ruts near the accident site were deeper than the average tread depth of the drive axle tires, they were below TxDOT's recommended resurfacing threshold of 0.50 inch or deeper. The rutting in the right wheel path of the right lane was between 0.25 and 0.35 inch, equal to or higher than the average tread depth for the right tires (0.22 and 0.25 inch). The rutting in the left wheel path of the right lane was between 0.40 and 0.42 inch, again higher than the average tread depths of the left tires (0.125 and 0.14 inch). However, because the majority of these ruts were between 0.25 and 0.50 inch deep, they met TxDOT criteria for a "shallow" rutting problem, and resurfacing was not required.

At locations where drainage is poor, it is possible that, in a heavy storm, the water accumulating in the ruts could exceed the tread depth of many tires, not just tires with minimal tread depths, leading to a reduction in available friction. Even the front tires on the motorcoach, which were only 1 month old, had tread depths of less than 0.50 inch (14/32 [0.44] and 15/32 [0.47] inch). For passenger cars, new tire tread depths can vary from 8/32 to 11/32 inch. About 80 percent of passenger cars have at least one tire with a tread depth of less than 8/32 [0.25] inch, and the average tread depth for all tires is 6.8/32 [0.21] to 7.0/32 [0.22] inch.[79] Although the States have no uniform threshold for rut depths before rehabilitation occurs, rut depths greater than 0.50 inch are generally unacceptable. The Safety Board concludes that a rut-depth threshold of 0.50 inch is insufficient because 0.50 inch exceeds the tread depths of most vehicle tires, and standing water in the ruts can lead to reduced tire-roadway friction situations in wet weather.

Differing friction conditions within a travel lane can also influence vehicle handling. The average rut depth in the right lane, left wheel path, was 0.11 inch greater than in the right wheel path. Thus, more water was probably standing or flowing downgrade in the left wheel path than in the right wheel path, making it necessary for the left tires to push more water out from between the tires and the pavement to maintain traction. Furthermore, the tread depth for the right drive axle tires (minimum of 5/32 and 6/32 inch for the inner and outer tires, respectively) differed from the left drive axle tires (minimum of 2/32 and 3/32 inch for the inner and outer tires, respectively). The reduced tread depth further diminished the ability of the left tires to channel water away from the tire and roadway interface and to continue to maintain traction on the road surface. This caused a differential force between the left and right tires that resulted in the motorcoach turning counterclockwise, requiring the driver to input a steering force to the right to maintain his course.

[79] Kristin Thiriez and Rajesh Subramanian, "Research Note: Tire Pressure Special Study Tread Depth Analysis," DOT HS 809 359 (Washington, DC: National Center for Statistical Analysis, NHTSA, October 2001).

Research has shown that when the coefficients of friction in the wheelpaths differ, this differential friction may cause a vehicle to spin out of control when braking.[80] The coefficient of friction was 0.16 for a smooth tire in the right wheelpath and 0.20 in the left wheelpath, a 20-percent difference in friction. Research indicates that even a 17-percent difference in friction resulted in rotations during braking that increased as speed increased, up to 95 degrees rotation at 50 mph.[81] In this accident, the driver attempted to compensate for such rotation by steering, resulting in further loss of control of the motorcoach. The Safety Board concludes that the greater rut depth in the left wheel path and the differential friction between the wheelpaths resulted in a destabilizing counterclockwise rotational force on the motorcoach.

### *Roadway Friction*

When a roadway surface is flooded, as it was when this accident occurred, a vehicle may hydroplane. Hydroplaning occurs when a tire is unable to push the water on the surface out from the contact area between the tire and the roadway surface, resulting in a reduction in friction and causing the tire to slide across the top of the water. As speed increases, water cannot be pushed out from between the tire and the roadway quickly, thus reducing the available friction. To determine whether the motorcoach could have experienced this phenomenon, the speed at which hydroplaning would occur was calculated for each tire.[82] Calculations indicate that the lowest speed at which one of the tires would hydroplane was about 71 mph for the front left tire, which had the lowest tire pressure (73 psi). The remaining tires would not hydroplane until the speed reached 73 to 79 mph. The motorcoach driver's and witness' statements, as well as the simulation, indicate that the motorcoach was traveling about 60 mph; therefore, the Safety Board concludes that the motorcoach did not hydroplane before losing control.

A study of the effect of water depth on braking coefficients indicates that "a progressive loss in braking force coefficient" can occur long before full hydroplaning develops.[83] In this accident, the drive axle tires likely locked up when the motorcoach was rapidly steered, and the brakes were applied, resulting in the motorcoach beginning to slide. The driver's attempt to regain control by rapid steering input was unsuccessful because no traction was available to the tires. Probably to correct for the sliding, the bus driver rapidly turned the steering wheel to the right, and because the available friction between the drive axle tires and the roadway was exceeded to the extent that the drive axle tires were unable to follow the steering maneuver, the motorcoach's rear continued to slide forward and to the right. As stated earlier, the bus driver's reaction occurred in a timely manner in relation to the distance from which he could see the stopped traffic, yet despite this, he would not have been able to avoid hitting stopped traffic. The Safety Board

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[80] John C. Burns, "Differential Friction—A Potential Skid Hazard," 1976 Annual Meeting, Transportation Research Board (Washington, DC: Transportation, Research Board, 1976).

[81] Burns, 2.

[82] Equation derived from: Don L. Ivey. *Truck Tire Hydroplaning—Empirical Confirmation of Horne's Thesis* (College Station, Texas: Texas Transportation Institute, May 1971).

[83] G.C. Staughton and T. Williams, *Tyre Performance in Wet Surface Conditions,* Transport and Road Research Laboratory, Laboratory Report 355 (United Kingdom: Ministry of Transport, 1970).

concludes that the water accumulation on the roadway, likely due to the low macrotexture depth, rutting, and inadequate cross slope, contributed to the loss of available friction between the tire and the road.

Wet pavement friction is a measure of the force generated when a tire slides on a wet pavement surface. Wet pavement friction decreases with increasing speed.[84] Friction numbers can be used to evaluate pavement friction and compare pavement with other surfaces or the same pavement over time. Many factors influence the friction, including surface design, age, traffic volume, seasonal changes, and speed. The level of friction required depends upon the traffic characteristics, climate, and roadway geometry.

TxDOT uses a statistical evaluation to determine the degree to which the friction of a roadway, derived from an ASTM smooth tire tested at 40 mph on wet pavement, is below the mean. Postaccident testing at 50 mph in the vicinity of the accident site revealed the average friction coefficients in the right lane, right and left wheel paths, of 0.16 and 0.20, respectively, and in the left lane, right and left wheel paths, of 0.36 and 0.47, respectively. TxDOT's PMIS showed pavement friction coefficients in the right lane of 0.12 in 2000 and 0.13 in 2002. (These variations can be attributed to differences in the location of the skid trailer.) All of the pavement friction values in the right lane were very low; in fact, they were equivalent to performance on ice (see the discussion later in this section regarding Texas roadway friction).

Most States set minimum friction quality standards for design and maintenance of pavement that only take into consideration passenger cars, not commercial vehicles. Yet, according to the NCHRP Report 400:

> Truck tires tend to have lower wet friction coefficients than passenger car tires because they are designed primarily for wear resistance. Olson et al.[85] estimated that truck tires have coefficients of friction that are about 70 percent of those of passenger car tires.[86]

The guidelines currently used by AASHTO for skid-resistant pavement design date from 1976 and are based on passenger car tire characteristics. The guidelines have not been updated to reflect changes in vehicle or tire characteristics, data collection, traffic flow, construction techniques and materials, or other factors that affect pavement surface characteristics. NCHRP Project 1-43, "Guide for Pavement Friction," due to be published in October 2005, is intended to update some of the information in AASHTO's 1976 guidelines.

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[84] *NCHRP Synthesis of Highway Practice 291: Evaluation of Pavement Friction Characteristics*. (Washington, DC: Transportation Research Board, 2000) 5.

[85] P.L. Olson, D.E. Cleveland, P.S. Fancher, L.P. Kostyniuk, and L.W. Schneider, *Parameters Affecting Stopping Sight Distance,* NCHRP Report 270 (Washington, DC: Transportation Research Board, National Research Council, June 1984).

[86] Daniel B. Fambro, Kay Fitzpatrick, and Rodger J. Koppa, *Determination of Stopping Sight Distances,* NCHRP Report 400 (Washington, DC: Transportation Research Board, National Research Council, 1997) 17.

Each State's requirements for pavement quality are unique in terms of frictional standards for highway functional classifications, climatic conditions, liability considerations, and available aggregate materials; thus, the FHWA believes that evaluating skid resistance nationally is not feasible, and it has set no Federal standards for minimum frictional quality for wet pavement. The FHWA requires that States have minimum frictional quality standards for passenger car tires on wet pavement but does not require such standards for commercial vehicle tires. Although the Safety Board understands the FHWA's reluctance to set pavement standards because of the State variations in roadway materials and environments, research to determine minimal acceptable pavement standards, taking into consideration tire frictional properties, could help States understand the effects of inadequate pavement conditions and prevent conditions such as those found at the accident site from developing.

The FHWA does not specify a minimum frictional quality standard for interstate highways. A review of Texas PMIS skid data for fiscal years 1999 and 2000 revealed that 50 percent of the roads in the interstate highway system had coefficients of friction of 0.26 or below; 50 percent of the U.S.-numbered highways in Texas, 0.31 or below; 50 percent of State highway system roads, 0.35 or below; and 50 percent of the farm-to-market roads, 0.41 or below. Coefficients of friction on Texas interstate highways have values that are generally 0.10 to 0.15 units lower than on State highways and farm-to-market roadways because noninterstate roadways are typically surfaced with high macrotexture seal coats.[87] These surfaces provide higher coefficients of friction than the hot-mix asphalt or Portland cement concrete used to surface Texas interstate highways, but they are also noisier and less durable.

Coefficients of friction on icy surfaces can range from 0.12 to 0.25.[88] TxDOT PMIS data revealed that the mean coefficient of friction on all Texas roadways is 0.36 and that 50 percent of the interstate highways in Texas have coefficients of friction 0.5 to 1.0 standard deviation below this mean. The accident location had even lower coefficients of friction. As coefficients of friction decrease, the required stopping distance increases.

Though no nationwide recommended minimum coefficient of friction exists for highways, those in use by other States can provide a basis for comparison. The coefficients of friction on I-35 were close to those coefficients of friction found on icy surfaces. TxDOT was aware of the low frictional qualities of I-35 as early as 2000, when the PMIS data indicated a coefficient of friction of 0.12. Despite this, TxDOT had no immediate plans to repave this roadway to increase its frictional qualities because many interstate roadways in Texas have similar coefficients of friction and all of the other

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[87] However, as these seals lose aggregate over time, they can form a layer of asphalt on the surface that is extremely slippery.

[88] (a) J. Stannard Baker, *Traffic Accident Investigation Manual* (Evanston, Illinois: Northwestern University Traffic Institute, 1975). (b) Francis Navin, Michael Macnabb, and Connie Nicoletti, *Vehicle Traction Experiments on Snow and Ice*, SAE 960652 (Warrendale, PA: Society of Automotive Engineers, 1996). (c) A.H. Easton, "Summary of Tests on Motor Vehicles Under Winter Conditions," *Highway Research Board Proceedings, 1961* (Washington, DC: Highway Research Board, 1961) 565-581. (d) M. McBride, "Skid Tests on Nine Vehicles on an Ice Covered Surface," *Accident Reconstruction Journal*, Vol. 4, No. 2 (Overland Park, KS: Criterion Press, 1992). (e) J. Hunter, *Reconstructing Collisions Involving Ice and Slippery Surfaces*, SAE 930896 (Warrendale, PA: Society of Automotive Engineers, 1993).

factors (distress, ride, and condition) were rated at the highest level (A). The Safety Board concludes that TxDOT's PMIS does not adequately identify roadways where hazardous conditions exist due to low coefficients of friction and does not expeditiously prioritize these locations for rehabilitation, increasing the risk for accidents such as the one that occurred at this location. The Safety Board believes that TxDOT should change its PMIS to increase its emphasis on roadways with low coefficients of friction in determining maintenance priorities.

### *Tire Friction*

The friction testing results for the drive axle tires were 0.10 on 0.19 inch of water and 0.15 on 0.02 inch of water (equivalent to performance on ice), values significantly lower than those of the front tires (0.28 to 0.30), primarily because the drive axle tires had a much lower tread depth (2/32 versus 14/32 inch). As was demonstrated by the testing, the tread depth can significantly affect the friction available in wet weather; available friction is critical to the vehicle's ability to stop.

Calculations, based on the tire coefficients of friction derived from friction testing[89] and the configuration of the brakes, indicated that the drive axle brakes would have locked up at a brake application pressure of about 22 psi. The front and tag axle tires would have required a brake pressure of about 32 and 33 psi, respectively, before they locked up on the same low friction surface of the right lane. This difference can lead to instability of the vehicle during hard braking or emergency maneuvers. Had the drive axle tires been the same tread depth as the front axle tires, they would not have locked up until a brake application pressure of 47 psi was applied.[90] The Board's simulation indicated that the driver likely applied the brakes at a pressure of 35 psi. The simulation further showed that when tires with tread depths similar to those of the front tires (14/32 or 15/32 inch on all the wheels) were used, the driver would likely have been able to maintain sufficient control of the motorcoach to avoid crossing into the southbound lanes. While the motorcoach would have left the roadway, the Suburban probably would not have been hit and the motorcoach probably would not have rolled over.

Research and testing on passenger cars indicate that "friction forces at highway speeds are reduced to half or less of the new tire value if the tire wear exceeds about 50 percent,"[91] as it did on the drive axle tires. This research also indicated that the lateral friction of tires decreases well before hydroplaning is expected to occur.[92] Further, when the worn tires are placed on the rear of passenger cars, the handling of the vehicle changes, since the rear tires have more tendency to slide.

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[89] These tire coefficients of friction were measured on a roadway surface similar to the surface measured on scene.

[90] The drive axle wheels require more brake pressure to lock than other wheels because the drive axle supports more of the motorcoach's weight than the other axles.

[91] William Blythe and Terry D. Day, *Single Vehicle Wet Road Loss of Control; Effects of Tire Tread Depth and Placement*, SAE 2002-01-0553 (Warrendale, PA: Society of Automotive Engineers: 2002).

[92] Blythe and Day, 10.

Tire friction testing also indicated that the lateral friction, the stability of a tire during turns and lateral maneuvers, was much lower for the rear tires (0.23 to 0.26)[93] than the front tires (0.46 to 0.54). Thus, when a maneuver such as braking or steering is attempted, the worn rear tires, with reduced longitudinal and lateral friction, are unable to maintain their grip on the road and will begin to slide rather than follow the front tires through the intended maneuver. Research on passenger vehicles found that "normal lane change maneuvers can lead to loss of control on a wet road if sufficient difference in tread depth exists front to rear, with the better treaded tires on the front axle of a passenger car."[94] Lower tread depths on the rear tires of passenger vehicles create an inherent safety problem, and while they are likely to have the same effect on commercial vehicles, which was confirmed in the simulation, the extent of this effect cannot be determined. In this accident, when the driver tried to brake and then to abruptly turn the wheel back to the right when the drive axle tires started to slip, little lateral friction was available for the maneuver, and thus the motorcoach continued to rotate counterclockwise. Yet, with tires that had a greater tread depth, the motorcoach probably would have responded to the rapid right steering maneuver and would not have continued its counterclockwise rotation. The Safety Board concludes that the minimum tread depths of the drive axle tires, including the smaller tread depth on the left drive axle tires, particularly in combination with the nearly new front tires, contributed to wheel lockup and the subsequent rotation of the motorcoach.

The FMCSRs[95] currently require that the tread depth for the front wheels of a commercial vehicle be at least 4/32 inch and the tread depth for all other tires be at least 2/32 inch. The CVSA guidelines for placing a vehicle out of service include steer axle tire treads of less than 2/32 inch in two adjacent grooves and any other tire treads less than 1/32 inch in two adjacent grooves. The effect of tread depth on commercial vehicle handling has not been evaluated since these requirements were instituted over 30 years ago, and no data are available to determine how these tread depth requirements were determined. The Safety Board previously made a recommendation to NHTSA on this matter as a result of its investigation of the November 16, 1980, motorcoach accident near Luling, Texas,[96] in which the motorcoach lost traction on the wet pavement and skidded off the road:

> <u>H-81-33</u>
>
> Accelerate activity to establish rulemaking action for minimum frictional quality standards for commercial vehicle tires.

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[93] At 60 mph and 0.11-inch water depth.

[94] Blythe and Day, 14.

[95] Title 49 CFR 393.75.

[96] National Transportation Safety Board, *East Side Church of Christ Bus Skid and Overturn U.S. Route 183 Near Luling, Texas, November 16, 1980,* Highway Accident Report NTSB/HAR-81/04 (Washington, DC: NTSB, 1981).

Yet nothing was done, and the recommendation was classified "Closed—Unacceptable Action" on August 21, 1986 (see appendix B). In 1988, the Safety Board issued the following recommendation to the FHWA as a result of the May 4, 1987, accident in Beaumont, Texas:[97]

> H-88-1
>
> Revise Sections 393.75(B) and (C) of the *Federal Motor Carrier Safety Regulations* to prohibit the use of tires worn below 4/32 inch on any axle of a commercial interstate vehicle.

Again, no action was taken and the recommendation was classified "Closed—Unacceptable Action" on May 19, 1989 (see appendix B). Yet, this accident and recent research[98] show that reduced tread depth can lead to reduced friction and, ultimately, loss of control. Because no requirement exists that the tires have similar tread depths, the Safety Board believes that NHTSA should conduct testing on the effects of differing tread depths for the steer and drive axle tires. The Safety Board also believes that once NHTSA's testing is complete, the FMCSA should modify the tread depth requirements for each axle to reflect the results of the research. In addition, because the adverse effects of mounting worn tires on the rear axle of vehicles are not widely known,[99] it is important that both commercial vehicle owners and consumers are aware of this information. The Safety Board will inform the United Motorcoach Association, the American Bus Association, the American Trucking Associations, the Owner-Operator Independent Drivers Association, the American Automobile Association, and the National Safety Council of the adverse handling that can result when worn tires are placed on the rear axles of vehicles, particularly when the front tires are fairly new with good tread depths.

### *Commercial Vehicle Tires—Special Considerations*

The coefficient of friction measured by friction testing consists of both the roadway friction (as measured by the pavement friction test) and the friction provided by the tires. As stated earlier, when a tire is unable to channel water from under the area in contact with the roadway surface, the friction available to that tire decreases. In this accident, the roadway had a low friction value, and the drive axle tires were at a minimum tread depth. Combined, these factors led to the drive axle tires having very little friction available to support braking or to follow steering maneuvers. In fact, the friction available to the drive axle tires was similar to that available on ice. Once these tires lost traction, the driver began to steer and increase the amount of braking but was unable to regain control of the motorcoach because the remaining tires also likely began to lose traction. The Safety Board concludes that the minimal friction available to the tires and on the roadway combined to cause the motorcoach to lose control when the driver attempted to maneuver to avoid stopped traffic.

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[97] National Transportation Safety Board, *Tractor-Semitrailer/Intercity Bus Head-on Collision Interstate 10, Beaumont, Texas, May 4, 1987*, Highway Accident Report NTSB/HAR-88/01 (Washington, DC: NTSB, 1988).

[98] Blythe and Day.

[99] Tire manufacturers do disseminate this information to their maintenance facilities.

The minimum permissible tread depth on a commercial vehicle tire, which was established in 1969, is 2/32 inch for any tire except the steer axle tires. As shown in the testing and simulation, the permissible tread depth did not provide the motorcoach driver with enough friction to maneuver the vehicle on wet pavement in an emergency situation, thus leading to the accident. Even the right drive axle tires, with their 4/32-inch tread depths, had coefficients of friction that were not much greater than those experienced by the left drive axle tires with their 2/32-inch tread depths. The Safety Board issued Safety Recommendation H-88-1 in 1988 asking that the FHWA prohibit the use of tires worn below 4/32 inch on *any* axle, yet the minimums were not changed (see appendix B). Because the interaction between the tires and the pavement can affect the amount of friction available to vehicles, the Safety Board concludes that to prevent accidents similar to this one, commercial vehicle tire-roadway interaction, which is not currently being considered, must be taken into account when determining the necessary wet pavement friction of the roadway and tire tread depth minimums. This is particularly true for commercial vehicles, for which the tire coefficients of friction are already lower than for passenger vehicles.

The FHWA's Truck Pavement Interaction research program focuses primarily on pavement performance and damage mitigation. Research on the interaction of commercial vehicle tires, the effects of tread depth, and pavement friction has not been conducted in over 30 years, and this accident demonstrates that the current minimum requirements for commercial vehicle tire tread depth are inadequate, especially when combined with the minimal frictional qualities of Texas's interstate highway system. The Safety Board believes that the FHWA should conduct research on commercial vehicle tire and wet pavement surface interaction to determine minimum frictional quality standards for commercial tires on wet pavement; once completed, the FHWA should 1) revise the tire requirements for commercial vehicles operating on wet pavement at highway speeds, and 2) develop minimum acceptable pavement coefficients of friction and maximum permissible pavement rut depths as part of roadway maintenance requirements, as appropriate.

## Texas Wet Weather Accident Reduction Program

Texas established the WWARP to identify locations for improvement throughout the State that are overrepresented in wet weather accidents. Currently, the Texas WWARP threshold for determining hazardous roadway segments requires that five accidents occur within a 1/10-mile (528-foot) segment on an interstate roadway. This threshold distance is fairly short given the high speeds, traffic volumes, number and weight of trucks, and limited number of intersecting roadways found on interstates. By limiting segments to 1/10 mile, TxDOT may fail to identify longer segments of roadway that have equally hazardous roadway conditions in wet weather. The WWARP indicates that more than half (14) of all the district offices in Texas had zero or one location identified as hazardous. The urban district offices of Houston, San Antonio, Dallas, Austin, and Fort Worth, however, had a disproportionately high number of wet weather accident sites identified

(410 of the total 467 reported high-accident sites in the State). Because of the threshold the WWARP uses for identifying hazardous locations, the program is weighted toward identifying locations in high population areas, virtually ignoring other locations that are just as hazardous but in less densely populated areas.

Sixteen percent of the accidents that occurred on I-35 in the vicinity of the accident from 1996 to 2002 were in wet weather. That segment of roadway was exposed to precipitation only 2.35 percent of the period. Thus, although travelers had nearly a seven times greater chance of being in an accident in wet weather than dry weather at the accident location, the WWARP did not identify this area as a high-accident location. The 2000 WWARP report did not indicate that I-35 in the vicinity of this accident had five or more accidents in the 1/10 mile surrounding the accident site.

The data used for the WWARP are 3 years old. Because of the lag time in this data, locations that have pavement friction issues in wet weather may not be identified quickly enough, as pavement quality deteriorates over time. Further, this accident location had low friction values, a "shallow" rutting problem, and poor roadway geometry that may have indicated an increased accident risk. The Safety Board concludes that Texas's WWARP methodology is not sufficiently refined to measure wet weather accident risk, fails to identify the greater risk of being involved in a wet weather accident on the segment of I-35 in the vicinity of the accident, and, generally, does not identify problems in a timely manner.

In the 5 miles on either side of the accident site, fewer than three accidents per 1/10 mile occurred within a 3-year time frame (under both wet and dry pavement conditions), on average. Yet this location had a higher percentage of wet weather accidents than other similar U.S. highway segments (16 percent versus 13 percent).[100] When accidents occur on an interstate, the results can be severe because of the high speeds and high traffic volumes. In the vicinity of the accident, the poor roadway conditions consisted of low macrotexture pavement depths, a rutting problem, and low skid numbers. These roadway conditions can be an indicator of potential wet weather problems, and, by not taking these conditions or roadway geometry into consideration, Texas's WWARP may not identify highly dangerous locations. The Safety Board believes that TxDOT should revise and validate its WWARP so that improvement priorities are not disproportionately influenced by the number of accidents that occur but also consider locations where surface conditions and geometry lead to very low friction coefficients and dangerous conditions.

Each State has its own method for determining whether a roadway's friction is a factor in wet weather accidents or has fallen to such a level that the roadway needs to be repaved. For instance, the Illinois Department of Transportation rating guidelines (see table 10), state it is "uncertain" whether the friction in the right lane of I-35 would have

[100] NHTSA estimates that, in 2003, approximately 13 percent of all accidents on the interstate highway system occurred in wet weather. For further information, see NHTSA, *Traffic Safety Facts 2003: A Compilation of Motor Vehicle Crash Data From the Fatality Analysis Reporting System and the General Estimates System* (Washington DC: U.S. DOT/NHTSA, 2004) 47.

been flagged as potentially contributing to wet weather accidents, given the pavement friction test numbers (see table 8). For the left lane, the Illinois guidelines indicate friction "may not be a factor" contributing to wet weather accidents. The Illinois system for wet weather pavement management is considerably different from the Texas system because it does not rely on the number of accidents to evaluate and remedy locations that may have more wet weather accidents, as Texas's WWARP does. Furthermore, Illinois drivers are exposed to more wet weather (3.8 percent of 2003), yet experience the same percentage of wet weather accidents (16 percent of all accidents occurred in wet weather in 2003) as drivers in Texas.

While the FHWA provides limited guidance and one possible method of identifying and reducing wet weather accidents,[101] no additional guidance on best practices has been developed by the FHWA since the technical advisory *Skid Accident Reduction Program* was published in 1980. Thus, the States develop their own methodologies, which may or may not be adequate. The Safety Board concludes that Federal guidance on identifying and eliminating locations with wet weather accident problems is limited; had more comprehensive guidance existed, Texas may have implemented a more robust WWARP. The Safety Board believes that the FHWA should review State programs that identify and eliminate locations with a high risk of wet weather accidents and develop and issue a best practices guide on wet weather accident reduction.

## FMCSA Exemptions

Central Texas Trails met FMCSR requirements and received a satisfactory rating after the accident, despite having had three reportable accidents (including the subject accident) in the previous year. All three of these accidents occurred during intrastate operation. Though the FMCSRs state that the accident rate is determined by both interstate and intrastate operations (accidents and mileage), a 2002 FMCSA memorandum prohibits inspectors from including intrastate crashes or mileage when determining out-of-service violations during compliance reviews. Thus, according to the FMCSA's compliance review, the accident rate for this carrier was zero (no interstate accidents in the previous 12 months). Had the three intrastate accidents and mileage for the previous 12 months been included in the FMCSA's calculations, the accident rate would have been about 2.64 per million miles traveled, resulting in an unsatisfactory rating in that area and an overall conditional rating. While a conditional rating would not have prevented Central Texas Trails from operating and may not have prevented this accident, it may have placed the carrier under greater scrutiny by the FMCSA or State officials.

Although it is the FMCSA's policy to oversee interstate operations and it is the States' responsibility to oversee intrastate operations, violations recorded in *both* types of operation are directly relevant to the overall safety posture of a carrier and thus should be considered. Regardless of whether a carrier is engaged in interstate or intrastate

[101] Technical Advisory T5040.17.

operation, its vehicles and drivers are often operating on the same roads as the traveling public and interacting with the same vehicles. Although it did not have an impact on this accident, the exclusion of intrastate mileage and accidents from the FMCSA's compliance reviews can lead to an inaccurate representation of a motor carrier's safety posture. The Safety Board is encouraged that Congress has addressed this issue in the SAFETEA legislation.

## Survival Aspects

### *Motorcoach*

The passengers within the motorcoach likely sustained their injuries from being thrown to the right into other passenger seats and into windows and other interior components as the motorcoach rotated across the median and southbound lanes and rolled over onto its right side. The passengers found under the motorcoach made contact with the windows that shattered and broke away and were subsequently ejected during the motorcoach's overturn. The motorcoach's interior passenger compartment was not compromised by intrusion during the accident sequence and therefore adequate survivable space was available. Given the available postaccident survivable space within the passenger compartment, had passengers remained in their seating areas, their exposure to injury-causing impacts and to ejection would have been reduced and they may not have sustained such serious, or fatal, injuries. The headrests on the aisle seats, which no longer had interior padding, created another possible injury-causing mechanism inside the motorcoach for nonejected passengers. The Safety Board concludes that the lack of motorcoach occupant protection systems to retain passengers in their seating compartments during the accident sequence contributed to passengers being partially or fully ejected from the motorcoach and to their serious and fatal injuries due to contact with non-occupant-protected surfaces, other passengers, or surfaces outside of the motorcoach. The Safety Board will inform the American Bus Association and the United Motorcoach Association that the padding on the headrests on the aisle seats can become worn, possibly causing injuries in an accident, and should be inspected and replaced, as necessary.

The Safety Board has made recommendations to NHTSA in the past regarding the importance of keeping motorcoach occupants within their seating compartment during collisions to prevent serious injuries. (See appendix B.) NHTSA has informed the Safety Board that, in cooperation with Transport Canada, it is conducting research on window glazing material designed to keep occupants inside the motorcoach. The Safety Board encourages NHTSA to continue its work on motorcoach occupant protection issues. The Safety Board will also inform the American Bus Association and the United Motorcoach Association of the circumstances of this accident and encourage them to reiterate to their members the importance of providing occupant protection systems.

### *Suburban*

There was little, if any, survivable space available for the driver and front seat passenger in the Suburban. The crush damage was so significant that the airbags and lap/shoulder belts could not have prevented the fatal injuries that were sustained. The passenger in the rear seat was restrained but did not experience as much crush. The Safety Board concludes that despite the peak deceleration experienced by the passengers of the Suburban (about 46.8 g, as found during the simulation),[102] the passenger in the rear seat quite likely sustained serious, rather than fatal, injuries, because of the protection provided by the lap/shoulder belt and the limited crush that occurred within his seating area.

[102] The deceleration recorded by the SDM was about 20 g and averaged over 110 milliseconds. The deceleration determined by the simulation is an instantaneous peak deceleration. Furthermore, the SDM stops recording 150 milliseconds after the event, so the full deceleration experienced by the passengers may not have been recorded if it extended beyond the recording capabilities of the SDM.

# Conclusions

## Findings

1. The driver was neither fatigued nor under the influence of alcohol or performance-impairing drugs, and, although severely overweight and suffering from hypertension, the driver had no medical conditions that contributed to the accident.

2. The emergency response was timely.

3. Based on the sight distance available to the driver and the time at which the driver began to apply the brakes and steer to avoid traffic ahead, his reaction was not delayed or impaired.

4. Although a median barrier would not have prevented the motorcoach from leaving the travel lanes, it may have either redirected the motorcoach or slowed it significantly before entering the southbound lanes, possibly reducing the severity of the collision with the Chevrolet Suburban.

5. The wet pavement at the accident site, combined with Interstate 35's roadway geometry and speed limit exceeding the design speed, created a situation in which drivers may not have had enough time to react and come to an emergency stop on the interstate or to avoid a collision.

6. Although the speed limit on Interstate 35 was 70 mph and the design speed was 60 mph, the driver would have had to have been traveling 50 mph or less to avoid the collision or at least to have reduced its severity.

7. Despite the safety factors that are incorporated into roadway design, roadways with speed limits exceeding their design speed can constitute a hazard in wet weather.

8. When redesigning a roadway for a higher design speed is not feasible, variable speed limit signs can be used as a countermeasure to reduce speeds and increase safety.

9. The low macrotexture depth at the accident site prevented proper drainage of the water from the roadway, allowing excessive water to remain on the road surface, which, in turn, contributed to its minimal frictional qualities.

10. A rut-depth threshold of 0.50 inch is insufficient because 0.50 inch exceeds the tread depths of most vehicle tires, and standing water in the ruts can lead to reduced tire-roadway friction situations in wet weather.

11. The greater rut depth in the left wheel path and the differential friction between the wheelpaths resulted in a destabilizing counterclockwise rotational force on the motorcoach.

12. The motorcoach did not hydroplane before losing control.

13. The water accumulation on the roadway, likely due to the low macrotexture depth, rutting, and inadequate cross slope, contributed to the loss of available friction between the tire and the road.

14. The Texas Department of Transportation's Pavement Management Information System does not adequately identify roadways where hazardous conditions exist due to low coefficients of friction and does not expeditiously prioritize these locations for rehabilitation, increasing the risk for accidents such as the one that occurred at this location.

15. The minimum tread depths of the drive axle tires, including the smaller tread depth on the left drive axle tires, particularly in combination with the nearly new front tires, contributed to wheel lockup and the subsequent rotation of the motorcoach.

16. The minimal friction available to the tires and on the roadway combined to cause the motorcoach to lose control when the driver attempted to maneuver to avoid stopped traffic.

17. To prevent accidents similar to this one, commercial vehicle tire-roadway interaction, which is not currently being considered, must be taken into account when determining the necessary wet pavement friction of the roadway and tread depth minimums.

18. Texas's Wet Weather Accident Reduction Program methodology is not sufficiently refined to measure wet weather accident risk, fails to identify the greater risk of being involved in a wet weather accident on the segment of Interstate 35 in the vicinity of the accident, and, generally, does not identify problems in a timely manner.

19. Federal guidance on identifying and eliminating locations with wet weather accident problems is limited; had more comprehensive guidance existed, Texas may have implemented a more robust Wet Weather Accident Reduction Program.

20. The lack of motorcoach occupant protection systems to retain passengers in their seating compartments during the accident sequence contributed to passengers being partially or fully ejected from the motorcoach and to their serious and fatal injuries due to contact with non-occupant-protected surfaces, other passengers, or surfaces outside of the motorcoach.

21. Despite the peak deceleration experienced by the passengers of the Chevrolet Suburban (about 46.8 g, as found during the simulation), the passenger in the rear seat quite likely sustained serious, rather than fatal, injuries, because of the protection provided by the lap/shoulder belt and the limited crush that occurred within his seating area.

## Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was Texas's decision to set a speed limit on Interstate 35, in the vicinity of the accident, that did not take into account the roadway's limited sight distance or its poor conditions in wet weather; as a result, the bus driver was unable to detect the stopped vehicles as he approached the traffic queue and lost control of the motorcoach due to low pavement friction. Exacerbating the poor roadway conditions were the minimum tread depths on the motorcoach's drive axle tires and differing tread depths on its front and rear tires, both of which were allowed under the *Federal Motor Carrier Safety Regulations* but reduced the friction available to the motorcoach. Contributing to the severity of the accident were the lack of a temporary or permanent median barrier, which might have redirected the motorcoach or reduced the speed at which it crossed the median into the southbound lanes, and the lack of an occupant protection system for the motorcoach passengers.

# Recommendations

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

### To the Federal Highway Administration:

Issue guidance to your field offices describing the inadequate stopping sight distance that could occur when poor vertical geometries exist at locations with low coefficients of friction and speeds higher than the design speed and work with the States to inventory such locations. (H-05-12)

Once the locations in Safety Recommendation H-05-12 have been identified, assist the States in developing and implementing a plan for repaving or other roadway improvements. (H-05-13)

Issue guidance recommending the use of variable speed limit signs in wet weather at locations where the operating speed exceeds the design speed and the stopping distance exceeds the available sight distance. (H-05-14)

Conduct research on commercial vehicle tire and wet pavement surface interaction to determine minimum frictional quality standards for commercial tires on wet pavement; once completed, 1) revise the tire requirements for commercial vehicles operating on wet pavement at highway speeds, and 2) develop minimum acceptable pavement coefficients of friction and maximum permissible pavement rut depths as part of roadway maintenance requirements, as appropriate. (H-05-15)

Review State programs that identify and eliminate locations with a high risk of wet weather accidents and develop and issue a best practices guide on wet weather accident reduction. (H-05-16)

### To the National Highway Traffic Safety Administration:

Conduct testing on the effects of differing tread depths for the steer and drive axle tires. (H-05-17)

### To the Federal Motor Carrier Safety Administration:

Once the testing in Safety Recommendation H-05-17 is complete, modify the tread depth requirements for each axle to reflect the results of the research. (H-05-18)

**To the Texas Department of Transportation:**

> Inventory highway locations where poor vertical geometries, combined with low coefficients of friction and speeds greater than the design speed of the roadway, may create a situation in which traffic has inadequate stopping sight distance, and develop and implement a plan for repaving or other roadway improvements. (H-05-19)
>
> Install variable speed limit signs or implement alternate countermeasures at locations where wet weather can produce stopping distances that exceed the available sight distance. (H-05-20)
>
> Change the Pavement Management Information System to increase its emphasis on roadways with low coefficients of friction in determining maintenance priorities. (H-05-21)
>
> Revise and validate your Wet Weather Accident Reduction Program so that improvement priorities are not disproportionately influenced by the number of accidents that occur but also consider locations where surface conditions and roadway geometry lead to very low friction coefficients and dangerous conditions. (H-05-22)

## BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Member

**Adopted: July 12, 2005**

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# Appendix A

## Investigation

The National Transportation Safety Board was notified of the Hewitt, Texas, accident on February 14, 2003. The Safety Board dispatched an investigative team consisting of members from the Washington, D.C.; Atlanta, Georgia; and Fort Worth, Texas, offices. Groups were established to investigate human performance; motor carrier operations; and highway, vehicle, and survival factors and to conduct on-scene documentation.

Representatives of the Texas Department of Transportation, the Texas Department of Public Safety, Central Texas Trails, Motor Coach Industries, and Bendix Commercial Vehicle Systems, LLC, participated in the investigation.

No public hearing was held; no depositions were taken.

# Appendix B

## Recommendation History

## Tire Tread Depth

### *Luling, Texas—November 16, 1980*

On November 16, 1980, the Safety Board investigated a motorcoach accident near Luling, Texas, in which the motorcoach lost traction on the wet pavement and skidded off the road.[1] The Safety Board determined that the probable cause of the accident was the low wet cornering capability of the marginal, yet "legal," rear bus tires and the low frictional quality of the wet pavement, which combined to produce loss of rear tire traction and vehicle control as the bus was being operated at or near the posted 55 mph speed limit.

As a result of that accident, the Safety Board recommended that the National Highway Traffic Safety Administration (NHTSA):

> H-81-33
>
> Accelerate activity to establish rulemaking action for minimum frictional quality standards for commercial vehicle tires.

This recommendation was classified "Closed—Unacceptable Action" on August 21, 1986.

The Safety Board also recommended that the Texas Department of Public Safety (Texas DPS):

> H-81-41
>
> Reevaluate tire tread depth inspection criteria that limits the tread depth criteria to only one tire in each set of dual wheels while permitting that tire to have less than 2/32 inch of tread depth in the shoulder grooves at the same time.

On June 20, 1983, the Texas DPS responded that the inspection requirement of 2/32 inch applies to both tires on a dual set of wheels. A December 7, 1983, letter indicated that the Texas DPS would adhere to the standards prescribed by the U.S.

[1] National Transportation Safety Board, *East Side Church of Christ Bus Skid and Overturn U.S. Route 183 Near Luling, Texas, November 16, 1980,* Highway Accident Report NTSB/HAR-81/04 (Washington, DC: NTSB, 1981).

Standards Institute for Highway Traffic Safety but would continue to study the tread depth criteria. On March 6, 1995, because of a lack of relevant information from the Texas DPS, Safety Recommendation H-81-41 was classified "Closed—Unacceptable Action."

### *Beaumont, Texas—May 4, 1987*

On May 4, 1987, a tractor-semitrailer jackknifed on wet pavement near Beaumont, Texas, crossed the median, and struck a motorcoach, resulting in six fatalities.[2] The Safety Board determined that tractor likely jackknifed or partially hydroplaned because the rear tractor tires were in poor condition with minimal tread depth and low tire pressures, which resulted in reduced cornering and braking forces. As a result of that accident, the Safety Board recommended that the Federal Highway Administration (FHWA):

> H-88-1
>
> Revise Sections 393.75(B) and (C) of the *Federal Motor Carrier Safety Regulations* to prohibit the use of tires worn below 4/32 inch on any axle of a commercial interstate vehicle.
>
> H-88-2
>
> Issue an On-Guard Bulletin to advise owners, operators, maintenance personnel, and State commercial vehicle inspectors of the problems associated with operating vehicles equipped with tires worn below 4/32 inch tread groove depths.

On August 25, 1988, the FHWA responded that, in late 1987, it had identified the "hydroplaning of heavy vehicles" as a high-priority national problem area for research, which the FHWA believed should provide a basis for determining minimum tread depth standards. However, the FHWA stated that because of budget constraints, research on hydroplaning could not begin until 1991. Because of the FHWA's inaction on this critical safety issue, on May 19, 1989, the Safety Board classified Safety Recommendations H-88-1 and -2 "Closed—Unacceptable Action." No further research was conducted in 1991.

The Safety Board also recommended that the United Bus Owners of America, the American Bus Association, and the American Trucking Associations, Inc.:

> H-88-5
>
> Advise members of the circumstances of the May 4, 1987, accident in Beaumont, Texas, and the potential vehicle handling problems that may be encountered with using tires with marginal tread depth.

[2] National Transportation Safety Board, *Tractor-Semitrailer/Intercity Bus Head-on Collision Interstate 10, Beaumont, Texas, May 4, 1987*, Highway Accident Report NTSB/HAR-88/01 (Washington, DC: NTSB, 1988).

Both the American Trucking Associations, Inc., and the United Bus Owners of America provided the information to their members; the recommendation was consequently classified "Closed—Acceptable Action" for the American Trucking Associations, Inc., on July 25, 1988, and for the United Bus Owners of America on June 28, 1988. There is no record of a response from the American Bus Association.

## Pavement Friction

The Safety Board has made numerous recommendations regarding pavement surface conditions and pavement friction.

### *Bethesda, Maryland—October 11, 1975*

On October 11, 1975, a motorcoach lost traction on a wet roadway near Bethesda, Maryland.[3] The vehicle began to slide and then rolled over, injuring 26 occupants. As a result of its accident investigation, the Safety Board recommended that the FHWA:

> H-76-24
>
> Establish minimum skid resistance values both for newly constructed and for existing pavement surfaces. Such minimum values must provide an acceptable margin of safety to accommodate all vehicle types under normal as well as predictable emergency maneuvering, and should consider the known varieties of commercial tire rubber compounds and the relationship of design speed and highway geometrics. After the minimum skid resistance values are determined, revise applicable highway design and pavement maintenance manuals accordingly.

The FHWA responded that skid resistance is an extremely complex and technically controversial subject, noting that States must individually evaluate pavement design and construction and maintenance practices to ensure that skid resistance properties are suitable for the traffic and must establish procedures to identify and correct skid-prone locations. Further, the FHWA wrote that it could not correlate skid test results between States; thus, evaluating skid resistance nationally is not feasible. Safety Recommendation H-76-24 was "Closed—Superseded" on October 7, 1976, by Safety Recommendations H-80-23, -52, and -56, issued as a result of the Safety Board's 1980 skid resistance study.[4]

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[3] National Transportation Safety Board, *Special Investigation—Metropolitan Coach Corporation, Charter Bus Accident, Bethesda, Maryland, October 11, 1975,* Highway Accident Report NTSB/HAR-76/06 (Washington, DC: NTSB, 1976).

[4] National Transportation Safety Board, *State Highway Skid Resistance Programs*, Safety Effectiveness Evaluation NTSB/SEE-80/06 (Washington, DC: NTSB, 1980).

Also as a result of the Bethesda accident investigation,[5] the Safety Board recommended that NHTSA:

H-76-25

Compare frictional coefficients obtained with a commercial vehicle tire to that obtained with an ASTM E-274 skid-test tire and publish findings. Also, determine whether there is a greater tendency for commercial truck and bus tires than passenger car tires to lose traction on wet pavement.

H-76-26

Develop a Federal Motor Vehicle Safety Standard to require a minimum frictional coefficient for all commercial motor vehicle tires.

NHTSA responded that it had completed the testing and found significant differences in design and load ratings between commercial vehicle and passenger car tires; further, although commercial tires displayed no greater tendency to lose traction on wet pavement, a greater tendency to lose traction does exist on dry pavement or ice. As a result, Safety Recommendation H-76-25 was classified "Closed—Acceptable Response" on January 2, 1986.

NHTSA also responded that it concurred with Safety Recommendation H-76-26 and that, although it was addressing higher priority items, it would continue to collect data on truck tire traction. Based on NHTSA's response, Safety Recommendation H-76-26 was classified "Closed—Acceptable Alternate Action" on April 5, 2001. No standards were developed.

### *Scipio, Utah—August 26, 1977*

On August 26, 1977, near Scipio, Utah, a van and truck tractor-semitrailer collided head-on during a moderate-to-heavy rainstorm, killing eight passengers in the van.[6] The Safety Board recommended that NHTSA:

H-79-6

Examine the full potential effect of fluctuating and progressively lower pavement frictional quality on vehicle performance.

On April 20, 1979, NHTSA responded that it had an ongoing effort to develop data on commercial tire traction characteristics. On July 15, 1991, NHTSA wrote that it would explore options for implementing a task force's recommendation that a standardized measurement procedure be developed, noting that full-scale testing could then be

[5] NTSB/HAR-76/06.

[6] National Transportation Safety Board, *Osterkamp Trucking, Inc., Truck/Full Trailer and Dodge Van Collision, U.S. 91, Near Scipio, Utah, August 26, 1977,* Highway Accident Report NTSB/HAR-79/01 (Washington, DC: NTSB, 1979).

conducted to establish a database of pertinent tire characteristics that could serve as input to vehicle dynamics models and as benchmarks for vehicle component design. Based on this response, Safety Recommendation H-79-6 was classified "Closed—Acceptable Action" on July 15, 1991.

As a result of the same accident, the Safety Board recommended that the FHWA:

H-79-7

Evaluate the procedures used in the Safety Board's investigation of this accident [testing friction of both left and right wheel tracks] for possible inclusion in FHWA guidelines for determining the frictional quality of pavements during pavement inventory programs.

The FHWA responded on September 19, 1979, that it uses the ASTM E-274 test procedure, which calls for the testing of the center of the left wheel track to provide a skid number, and that testing both wheel tracks is impractical. On February 12, 1980, the FHWA wrote that it had not found evidence that different friction levels between the left and right wheel tracks causes a significant increase in accidents. The FHWA stated that it would advise the States it favors having skid testers equipped to test both wheel tracks and that such testing is advisable when investigating high-accident sites. Safety Recommendation H-79-7 was classified "Closed—Acceptable Action" on April 4, 1980.

## Skid Accident Prevention

### *State Highway Skid Resistance Programs Study—1980*

In 1980, the Safety Board concluded a nationwide study on improvements in skid resistance standards.[7] The study identified the magnitude, location, and characteristics of fatal accidents on wet pavement by analyzing national accident and weather data. The data indicated that fatal accidents occur about four times more often on wet pavement than might be expected. The data also identified States with a significantly higher than expected percentage of fatal accidents on wet pavement. As a result of its study, the Safety Board recommended that the FHWA:

H-80-21

In conjunction with the National Oceanic and Atmospheric Administration, provide weather data to Federal, State, and local agencies, and promote and use these data to reduce accidents on wet pavement.

[7] National Transportation Safety Board, *State Highway Skid Resistance Programs*, Safety Effectiveness Evaluation NTSB/SEE-80/06 (Washington, DC: NTSB, 1980).

H-80-22

Promote further research into the relationship of wet-pavement accidents (1) to low void ratios in pavement surface mixes, (2) to highway construction materials, and (3) to artificial light conditions.

H-80-23

Test the use of the Wet Fatal Accident Index (WFAI) as an aid to identify and evaluate State programs aimed at reducing accidents on wet pavement.

The FHWA responded on August 18, 1981, to all three safety recommendations. The FHWA stated that it believed decisions on the source and use of weather data rested with State officials. The FHWA further stated that it was investigating pavement surface texture parameters to determine whether they could be used to better describe skid resistance characteristics, noting that once the parameters of microtexture and macrotexture were more definitively understood, they could be better correlated with wet pavement accidents. The FHWA also stated that several other pavement surface texture studies were ongoing. The FHWA further wrote that the States could develop their own programs to identify high-accident locations, using the WFAI or a similar program. Based on the FHWA's response, Safety Recommendations H-80-21 and -22 were classified "Closed—Acceptable Action," and Safety Recommendation H-80-23 was classified "Closed—Acceptable Alternate Action" on November 13, 1981.

In its 1980 skid resistance study,[8] the Safety Board also evaluated the safety effectiveness of a sample of State highway programs. As a result, the Safety Board recommended that the FHWA:

H-80-52

Develop program objectives for comprehensive wet weather skid resistance programs that can be used to both guide and evaluate State programs.

The FHWA responded on April 26, 1982, that it had supplied a technical advisory to the States, *Skid Accident Reduction Program*. Based on this action, Safety Recommendation H-80-52 was classified "Closed—Acceptable Action" on January 19, 1983.

Also as a result of its skid resistance study,[9] the Safety Board recommended that the FHWA:

[8] NTSB/SEE-80/06.

[9] NTSB/SEE-80/06.

H-80-54

Issue a revised Federal-Aid Highway Program Manual (FHPM 6.2.4.3) which promotes (1) full width surface treatments, (2) skid trailers with left and right wheel locking capabilities, (3) skid testing at the posted speed limit, as proposed in the FHWA NPRM "Skid Resistance Pavement Surface Design," (4) evaluation of the skid resistance properties of all newly developing surface treatments, and (5) increased Federal participation on skid resistance projects.

H-80-55

To assure comprehensive, coordinated skid resistance programs, promote further research to examine (1) the measurement of rutting and its effects on wet pavement accidents; (2) more effective signing system to advise motorists of safe speeds on slippery, rutted, or poorly drained wet surfaces and on all new surfaces; (3) use of tire tread depths more representative on those used by motorists to measure skid resistance; and (4) the effect on skid resistance of immediately allowing heavy truck traffic on newly constructed or newly overlayed surfaces.

H-80-56

Develop a program to enhance dissemination of and the sharing among States of skid resistance information. Elements of the program should include: (1) the compilation of an instructional text for a state-of-the-art manual for Federal, State, local, and county agencies; (2) periodic regional meetings to review skid resistance research and successful operating programs; and (3) periodic publication of a description of State programs and current research studies on skid resistance.

The FHWA responded to these recommendations on September 13, 1985, after conducting a survey of the States on skid resistance. The FHWA stated (1) that it had issued a memorandum to field offices advising action to eliminate partial width resurfacing, (2) that it recommends both wheel paths be tested when evaluating high-accident sites, (3) that it believes skid testing in accordance with ASTM Standard E274 at 40 mph is a reliable tool for inventory purposes and identifying skid-prone locations, (4) that current policy and guidance indicate the States should evaluate their pavements, and (5) that since Federal-Aid participation is dictated by law, situations outside of Federal-Aid participation would require the FHWA to recommend to Congress that "slippery pavements" be given priority over other safety improvement programs. Based on this response, Safety Recommendation H-80-54 was classified "Closed—Acceptable Alternate Action," and Safety Recommendation H-80-56 was classified "Closed—Superseded" by Safety Recommendation H-82-34, issued as a result of the Safety Board's 1980 study on wet pavement accidents.[10]

[10] National Transportation Safety Board, *Fatal Highway Accidents on Wet Pavement, the Magnitude, Location, and Characteristics*, Highway Safety Study NTSB/HSS-80/01 (Washington, DC: NTSB, 1980).

The FHWA also responded on September 13, 1985, that (1) the measurement of rutting on a large-scale basis had just become possible and testing was underway, with planned completion in March 1986; (2) the development of signing systems had reached an impasse because of the cost and reliability of such systems; (3) truly representative tire depths can change rapidly, and by using testing standards for both ribbed and smooth tires, the pavement's macrotexture and microtexture can be measured; and (4) no evidence exists that heavy traffic on fresh asphalt pavement causes skidding problems. On May 18, 1988, the FHWA wrote that a system had been developed and tested to inventory roadway topography and the extent of water ponding and depth of flow at various rainfall rates. The letter also stated that the FHWA was sponsoring a research study to evaluate a prototype variable speed limit sign. Consequently, on May 18, 1988, Safety Recommendation H-80-55 was classified "Closed—Acceptable Action."

### *Luling, Texas—November 16, 1980*

Recommendations regarding pavement condition were also issued as a result of the Luling, Texas, accident investigation.[11] The Safety Board recommended that the FHWA:

> H-81-39
>
> Evaluate Pennsylvania Department of Transportation policies for the placement of "Slippery When Wet" signs and the detection and correction of potential wet pavement problem locations for national policy purposes.

On November 17, 1982, the FHWA responded that it had reviewed documents on Pennsylvania's policies for improving sites with low skid resistance and that they satisfactorily implement the FHWA's advisory on the elements of a skid accident reduction program. Based on this action, Safety Recommendation H-81-39 was classified "Closed—Acceptable Action" on January 27, 1983.

## Notice of Proposed Rulemaking, "Skid Resistant Pavement Surface Design"

On March 4, 1982, the FHWA announced the withdrawal of its Notice of Proposed Rulemaking (NPRM) on "Skid Resistant Pavement Surface Design." This rulemaking, initiated in November 1977, solicited comments on the broad issue of skid-resistant pavement surfaces and wet pavement accident reduction. In April 1980, the scope of the rulemaking was narrowed to a few areas with the potential to significantly reduce accidents on wet pavement. In part, the rulemaking would have required aggregates from acceptable prequalified sources, analysis of wet pavement data, and, as stated in the NPRM, "periodic review of State highway agency practices relating to skid resistant pavement surfaces" to ensure that the skid-resistant pavement surfaces were maintained.

[11] NTSB/HAR-81/04.

In response to the withdrawal, the Safety Board recommended in its 1980 study on wet pavement accidents[12] that the FHWA:

> H-82-34
>
> Conduct and publish a comprehensive review of each State's Skid Accident Reduction Program to identify problem areas, to develop corrective recommendations where necessary, and to disseminate more widely innovative local practices of proven value and general applicability.

The Safety Board classified Safety Recommendation H-82-34 "Closed—Acceptable Action" on July 28, 1988.

## Motorcoach Occupant Protection Systems

The Safety Board's 1999 bus crashworthiness study[13] found that one of the primary causes of preventable injury in motorcoach accidents was occupant motion out of the seat during a collision. As a result of this study, the Safety Board recommended that NHTSA:

> H-99-47
>
> In 2 years, develop performance standards for motorcoach occupant protection systems that account for frontal impact collisions, side impact collisions, rear impact collisions, and rollovers.
>
> H-99-48
>
> Once pertinent standards have been developed for motorcoach occupant protection systems, require newly manufactured motorcoaches to have an occupant crash protection system that meets the newly developed performance standards and retains passengers, including those in child safety restraint systems, within the seating compartment throughout the accident sequence for all accident scenarios.

On October 27, 2000, NHTSA responded that it had initiated a research plan in conjunction with motorcoach manufacturers to support the motorcoach crashworthiness recommendations, which were subsequently classified "Open—Acceptable Response," on April 18, 2001. On August 28, 2001, following the Board's investigation of a motorcoach accident in New Orleans, Louisiana,[14] in which 10 of the 22 passengers who died had been ejected from the bus, the Safety Board reiterated Safety Recommendations H-99-47 and -48 to NHTSA. In its report on the New Orleans accident, the Safety Board noted that it

[12] NTSB/HSS-80/01.

[13] National Transportation Safety Board, *Bus Crashworthiness Issues*, Highway Special Investigation Report NTSB/SIR-99/04 (Washington, DC: NTSB, 1999).

[14] National Transportation Safety Board, *Motorcoach Run-off-the-Road, New Orleans, Louisiana, May 9, 1999*, Highway Accident Report NTSB/HAR-01/01 (Washington, DC: NTSB, 2001).

had identified occupant protection issues similar to those discussed in the *Bus Crashworthiness Issues* report. On March 6, 2002, NHTSA advised the Safety Board that it helped organize the Bus Manufacturers Council to create industry-wide standards to enhance motorcoach safety. NHTSA also stated that it had sponsored a motorcoach public safety meeting on April 30, 2002. However, by the time the Safety Board's report on the Victor, New York, accident[15] had been adopted on June 22, 2004, little progress had been made on these recommendations, and they were again reiterated.

In a June 3, 2004, meeting, NHTSA reported that it is currently focusing on roof crush and window retention technology to help prevent ejections. In June 2004, Transport Canada issued a report on motorcoach window retention and the forces generated by occupants on window retention. In an October 5, 2004, letter, NHTSA stated it is building upon the results of Transport Canada's report and is developing a program to test motorcoach windows and the surrounding structure to determine feasible occupant protection improvements using advanced glazing materials and bonding techniques, as well as evaluating the structure's role in window retention. NHTSA expects to complete the research by September 2006. Therefore, on March 18, 2005, the Safety Board classified Safety Recommendations H-99-47 and -48 "Open–Acceptable Action," pending development of industry-wide standards for occupant protection.

## FMCSA and Surface Deployment and Distribution Command Inspections

On June 23, 2002, near Victor, New York, a motorcoach, operated by Arrow Line, Inc. (Arrow), departed the roadway and crashed, killing 5 passengers and injuring 41.[16] Arrow had undergone inspections by the Military Traffic Management Command (MTMC)[17] and serious violations and operational deficiencies were noted, yet this information was not transmitted to the FMCSA, nor was it required to be. Consequently, Arrow continued to operate with a satisfactory rating from the FMCSA. As a result of the investigation, the Safety Board recommended that the FMCSA:

> <u>H-04-20</u>
>
> Utilize motor carrier safety information, including results of compliance audit reports provided by the U.S. Department of Defense Surface Deployment and Distribution Command, to determine whether further review of a motor carrier is warranted.

[15] National Transportation Safety Board, *Motorcoach Run-off-the-Road and Overturn, Victor, New York, June 23, 2002,* Highway Accident Report NTSB/HAR-04/03 (Washington, DC: NTSB, 2004).

[16] NTSB/HAR-04/03.

[17] Now the Surface Deployment and Distribution Command (SDDC).

The Safety Board also recommended that the SDDC:

H-04-21

> Provide motor carrier information, including timely results of passenger carrier inspection processes and ratings, to the Federal Motor Carrier Safety Administration.

On October 13, 2004, the FMCSA replied that the SDDC now forwards to the FMCSA copies of all compliance audits for carriers with the lowest ratings, which would indicate serious safety violations. FMCSA headquarters staff review these compliance audits and forward them to the appropriate field offices for investigation. The SDDC sent a similar response on August 23, 2004, noting that it is coordinating with the FMCSA to meet periodically to discuss inspection criteria and further promote communications between the two agencies. Based on these actions, the Safety Board classified Safety Recommendation H-04-20 “Closed—Acceptable Action” on April 1, 2005, and Safety Recommendation H-04-21 “Closed—Acceptable Action” on February 15, 2005.

# Appendix C

## Tire Friction Testing Results

| Tire | Minimum tread depth | Velocity (mph) | Water depth (inches) | Longitudinal coefficient of friction | Peak longitudinal friction | Average peak lateral friction | Cornering stiffness (lbs/deg) | Cornering stiffness coefficient* |
|---|---|---|---|---|---|---|---|---|
| Left front | 14/32 | 60 | 0.02 | - | - | - | - | - |
| | | 60 | 0.11 | 0.27 | 0.52 | 0.46 | 888 | 0.161 |
| | | 60 | 0.19 | - | - | - | - | - |
| Right front | 15/32 | 40 | 0.02 | 0.53 | 0.68 | 0.74 | 888 | 0.181 |
| | | 40 | 0.11 | 0.25 | 0.54 | 0.70 | 914 | 0.166 |
| | | 40 | 0.19 | - | - | 0.70 | 998 | 0.162 |
| | | 60 | 0.02 | 0.30 | 0.65 | 0.61 | 936 | 0.170 |
| | | 60 | 0.11 | 0.29 | 0.48 | 0.54 | 782 | 0.142 |
| | | 60 | 0.19 | 0.28 | 0.49 | 0.46 | 706 | 0.128 |
| | | 70 | 0.02 | 0.24 | 0.57 | 0.51 | 891 | 0.162 |
| | | 70 | 0.11 | 0.25 | 0.41 | 0.40 | 686 | 0.125 |
| | | 70 | 0.19 | 0.22 | 0.40 | 0.29 | 617 | 0.112 |
| Left outer drive | 3/32 | 40 | 0.02 | 0.26 | 0.64 | - | - | - |
| | | 40 | 0.11 | 0.25 | 0.54 | - | - | - |
| | | 40 | 0.19 | 0.25 | 0.55 | - | - | - |
| | | 60 | 0.02 | - | - | - | - | - |
| | | 60 | 0.11 | 0.12 | 0.21 | 0.23 | 542 | 0.100 |
| | | 60 | 0.19 | - | - | - | - | - |
| | | 70 | 0.02 | - | - | - | - | - |
| | | 70 | 0.11 | - | - | - | - | - |
| | | 70 | 0.19 | - | - | - | - | - |
| Left inner drive | 2/32 | 40 | 0.02 | - | - | 0.54 | 1099 | 0.204 |
| | | 40 | 0.11 | 0.24 | 0.60 | 0.49 | 976 | 0.181 |

| Tire | Minimum tread depth | Velocity (mph) | Water depth (inches) | Longitudinal coefficient of friction | Peak longitudinal friction | Average peak lateral friction | Cornering stiffness (lbs/deg) | Cornering stiffness coefficient* |
|---|---|---|---|---|---|---|---|---|
| | | 40 | 0.19 | 0.28 | 0.57 | 0.48 | 961 | 0.178 |
| | | 60 | 0.02 | 0.15 | 0.37 | 0.31 | 734 | 0.136 |
| | | 60 | 0.11 | 0.12 | 0.27 | 0.24 | 489 | 0.091 |
| | | 60 | 0.19 | 0.10 | 0.24 | 0.20 | 494 | 0.091 |
| | | 70 | 0.02 | 0.12 | 0.26 | 0.20 | 571 | 0.106 |
| | | 70 | 0.11 | 0.09 | 0.17 | 0.12 | 280 | 0.052 |
| | | 70 | 0.19 | 0.10 | 0.14 | 0.09 | 217 | 0.040 |
| Right outer drive | 6/32 | 40 | 0.02 | 0.27 | 0.59 | - | - | - |
| | | 40 | 0.11 | - | - | - | - | - |
| | | 40 | 0.19 | - | - | - | - | - |
| | | 60 | 0.02 | - | - | - | - | - |
| | | 60 | 0.11 | 0.12 | 0.23 | 0.26 | 569 | 0.105 |
| | | 60 | 0.19 | - | - | - | - | - |
| | | 70 | 0.02 | - | - | - | - | - |
| | | 70 | 0.11 | - | - | - | - | - |
| | | 70 | 0.19 | - | - | - | - | - |
| Right inner drive | 5/32 | 40 | 0.02 | 0.29 | 0.66 | 0.55 | 1059 | 0.196 |
| | | 40 | 0.11 | 0.28 | 0.58 | 0.50 | 936 | 0.173 |
| | | 40 | 0.19 | 0.27 | 0.59 | 0.50 | 932 | 0.173 |
| | | 60 | 0.02 | 0.16 | 0.34 | 0.30 | 774 | 0.143 |
| | | 60 | 0.11 | 0.13 | 0.27 | 0.24 | 546 | 0.101 |
| | | 60 | 0.19 | 0.12 | 0.23 | 0.16 | 559 | 0.104 |
| | | 70 | 0.02 | 0.12 | 0.24 | 0.22 | 631 | 0.117 |
| | | 70 | 0.11 | 0.09 | 0.18 | 0.15 | 352 | 0.065 |
| | | 70 | 0.19 | 0.09 | 0.17 | 0.09 | 260 | 0.048 |

*The cornering stiffness coefficient was derived as the tire turned from 0 to 1 degree.