Derailment and Hazardous Materials Release of Union Pacific Railroad Unit Ethanol Train Graettinger, Iowa March 10, 2017

Accident Report

NTSB/RAR-18/02
PB2019-100084

National
Transportation
Safety Board

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Railroad Accident Report

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National Transportation Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

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Abstract: On March 10, 2017, about 12:50 a.m., central standard time, an eastbound Union Pacific Railroad (UP) unit ethanol train with 3 locomotives, 98 loaded tank cars, and 2 buffer cars derailed near milepost 56.8 at a timber railroad bridge near Graettinger, Iowa. Twenty loaded tank cars derailed. Fourteen of the derailed tank cars released about 322,000 gallons of undenatured ethanol, ethyl alcohol without a denaturant added to it, fueling a postaccident fire. The accident occurred near Jack Creek. There were no injuries and three nearby homes were evacuated. About 400 feet of railroad track and a 152-foot railroad bridge were destroyed in the accident. UP estimated damages, excluding environmental remediation or the cost of clearing the accident, at $4 million.

The investigation focused on the following safety issues: the adequacy of UP's track maintenance and inspection program, the adequacy of the Federal Railroad Administration's (FRA) oversight, and the transportation of fuel ethanol without the use of volatile organic chemical denaturants. As a result of this investigation, the National Transportation Safety Board (NTSB) makes new safety recommendations to the FRA, the Pipeline and Hazardous Materials Safety Administration (PHMSA) and UP. The NTSB is also reiterating an existing safety recommendation to PHMSA.

For more detailed background information on this report, visit http://www.ntsb.gov/investigations/dms.html and search for NTSB accident ID DCA17MR007. Recent publications are available in their entirety on the Internet at http://www.ntsb.gov. Other information about available publications also may be obtained from the website or by contacting:

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Abbreviations and Acronyms

AAR	Association of American Railroads
AFP	alcohol fuel plant
Amtrak	National Railroad Passenger Corporation
AREMA	American Railway Engineering and Maintenance-of-Way Association
BTS	Bureau of Transportation Statistics
CFR	*Code of Federal Regulations*
CN	Canadian National Railroad
CORTEX	Crude Oil Route Track Examination
CPC-1232	Casualty Prevention Circular-Specification-1232 Tank Car
CWR	continuously welded rail
DOT	US Department of Transportation
DOT-111	US Department of Transportation Specification-111 Tank Car
DOT-117	US Department of Transportation Specification-117 Tank Car
DPU	distributed power unit
EERC	Ethanol Emergency Response Coalition
EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
FAST Act	Fixing America's Surface Transportation Act
FE	finite element
FR	*Federal Register*
FRA	Federal Railroad Administration
FY	fiscal year
GRL	gross rail load

GRMS	gage restraint measurement system
HMR	Hazardous Materials Regulations
HHFT	high hazard flammable train
Iowa DNR	Iowa Department of Natural Resources
kpsi	kilo-pounds-per-square-inch
MGT	million-gross tonnage
MP	milepost
MTM	manager of track maintenance
NIMS	National Incident Management System
NIP	National Inspection Plan
NTSB	National Transportation Safety Board
PADD	Petroleum Administration for Defense Districts
PHMSA	Pipeline and Hazardous Materials Safety Administration
POD	point of derailment
psi	pounds-per-square-inch
RA	FRA regional administrator
RFA	Renewable Fuels Association
RFS	Renewable Fuel Standard
RIN	renewable identification numbers
RIP	Regional Inspection Plan
TSS	track safety standards
TTB	Alcohol and Tobacco Tax and Trade Bureau
UMLER	Universal Machine Language Equipment Register
UN	United Nations
UP	Union Pacific Railroad

USC	*United States Code*
YTD	year-to-date

Executive Summary

On March 10, 2017, about 12:50 a.m., central standard time, eastbound Union Pacific Railroad unit ethanol train, UEGKOT-09, with 3 locomotives, 98 loaded tank cars, and 2 buffer cars filled with sand derailed near milepost 56.8 at a timber railroad bridge near Graettinger, Iowa. Twenty loaded tank cars in positions 21 through 40 derailed. Fourteen of the derailed tank cars released about 322,000 gallons of undenatured ethanol, ethyl alcohol without a denaturant added to it, fueling a postaccident fire. The accident occurred near Jack Creek, a tributary of the Des Moines River. There were no injuries and three nearby homes were evacuated. About 400 feet of railroad track and a 152-foot railroad bridge were destroyed in the accident. Union Pacific Railroad estimated damages, excluding environmental remediation or the cost of clearing the accident, at $4 million. At the time of the accident, the wind was from the northwest at 17 mph gusting to 30 mph, visibility was 10 miles, and the temperature was 10°F.

The following are safety issues in this accident:

- Adequacy of Union Pacific Railroad's track maintenance and inspection program
- Adequacy of the Federal Railroad Administration's oversight
- Transportation of fuel ethanol without the use of volatile organic chemical denaturants

The National Transportation Safety Board determines that the probable cause of the derailment was a broken rail that occurred as the train was traveling over the west approach of the Jack Creek Bridge resulting from Union Pacific Railroad's inadequate track maintenance and inspection program and the Federal Railroad Administration's inadequate oversight of the application of federal track safety standards. Contributing to the consequences of this accident was the continued use of US Department of Transportation Specification-111 tank cars.

1 Factual Information

1.1 Accident Synopsis

On March 10, 2017, about 12:50 a.m., central standard time, eastbound Union Pacific Railroad (UP) unit ethanol train, UEGKOT-09, with 3 locomotives, 98 loaded tank cars, and 2 buffer cars filled with sand derailed near milepost (MP) 56.8 at a timber railroad bridge on the Estherville Subdivision, near Graettinger, Iowa.[1] Twenty loaded tank cars in positions 21 through 40 derailed. Fourteen of the derailed tank cars released about 322,000 gallons of undenatured ethanol, fueling a postaccident fire.[2] The accident occurred near Jack Creek, a tributary of the Des Moines River. There were no injuries and three nearby homes were evacuated. About 400 feet of railroad track and a 152-foot railroad bridge were destroyed in the accident. UP estimated damages at $4 million.[3] At the time of the accident, the wind was from the northwest at 17 mph gusting to 30 mph, visibility was 10 miles, and the temperature was 10°F. Figure 1 shows an aerial view of the accident.

[1] (a) All times in this accident report are central standard time. (b) According to Railway Age's Comprehensive Railroad Dictionary, a *unit train* is a train transporting a single commodity from one source to one destination in accordance with an applicable tariff and with assigned cars (Lewis and Others 1992); (c) Title 49 *Code of Federal Regulations* (*CFR*) Part 237.5, "Definitions," defines *railroad bridge* as any structure with a deck, regardless of length, which supports one or more railroad tracks, or any other undergrade structure with an individual span length of 10 feet or more located at such a depth that it is affected by live loads.

[2] *Undenatured ethanol* refers to pure ethyl alcohol without a denaturant added to it.

[3] This estimate does not include environmental remediation or the cost of clearing the accident.

Figure 1. The accident site.

1.2 The Accident

The train originated from the Green Plains Superior, LLC (Green Plains) ethanol plant in Superior, Iowa, as UP train UEGKOT-09 (accident train) on March 9, 2017. The Superior, Iowa, facility is situated on 238 acres, with 35,141 feet of track. The Green Plains facility has a single loading rack and two storage tanks for intermediate storage of denatured or undenatured ethanol. (See figure 2.)

Figure 2. Green Plains ethanol facility in Superior, Iowa. (Photograph courtesy of the Green Plains website.)

The two-person train crew (engineer and conductor) were called for duty on March 9, 2017, at 4:30 p.m. The train crew boarded a UP contractor-supplied van in Eagle Grove, Iowa, and were transported about 95 miles to Estherville, Iowa, where they boarded the lead locomotive. At Estherville, the crew received authority from the UP dispatcher to go to Green Plains, at Superior, Iowa, which was 6 miles west, to pick up their train. The train crew departed Estherville at 7:36 p.m. and arrived at Green Plains at 8:22 p.m.

Upon arrival at Green Plains, the train crew assembled the train, which at the time consisted of 2 locomotives on the head end of the train followed by a buffer car, followed by 99 tank cars loaded with ethanol.[4] The loaded tank cars were followed by another buffer car, and then a rear locomotive, also known as a distributed power unit (DPU). Before departing Green Plains, the train crew removed (set out) one tank car with mechanical defects they had been previously notified of; thus, the accident train consisted of 98 loaded tank cars.

UEGKOT-09 was a key train transporting about 2.9 million temperature-adjusted meter quantity gallons of undenatured ethanol, which is designated by the US Department of Transportation (DOT) as a Class 3 hazardous material.[5] The accident train was also classified as a high hazard flammable train (HHFT) and subject to route planning requirements, speed restrictions, and commodity-specific phase-out of DOT-111 tank cars and reporting requirements of the Hazardous Materials Regulations (HMR).[6]

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[4] A *buffer car* is placed between the locomotive engine and shipments when available to protect train crews from hazardous materials, as required by 49 *CFR* 174.85, "Position in train of placarded cars, transport vehicles, freight containers and bulk packagings," which requires that when the train length permits, placarded cars must not be nearer than the sixth car from the engine or occupied cars. Cars loaded with ethanol are placarded and, therefore, require separation from the locomotives. However, the regulation also says that when the train length does not permit, the placarded car must be placed near the middle of the train, but not nearer than the second car from an engine or occupied caboose.

[5] According to the Association of American Railroads (AAR) *key trains* are subject to speed restrictions and other operating criteria and would include any train with 20 car loads or intermodal portable tank loads of any combination of hazardous material (AAR 2016).

[6] An *HHFT* is a single train transporting 20 or more loaded tank cars of a Class 3 flammable liquid in a continuous block or a single train carrying 35 or more loaded tank cars of a Class 3 flammable liquid throughout the

The accident train was traveling at 28 mph when it approached the Jack Creek Bridge at MP 56.8. The track speed was restricted by UP to 30 mph between MP 56 and MP 57.[7] The engineer said that the train was operating smoothly as it approached the accident area. Shortly after crossing the Jack Creek Bridge, and 70 minutes into its trip, the train's emergency air brakes applied, without crew initiation.[8] The train crew described the brake application as a "lurch forward" immediately after which both crewmembers saw a bright orange flash outside the locomotive cab window. The crewmembers said that they turned in their seats to see a large fireball rising into the night sky.

The engineer immediately radioed the UP dispatcher in Omaha, Nebraska, and said that the train had experienced an undesired emergency brake application and had derailed, with cars piled up and several cars on fire.

After the lead locomotive stopped, the train crew assessed the derailment. They observed that the first 20 cars (still on the rails and attached to the lead locomotives) had separated from the burning derailed cars. The train crew pulled the first 20 cars about 1.5 miles away from the burning cars. Emergency responders asked the crew to use the rear DPU to pull the 52 unaffected cars, west of the derailed cars at the bridge, away from the burning cars. After this task was accomplished, the train crew boarded a UP contractor van and was transported back to Estherville for a federally required DOT toxicological test.

1.3 Hazardous Materials Release

Twenty tank cars, in positions 21 through 40, derailed. Of those, 14 tank cars released product. Ten of the derailed tank cars were breached from mechanical damage, while four tank cars with shell damage released product from leaking bottom outlets or top fittings and thermal damage that fueled a postaccident fire that burned for over 36 hours. Section 1.7 discusses how each tank car was damaged.

UP contractors transferred ethanol from four nonbreached tank cars involved in the derailment to undamaged tank cars, which were returned to the shipper. The contractors transferred the remaining product from eight of the breached tank cars to on-site frac tanks for temporary storage.[9] Based on recovery volumes, the amount of ethanol released in the accident was about 322,000 gallons.

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train consist. Specific operating requirements for HHFTs are found at 49 *CFR* 174.310, "Requirements for the operation of high-hazard flammable trains."

[7] Railroads can choose to operate at any speed, taking into account factors such as operational needs, track geometry, or territory grade. FRA regulations found in 49 *CFR* 213.9, "Classes of track: operating speed limits," set forth the maximum authorized speed per class. These speeds vary for freight and passenger trains because different railroad equipment has different capabilities. UP opted to operate at a maximum speed of 30 mph on the Estherville Subdivision. This falls into the speed range for FRA Class 3 track.

[8] *Emergency air brakes* engage through the rapid release of air pressure from the brake pipe, resulting in the correspondent increase of brake pressure. Engineers and conductors can apply the emergency air brakes from their brake valves on the locomotive. However, the emergency brake may also engage because of a broken brake pipe or disconnected air hoses. In the railroad industry, this is commonly known as an undesired emergency brake.

[9] A *frac tank*, originally manufactured for use in the oil and gas drilling industry, is a large mobile temporary storage tank that is used to hold waste water and chemicals. A typical frac tank holds about 21,000 gallons.

1.4 Emergency Response

Within 10 minutes of the accident, the Palo Alto County 911 dispatch center notified the Graettinger, Iowa, fire department of a train accident with burning ethanol cars and a grass fire. The Graettinger fire chief (fire chief) advised firefighters that this was a “full hazardous materials incident” and was the first to arrive on scene. He told National Transportation Safety Board (NTSB) investigators that he was mindful of the emergency response to the ethanol, the amount of radio traffic, the availability of law enforcement, the size of the accident site, the train crew’s location, and moving any cars that were not derailed. He said that he could see the fire when he first turned onto 435th Avenue. (See figure 3.) At this location, he found that the train was blocking a grade crossing and road access to houses near the derailment.

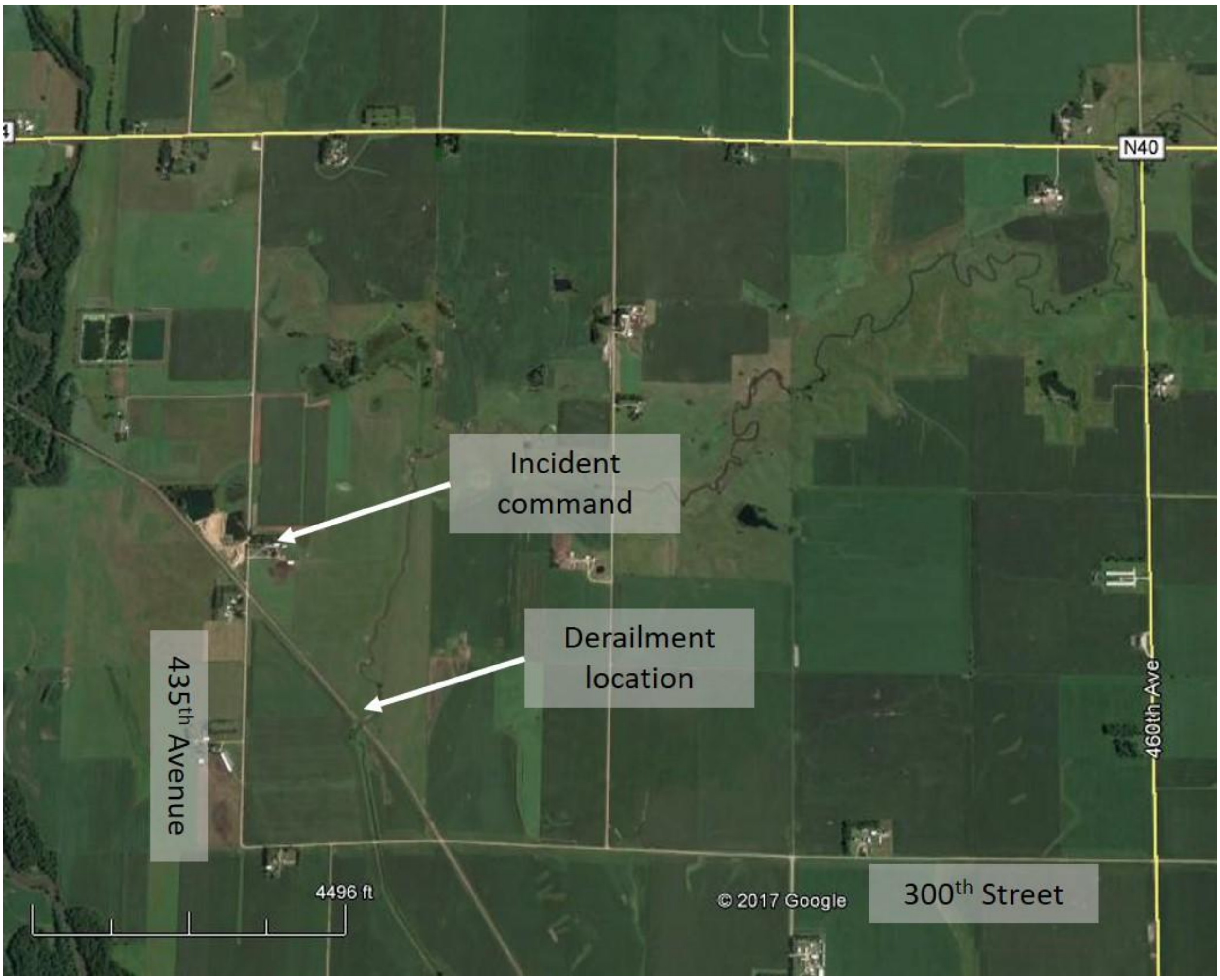

Figure 3. Map showing the locations of the incident command center and the derailment. (Map courtesy of Google.)

The fire chief requested additional resources and established incident command in the driveway of a nearby residence at 1:25 a.m., with an immediate goal of moving the nonderailed cars away from the fire and getting access to the nearby residences. The train crew arrived at the command post about 1:35 a.m. and created a plan with the fire chief to move the cars.

About an hour after the accident, the cars were clear of the grade crossing at 300th Street, and road access was restored to the nearby houses. Residents within a 0.5-mile radius were asked to voluntarily evacuate. The county emergency manager and the fire chief believed that the scene was stable, and they allowed the ethanol product to burn off while monitoring and cooling nearby tank cars with foam. The incident command was later transferred to UP at 3:30 a.m.

1.5 Postaccident Site Inspection

NTSB investigators inspected the nonderailed cars (1st through the 20th) that traveled over the Jack Creek Bridge. NTSB investigators observed that the wheels on the right side of several cars that rolled over the right-side rail (or south rail) exhibited fresh horizontal impact damage (impressions perpendicular to the wheel tread).[10] (See figure 4.) No such damage was observed on the wheels on the left side of the train. (See figure 5.)

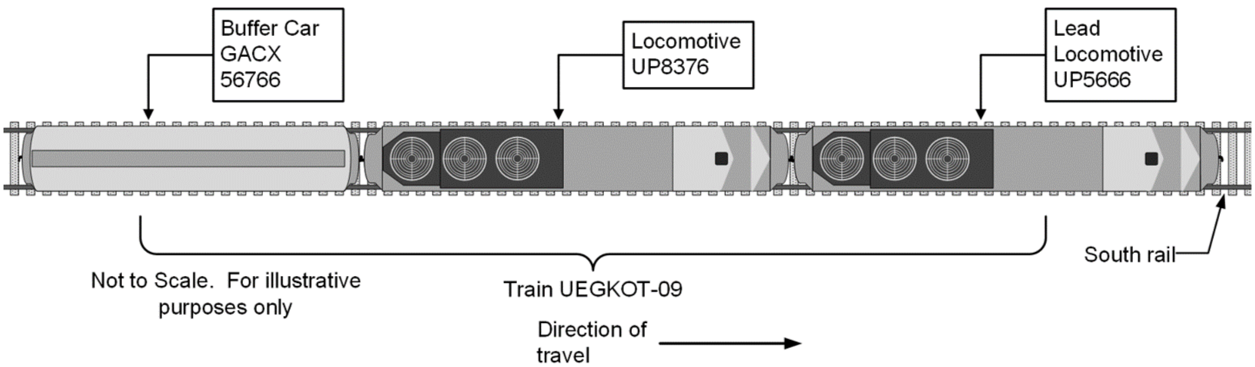

Figure 4. Illustration of train movement over rails.

[10] *Horizontal impact damage* is deformation to the surface of the wheel tread as a result of deviation from the normal wheel rail interface. This damage is the result of the wheel coming into contact with a discontinuity.

Figure 5. Wheel tread impact damage on TCBX 198115.

The damage began to appear on the fourth tank car, but was not present on the fifth or sixth tank cars. On tank cars 10 through 20, the impact damage was observed on every car, becoming more pronounced toward the 20th car, which was a tank car. The 20th car, TCBX 198115, was the last car that traveled through the derailment area without derailing.[11]

[11] The *wheel flange* is the inside rim which projects below the tread.

NTSB investigators completed walking track inspections from MP 57.10 to MP 56.35, through the derailment footprint.[12] During these inspections, they identified seven defects that did not meet the FRA minimum track standards outlined in Title 49 *Code of Federal Regulations* (*CFR*) Part 213, "Track Safety Standards." They included four crosstie distribution defects, one insufficient number of crossties in a rail segment, one rail fastener defect, and one concentrated load between the base of rail and tie plate.

Periodic gage measurements were taken on both tangent track (straight track) and the curve east of the derailment with no gage defects found. There were no rail joints in this track segment, and there were no defects to the rail anchoring; there was no longitudinal movement noticed in either direction. NTSB investigators did, however, note that the crosstie condition on this track segment was marginal in many areas.[13] They could find no obvious track disturbances or evidence of dragging equipment west of the location of the derailment at Jack Creek Bridge at MP 56.8.

Significant track structure damage in the immediate area of the derailment prevented a comprehensive inspection of an intact track structure. The total amount of damaged and displaced rail was about 400 feet. (See figure 6.) NTSB investigators recovered, identified, and arranged about 390 feet of the damaged and displaced rail. The fractured pieces were "reassembled" based on the manufacturer, manufacture dates, and rail fracture characteristics. Each section was visually examined on scene, labeled, and inventoried. A total of 14 pieces were sent to NTSB's Materials Laboratory in Washington, DC, for a metallurgical examination.

[12] (a) A *derailment footprint* is a commonly used term in the railroad industry to describe the area near the derailment that was affected by the forces exerted during the accident. This includes damaged and displaced track structure, the railroad subgrade, and the area surrounding the railroad property. (b) The derailment footprint included the area associated with the disturbed rail, tank cars, and bridge wreckage at MP 56.8.

[13] *Marginal* crossties are those that are near the end of useful service life and are close to being noncompliant with FRA track safety standards.

Figure 6. Aerial photograph of the derailed train and the damaged track.

1.6 Injuries

No injuries were reported as a result the accident.

1.7 Damages

1.7.1 Tank Car Damages

The orientation of the ethanol tank cars following the derailment is indicated in figure 7. After transloading the tank cars, crews staged them in a nearby farm field for examinations.

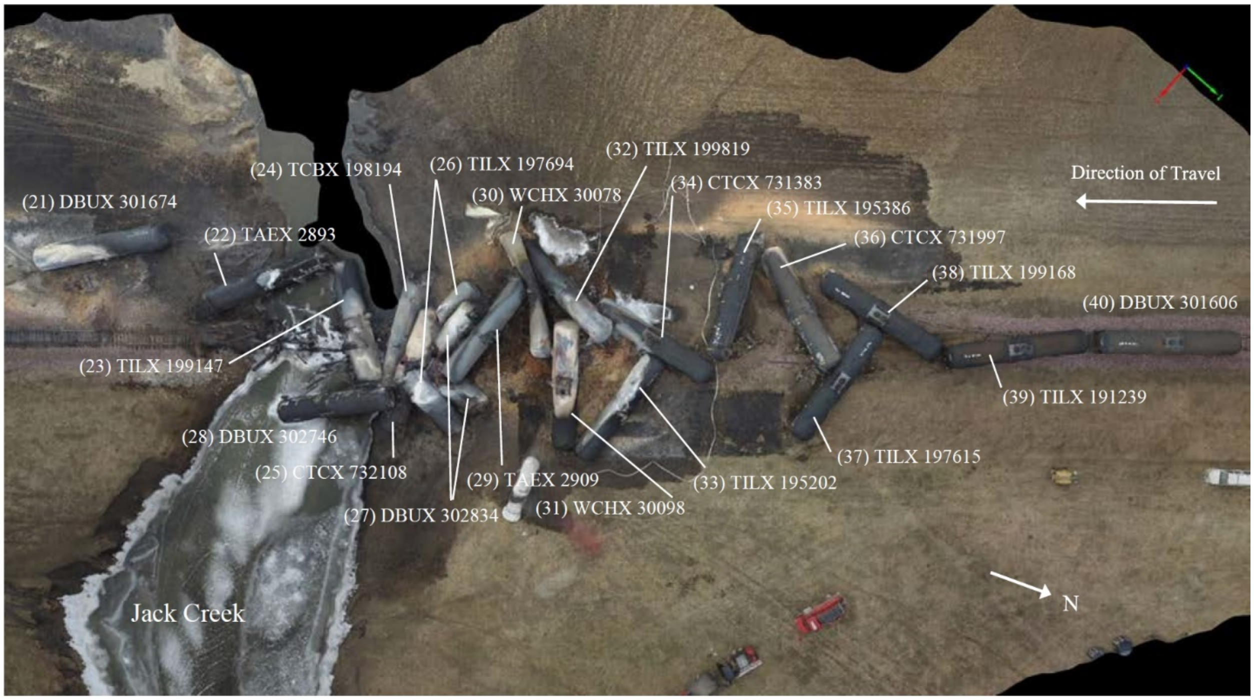

Figure 7. Derailment scene and tank car identification. The numbers in parentheses identify the location of the tank cars.

Table 1 summarizes the likely breaching mechanisms for the tank cars involved in this accident.

Table 1. US Department of Transportation Specification-111 breaching damage.

Line Number (from front)	Car Number	Head Breach	Shell Breach	Bottom Outlet Damage	Top Fittings Damage	Thermal Tear	Likely Breaching Mechanism
21	DBUX 301674				X		Vapor valve mechanically broken from multihousing flange
22	TAEX 2893			X			Bottom outlet valve operating handle was manipulated open by derailment forces, the nozzle sheared off
23	TILX 199147	X					A-end head punctured by coupler impact
24	TCBX 198194	X					Head punctured by a coupler or coupler shank impact
25	CTCX 732108		X		X		Large 10-feet tear, second irregular hole, liquid valve mechanically broken from multihousing flange
26	TILX 197694		X				Shell fractured in two pieces from 90° impact with TAEX 2909
27	DBUX 302834		X				Shell fractured in two pieces from 90° impact with TAEX 2909
28	DBUX 302746						No breach
29	TAEX 2909[a]	X					Head punctured by coupler or coupler shank impact

Line Number (from front)	Car Number	Head Breach	Shell Breach	Bottom Outlet Damage	Top Fittings Damage	Thermal Tear	Likely Breaching Mechanism
30	WCHX 30078	X	X				Tank midsection was torn and crushed between TAEX 2909 and TILX 199819, hole through Ring 6 and head from coupler impact
31	WCHX 30098			X			Bottom outlet valve was leaking, the nozzle was not sheared away from its flange
32	TILX 199819		X				Large shell tear in Ring 6
33	TILX 195202			X		X	Small thermal shell tear, the bottom outlet valve was leaking
34	CTCX 731383	X	X	X			Shell puncture and fractures on car bottom, head fractured on edge of severe dent having the shape of another tank head, BOV open
35	TILX 195386						No breach
36	CTCX 731997	X					Tear and crack indented and folded material from car-to-car impact

[a] Universal Machine Language Equipment Register (UMLER) database is a computer platform used by railroads, rolling stock owners, and repair shops to share rail car information. UMLER indicated TAEX 2909 replaced the original car number GATX 203812.

1.7.2 Track and Structures Damages

A 152-foot long timber bridge and about 232 feet of rail on the west approach and 16 feet of rail on the east approach were destroyed.

1.7.3 Environmental Remediation

UP contracted Arcadis, U.S., Inc., to support the derailment remediation efforts. These activities included collecting data to evaluate potential impacts to Jack Creek, implementing soil sampling and remediation, supporting ecological permitting, and preparing and submitting required reports to the Iowa Department of Natural Resources (Iowa DNR). The Arcadis report to the Iowa DNR concluded that most of the released ethanol was thought to have been consumed by the fire due to its size, duration, and intensity (Arcadis 2017). The Arcadis report further characterized the level of ethanol released to the soil in the vicinity of the derailment as relatively low. Arcadis reported that dissolved oxygen monitoring and ethanol testing did not indicate significant impact to the surface waters of Jack Creek.

1.8 Personnel Information

1.8.1 Accident Train Engineer

The accident train engineer was hired by UP in January 2005. Engineers and conductors are required to be trained and certified under a federally approved program.[14] He earned his latest certification as an engineer in June 2015. This certification was valid until June 2018. The engineer was part of a "pool crew," which means he would work multiple types of jobs in various locations. In his interview with NTSB investigators, the engineer said that it had been a while since he traveled through this territory. When asked if he had experienced a rough ride or track as the train traveled over the Jack Creek Bridge, the engineer said, "it did not seem rougher than normal."

1.8.2 Accident Train Conductor

The train conductor was hired by UP in September 2003. His latest certification as a conductor was in June 2012. This certification was valid until February 2020. The conductor was also part of a pool crew. In his interview with NTSB investigators, the conductor said he had traveled this territory many times. He told investigators that he was looking out the front window of the lead locomotive as the train approached the Jack Creek Bridge and did not notice any rough track leading up to the Jack Creek Bridge.

1.8.2.1 Personnel Electronic Devices

A review of cell phone records obtained by NTSB investigators showed that neither crewmember used their cell phones while on duty the day of the accident.

1.8.3 UP Track Supervisor

The manager of track maintenance (MTM) had been in that position with UP in this area for more than 20 years. At the time of the accident, he was responsible for the track maintenance on about 350 miles of track. The MTM supervised 15 track department employees; using them to maintain the assigned track.

The MTM told NTSB investigators that about 10 to 12 years ago, UP installed a large rail section from MP 0 to MP 32.2 on the Estherville Subdivision. He said a high percentage (about 90 percent) of rail defects are discovered in this section of the subdivision with 90-pound rail.[15] He said that there were not many service failures (broken rails) in the accident area, and that they had not had a derailment in the area in over 20 years until this accident. When asked about bridge inspections, the MTM stated that he does not see reports from those inspections.

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[14] Title 49 *CFR* Part 240, "Qualification and Certification of Locomotive Engineers."

[15] Rail is classified by its linear weight for every 3 feet. This rail was designated as S-9020 rail. In this report, the rail is referred to as "90-pound rail."

1.8.4 UP Track Inspector

The track inspector for the Estherville Subdivision had over 40 years of service with UP; he had been a track inspector for about 34 years and had inspected the Estherville Subdivision for about 25 years. He was assigned a territory that consisted of about 185 miles of main track, which included over 100 track switches and different yard and industry tracks. He told investigators he normally inspects alone, with the exception that he is occasionally accompanied by an FRA inspector or railroad manager.

He last inspected the track on the day before the accident and was the last qualified inspector to traverse it prior to the accident. He took no exception to the track near the derailment location. The only issue that he remembered finding in the area of the derailment during his many years of inspection was a broken rail west of the bridge. When asked about his interaction with the bridge inspectors, he stated that he does not normally join the bridge inspectors when they are conducting their work.

1.8.5 UP Bridge Inspector

The bridge inspector had been employed by UP in the bridge department since 2004 and started inspecting bridges in 2008. He was assigned to inspect about 425 bridges and between 180 and 200 culverts. He said that the accident bridge was inspected twice per year and was last inspected in October 2016. During this inspection, he documented that the first tie off the west end of the bridge had lost some ballast and was gapped (unsupported). The bridge inspector told investigators that the condition did not meet the federal guidelines for being low, but he documented the condition to be in the record. He said that if he found a defective condition, he would notify the track department and, if necessary, he could protect the track by implementing a speed restriction.

1.9 Work/Rest History

NTSB investigators examined the work and rest history for both the engineer and the conductor. The investigation determined that the engineer and conductor had been on duty for 8 hours 20 minutes at the time of the accident. Both the engineer and the conductor worked the previous day, March 8, 2017, beginning at 2:10 p.m., and completed their shift on March 9, 2017, at 1:45 a.m. Both crewmembers had more than the required 10 hours off duty from the previous day before reporting to work on March 9, 2017.[16]

1.10 Toxicological Information

Postaccident testing was required under the regulations because this event involved a major train accident involving a release of hazardous material, as required in 49 *CFR* 219.201, “Events for which testing is required.” After supporting the emergency responders by moving the nonderailed equipment, the crewmembers were transported for toxicological testing. The

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[16] Hours-of-service requirements are outlined in 49 *CFR* Part 228, Appendix A, “Requirements of the Hours of Service Act: Statement of Agency Policy and Interpretation.”

engineer tested positive for doxylamine in his urine but not in his blood, indicating the level in his blood several hours after the derailment was below the reporting cut off.[17] The reporting cut off is also the lowest blood level thought to correlate with any psychoactive effects of the drug such as drowsiness or impaired cognition (FAA 2017).

1.11 Operations Information

The Estherville Subdivision runs between Goldfield, Iowa, and Superior, Iowa, about 79 miles. It is primarily single main track with one passing siding; it is not a passenger route. Railroad operations on the subdivision are controlled by track warrant control out of UP's train dispatching center, located in Omaha, Nebraska. Track speed for the single main track was 30 mph at the accident location.

The UP employees involved in the accident were governed by the *General Code of Operating Rules* (UP 2015). UP's *Iowa Area Timetable No. 5* (UP 2016) also governed train movements. The *UP Air Brake and Train Handling Rules* (UP 2016a), *Instructions for Handling Hazardous Materials* (UP 2013), and *System Special Instructions* (UP 2016b) were also in effect. The train crew received its track warrant from the dispatcher in Omaha upon arriving at Estherville to pick up its locomotives.[18]

1.11.1 Locomotive Event Recorder Data

The leading locomotive's event recorder data indicated that about 34 seconds after crossing the Jack Creek Bridge at 12:50:49 a.m., while the train was traveling at a speed of about 28 mph, the brake pipe pressure decreased from 88 pounds-per-square-inch (psi) to 5 psi. The train's emergency brakes activated 1 second later, while maintaining a speed of 28 mph. Data indicated this was not an engineer-initiated activation. During the next 37 seconds, the train speed decreased from 28 mph to 0 mph.

1.12 Site Description

The Estherville Subdivision consists of a single main track with one passing siding between MP 0.0 and MP 79.3. It originates in Goldfield, Iowa, and ends in Superior, Iowa, with an average daily train count of one train every other day. During the on-scene phase of the investigation, NTSB investigators reviewed tonnage records from MP 48.49 to 70.56 and found the million-gross tonnage (MGT), or total tonnage, was 2.4 MGT.

The eastbound movements would traverse a grade ranging from +1.5 to -1.14 percent, from MP 79.3 to MP 56.45. From MP 56.85 to the point of derailment (POD) at 56.80, an eastbound train was on a slightly descending grade of -0.2 percent. In the accident location, the track alignment was tangent, meaning the track was straight and without curves.

[17] *Doxylamine* is an over-the-counter medication that is used as a nighttime sleep aid. https://www.rxlist.com/consumer_doxylamine_unisom/drugs-condition.htm. Accessed September 12, 2018.

[18] A *track warrant* authorizes main track use, which is restricted to defined movement limits, under the direction of the train dispatcher.

1.12.1 Track

The track construction consisted of 90-pound, continuously welded rail (CWR), manufactured by various companies.[19] The CWR was seated in 10-inch single-shoulder tie plates that lay between the bottom surface of the rail and the top surface of timber crossties. The rail was fastened through the tie plates to standard wooden crossties with conventional 6-inch cut track spikes. The spiking pattern used by UP prior to the derailment consisted of one rail-holding spike on the gage side and one rail-holding spike on the field side. The wooden crossties measured 9 inches by 7 inches by 8 feet 6 inches long, spaced 19.5 inches on center (nominal). The crossties were box anchored with rail anchors every other tie to restrain longitudinal movement of the CWR.[20] The track was supported by granite and limestone rock ballast.

1.12.2 Bridge

The Jack Creek Bridge was an 11-span, timber, open-deck bridge that measured 152 feet long. (See figure 8.) The bridge was destroyed by the derailment and ensuing fire.

Figure 8. Jack Creek Bridge in 2013. (Photographs courtesy of UP.)

According to UP documentation, this bridge was last inspected on October 11, 2016. The inspection record shows that the bridge was built in 1937 and the bridge deck ties were replaced in 1970. Although no defects or abnormalities were noted during this inspection, the UP bridge inspector mentioned in the report that there was insufficient ballast on the approach to the bridge with the comment, “high end, first tie off of bridge hanging 2 1/2 [inches].”[21] UP was unable to provide any documentation that this condition had been corrected prior to this derailment.

[19] *Continuous welded rail* is rail that has been welded together into lengths exceeding 400 feet.

[20] (a) *Box anchored* is a railroad term that means that each rail is affixed with two rail anchors at a given crosstie location and that those anchors (four per crosstie) would bear on the sides of a crosstie in order to restrict the potential longitudinal movement of the rail; (b) *Rail anchor* describes devices that are attached to the rail and bear against the side of the crosstie to control longitudinal movement. Certain types of rail fasteners also act as rail anchors and control rail movement by exerting a downward clamping force on the upper surface of the rail base.

[21] While the bridge inspector’s report did not include a notation on whether this was on the east- or west-end approach, during his interview with NTSB investigators, he stated there was a gap on the west-end approach.

1.12.3 On-board Image Recorder

The lead locomotive in this accident was equipped with a forward-facing video camera and an on-board image recording system. NTSB investigators reviewed the video and did not observe any discontinuities in the rail on the approach to the Jack Creek Bridge. (See figure 9.)

Figure 9. Still image of the track on approach to the Jack Creek Bridge.

The video shows a bright light from the fire originating from behind the locomotive sufficient to illuminate large areas of the surrounding terrain 42 seconds after the lead locomotive crossed the Jack Creek Bridge.

1.13 Mechanical Inspections

On March 9, 2017, at 10:22 p.m., about 2.5 hours prior to the derailment, the crew of UEGKOT-09 performed an FRA Class I brake test at Green Plains, LLC in Superior, Iowa, less than 20 miles from the accident location.[22]

NTSB investigators completed postaccident mechanical walking inspections and FRA Class 1 brake tests on all cars that did not derail, revealing very few defects. All of the inspected and tested cars revealed good integrity of the train's air brake system—all brakes applied and released as designed. None of the conditions observed on the cars were found to be causal to the train accident.

[22] According to 49 *CFR* 232.205, "Class I brake test-initial terminal inspection," a Class I brake test-initial terminal inspection is required on all cars in a train at the location where it is assembled. It verifies that the brake system on the train is operating as intended.

NTSB investigators also examined the derailed tank cars, truck assemblies, and 80-wheel sets after the postaccident recovery. All wheels were found to be intact except two fractured wheels with derailment damage. Several wheels showed indications of thermal exposure consistent with the tank car fire. As discussed in section 1.5, the wheels of the nonderailed cars (1st through 20th) on the south side of the train exhibited fresh horizontal damage on the wheel tread. None of the wheels from the nonderailed cars behind the 40th car (41st through 98th and the DPU) or from the lead locomotives exhibited any horizontal wheel marks on the wheel tread.

1.14 Track and Rail Inspection

This section discusses three types of inspections: track inspections, internal rail inspections, and track geometry inspections. Track inspectors typically visually inspect the track by walking or riding over the track in a hi-rail vehicle at a speed (20 mph or below) that allows the visual examination of the track structure.[23] They evaluate the track structure including ballast, crossties, track assembly fittings, and the physical conditions of rails; the roadbed and areas immediately adjacent to the roadbed; and the track geometry to determine whether they meet federal and railroad requirements.

With internal rail inspections, railroads use ultrasonic and induction inspection devices, either on a specialized inspection vehicle or handheld equipment, to examine rail for internal defects. In ultrasonic inspections, a transducer emits ultrasonic sound waves that penetrate the rail from various angles. Rail defects, such as cracks in the steel, and rail features will normally reflect the sound waves back to the transducers, and the reflected signals will display on a monitor.[24] The equipment operator assesses these reflected signals to identify the cause of the reflections, which could be cracks, other internal rail defects, or features of the rail profile. In induction inspections, coils moving along the rail at a fixed distance above the rail head detect and measure any distortion within the magnetic field, which is then assessed by the equipment operator. These assessments are also used to identify and locate potential defects.

Track geometry inspections are conducted with specialized railroad cars outfitted with measurement systems that automatically collect and evaluate the condition of the track structure. The systems collect measurements including track gage, alignment, and track surface, such as cross level, warp, and profile.

1.14.1 UP Track Inspection and Maintenance History

NTSB investigators reviewed the UP track inspection records from July 1, 2016, to March 9, 2017, for MP 0.0 to MP 78.46 on the Estherville Subdivision. FRA regulations found in 49 *CFR* Part 213, "Track Safety Standards," require that rail carriers prepare and sign track inspection records on the day of the inspection to document the frequency of inspections to ensure compliance with the rule. FRA track inspection records are required to reflect actual field conditions and deviations from regulations. UP elected to operate this section of track at FRA Class 3 speeds, which requires they inspect the main track at least once per calendar week.

[23] A *hi-rail vehicle* is equipped to run on a conventional highway and railroad track. Its primarily used as a track inspection conveyance.

[24] *Rail features* include bolt holes, welds, and joint bars.

Although the Estherville Subdivision did not meet the definition of a key route, UP had increased the frequency of track inspections on the subdivision from once a week to twice a week under a December 22, 2016, compliance agreement with the FRA (which is discussed further in section 1.14.6).[25] UP met its obligation to inspect the track segments that were to be checked on a weekly basis, including the siding. However, on the segment of track which was to be inspected twice a week, UP completed one during the week of February 19-25, 2017.

A review of UP track inspection records also showed that UP track inspectors had documented marginal tie conditions between Emmetsburg, Iowa, and Superior, Iowa. The inspector documented 49 locations between MP 44.5 and MP 78.4 with defective tie conditions between July 1, 2016, and November 4, 2016.

On March 9, 2017, a qualified UP track inspector conducted the last inspection of the track in the area of the derailment prior to the accident. The track inspection record noted two defects between MP 48.49 to MP 78.46, an area that includes the derailment footprint. The two recorded defects were unrelated to this accident. These defective conditions were not near the accident area and were repaired before train movements resumed over that portion of track.

A summary of UP's track inspections in this area in the 2 years prior to the accident, along with those by the FRA, can be found in appendix B.

1.14.2 UP Internal Rail Inspection History

UP provided the NTSB with the last two ultrasonic rail test reports for the Estherville Subdivision. The most recent test through the accident area was conducted on May 24, 2016. One defective rail condition was identified between MP 50.25 and MP 61.12, which was a defective plant weld at MP 56.54. UP installed a replacement rail on May 27, 2016.

The previous ultrasonic rail test conducted through the area of the derailment prior to the accident occurred on July 14, 2015. The report showed that no defective rails were identified between MP 48.84 and MP 61.25, including the footprint of the derailment.

1.14.3 Track Geometry Inspections

UP conducted a survey with a track geometry car once per year on the Estherville Subdivision. The last track geometry survey through the derailment area was conducted on August 15, 2016. No track geometry conditions or deviation from FRA minimum standards were identified between MP 54.16 and MP 57.64, including the area of the derailment. FRA had not conducted a survey using test vehicles from its Automated Track Inspection Program on the Estherville Subdivision.

[25] According to AAR Circular OT-55-P, a *key route* is any track with a combination of 10,000 car loads or intermodal portable tank loads of hazardous materials, or a combination of 4,000 car loadings of PIH or TIH (hazard zone A, B, C, or D), anhydrous ammonia, flammable gas, Class 1.1 or 1.2 explosives, environmentally sensitive chemicals, spent nuclear fuel, and high level radioactive waste over a period of 1 year (AAR 2016).

1.14.4 Federal Oversight of Track and Rail Inspections

The FRA's Office of Railroad Safety regulates safety throughout the railroad industry. To carry out its mission, FRA staff includes about 400 federal safety inspectors who operate from eight regional offices. Railroads that are part of the general system in the state of Iowa are overseen by FRA Region 6, headquartered in Kansas City, Missouri. FRA Region 6 personnel are responsible for the oversight of Colorado, Iowa, Kansas, Missouri, Nebraska, Wyoming (southeast area), and Illinois. In addition, the states of Iowa, Missouri, and Illinois departments of transportation have inspectors that work in conjunction with FRA staff. Track inspections in Region 6 were conducted by 16 safety inspectors: 10 FRA inspectors, 2 Iowa state inspectors, 2 Missouri state inspectors, and 2 Illinois state inspectors.

NTSB investigators reviewed FRA track inspection records from March 2015 through the day of the accident. The records indicate an FRA safety inspector last examined the derailment site on December 13, 2016.[26] This inspection report noted no defective conditions; however, the report contained a comment stating that the track was snow covered during the inspection. The comment also documented a marginal tie condition between Superior and Emmetsburg (which included the derailment location).

On August 10, 2016, the same safety inspector conducted an inspection from MP 78.4 to MP 44.0.[27] The inspector documented 10 locations with crossties that did not meet the minimum FRA track safety standards (TSS).[28] According to this report:

> Crosstie condition marginal from MP 49 Emmetsburg to MP 78 Superior. Within this area some very marginal tie conditions exist from MP 60 Graettinger to MP 70 south end of Estherville. Numerous areas with 5-10 or more ties in a row defective or nearly so. FRA class 2 speeds exist from MP 72 to 78. FRA class 3 speeds exist from MP 72 to the worst of the marginal ties extending to MP 49. This is an ethanol route with higher risk, especially on the most marginal area for ties and it [*sic*] being operated at FRA class 3 speeds.

The inspection records also show two FRA track inspections were conducted in the area of derailment on the Estherville Subdivision in 2015. These inspections were conducted in March and July by different inspectors and documented 11 defective conditions with 9 of those being locations with defective crossties. A March 2015 FRA inspection report stated:[29]

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[26] Title 49 *CFR* 209.3, "Definitions," defines an *FRA safety inspector* as "an FRA safety inspector, a state inspector participating in railroad safety investigations and surveillance activities under Part 212 of this chapter, or any other official duly authorized by FRA."

[27] For more information, see "FRA Inspection Report No. 67 – Dated August, 2016" in NTSB Docket DCA17MR007.

[28] FRA TSS, as outlined in 49 *CFR* 213.9, "Classes of track: operating speed limits," defines maximum operating speeds for several different classes of track. Class 3 track allows for a maximum operating speed of 40 mph for freight trains and 60 mph for passenger trains on Class 2 track, the maximum operating speed is 25 mph for freight trains and 30 mph for passenger trains. UP does not operate any passenger trains on the Estherville Subdivision.

[29] For more information, see "FRA Inspection Report No. 28 – Dated March, 2015" in NTSB Docket DCA17MR007.

> Tie condition between MP 48 and 78 is in poor condition and approaching defectve [*sic*] condition for intend [*sic*] class in many areas.

> An FRA inspector commented in a July 2015 FRA inspection report:[30]

> From MP 70 to MP 49 tie condition is marginal for the FRA class of track being operated in areas. Many areas where these ties are very close to the end of their life and another winter cycle will most likely put these areas in noncompliance. This is also a major ethanol hauling route.

1.14.5 FRA Inspection and Enforcement Data

According to inspection and enforcement data from the FRA, of the 42,076 track miles operated by UP nationwide, about 24,390 exist in FRA Regions 5 and 6. UP operates about 12,170 miles in Region 5 and about 12,220 in Region 6. The following table shows fiscal year (FY) 2016 data across both regions for inspections and observations.[31]

Table 2. FRA enforcement data on Regions 5 and 6: inspections and observations.

Region	Inspections	Observations	Units	Subunits	Defects	Violations
5	8,932	40,469	474,074	134,656	44,258	3,846
6	5,242	22,197	239,956	57,205	21,782	1,504

From these inspections, in FY 2016, Region 6 FRA assessed 42 total civil penalties. Of those, 7 were against UP for not meeting the minimum requirements of FRA TSS. While in Region 5, 17 FRA inspectors assessed 253 total civil penalties. Of those, 83 civil penalties against UP for deviation from FRA TSS. Accident data provided by the FRA specific to track-related derailments suggests a greater frequency of accidents in Region 5 compared to Region 6. Additional information comparing accident statistics on Regions 5 and 6, along with an MGT comparison across all regions in North America was provided by the FRA.[32]

A summary of FRA's track inspections in this area in the 2 years prior to the accident, along with those by UP, can be found in appendix B.

1.14.6 FRA Compliance Agreement with UP

FRA has many enforcement options available under 49 *CFR* Part 209, "Railroad Safety Enforcement Procedures," including civil penalties, criminal penalties, compliance orders, and emergency safety orders. In response to a June 3, 2016, UP HHFT derailment in which three tank cars ignited at a bridge ramp at the approach to Interstate 84 in Mosier, Oregon, UP entered into a compliance agreement with the FRA on December 22, 2016 (FRA 2016). This compliance

[30] For more information, see "FRA Inspection Report No. 55 & 76 - 2015" in NTSB Docket DCA17MR007.

[31] *Observations* are reviews of railroad employee activities, while *inspections* are reviews of physical assets.

[32] For more information, see "FRA Enforcement Data FY2016- Regions 5 & 6" in NTSB Docket DCA17MR007.

agreement required UP to agree to remedial actions to improve compliance with 49 *CFR* Part 213 and other safety requirements. Some of these remedial actions include:[33]

- Inventory curves with specified track components
- Increase walking or gage restraint measurement system (GRMS) inspections of track with specified physical characteristics
- Implement a program to eliminate elastic fasteners using lag screws to secure tie plates
- Implement increased track inspections

Because of the compliance agreement, UP was required to conduct hi-rail or walking track inspections of the Estherville Subdivision twice weekly, conduct track geometry car inspections at least three times per year, conduct ultrasonic rail testing at least two times per year, and conduct GRMS testing at least once per year.

1.14.7 FRA Interview

NTSB investigators interviewed the regional administrator (RA) for FRA Region 6.[34] The RA had been employed by the FRA for about 32 years and had been in the current position for about 5 years. The interview focused primarily on the following:

- Planning of inspection activities; use of the Regional Inspection Plan (RIP) and the National Inspection Plan (NIP)
- Regional guidance given to track inspectors; use of enforcement tools
- Portable track loading fixtures to supplement visual inspections
- 2016 compliance agreement between FRA and UP

The RA explained that both the RIP and the NIP are tools used to manage resources while conducting compliance inspections on the nation's railroads. He also told NTSB investigators that the inspection plans factor in hazards when allocating resources.

When asked if inspectors are allowed to use enforcement options, such as recommending the assessment of civil penalties, the RA stated, "our guidance gives the inspectors the flexibility, based on their judgment and the criteria that we have built into the general manual, to make decisions."

[33] To see a complete copy of the compliance agreement, see "FRA-UP Safety Compliance Agreement- Dated 12/22/2016" in NTSB Docket DCA17MR007.

[34] For more information, see "Interview of FRA Regional Administrator – Region 6" in NTSB Docket DCA17MR007.

The NTSB investigators asked the RA how the 2016 compliance agreement between the FRA and UP affected the inspection activity on the Estherville Subdivision. The RA answered, “It has absolutely no bearing on the Estherville Subdivision.” He said that it was his understanding that the compliance agreement applied to main track territory, not branch line territory. When asked for clarification regarding the difference between branch track and main track, he said that “a branch line is usually kind of a stub-end track with much lower densities.”[35] NTSB investigators informed the RA that the Estherville Subdivision is FRA Class 3 track, where trains operate at speeds up to 30 mph and asked if class of track is considered when designating a track as branch or main track.[36] The RA responded, “not to my knowledge.”

1.15 Postaccident Track Inspections

NTSB investigators conducted a postaccident hi-rail inspection on both sides of the derailment area from MP 49.09 to MP 69.34 to assess the overall condition of the track and to identify any additional rails that may have broken under the accident train prior to the POD; no broken rails were found. NTSB investigators inspected track from MP 54.53 to MP 49.09 (east of the derailment) and track from MP 58.0 to MP 69.34 (west of the derailment). Track from MP 54.53 to MP 58.0 was not inspected because equipment from the derailment was occupying the track. The overall track conditions were as follows: 90-pound CWR rail; the rail anchoring was consistent, with no indications of longitudinal movement observed; although NTSB investigators noted some geometry conditions, they did not find any geometry defects, as prescribed by UP and FRA standards; no gage issues were identified; and the crosstie condition was marginal, with several locations that were found to be noncompliant with FRA regulations.

On March 11, 2017, NTSB investigators conducted a walking inspection from MP 57.10 to MP 56.35 with FRA inspectors.[37] This inspection was conducted up to the disturbed track and the derailed rail cars on both sides of the accident bridge. FRA inspectors completed an inspection report documenting seven defects which included: four crosstie distribution defects, one insufficient number of crossties in a rail segment, one rail fastener defect, and one concentrated load between the base of rail and tie plate.

Based on the track alinement and track class, FRA minimum TSS allow no more than eight nondefective crossties per 39 feet of rail; the nondefective crossties must also be effectively distributed throughout the 39-foot rail segment.[38] During this walking inspection, from MP 57.10 to MP 56.35, NTSB investigators noted that tie conditions were marginal in this track segment.

[35] FRA regulations do not define “branch track.” Title 49 *CFR* 218.5, “Definitions,” states: “Main track means a track, other than an auxiliary track, extending through yards or between stations, upon which trains are operated by timetable or train order or both, or the use of which is governed by a signal system.” Thus, the compliance agreement did apply to the Estherville Subdivision.

[36] Railroads can choose to operate at any speed, taking into account many factors, such as operational needs, track geometry, or territory grade. FRA classes of track set forth the maximum authorized speed per class. These speeds vary for freight and passenger trains because different railroad equipment has different capabilities. UP opted to operate at a maximum speed of 30 mph on the Estherville Subdivision, which falls into the speed range for FRA Class 3 track.

[37] For more information, see “FRA Inspection Report No. 30- Dated March 11, 2017” in NTSB Docket DCA17MR007.

[38] FRA TSS can be found at 49 *CFR* 213.109, “Crossties.”

Two crosstie distribution defects and an insufficient number of crossties in a rail segment defect were identified less than 1,000 feet from the POD. The crossties observed were found to be defective, split, broken, or unable to hold fasteners.

NTSB investigators further noted during this postaccident walking inspection that the crosstie conditions improved as they approached Jack Creek Bridge from the west. Periodic gage measurements were taken on both tangent track and the curve east of the derailment with no gage defects found. There were no rail joints in this track segment and there were no rail anchoring defects; no longitudinal rail movement was noted.

In the area of the derailment, the track structure was misaligned as a result of derailment forces. NTSB investigators took gage measurements, observed track alignment, and measured track surface leading into the disturbed track. No exceptions were taken to the track geometry in the track segment from MP 57.10 into the derailment area. NTSB investigators noted profile conditions ranging from 3/4 inch to 1-1/4 inches in the areas with defective crossties. (See figure 10.)

Figure 10. Split and broken crossties, that are not holding fasteners, immediately west of MP 56.9. The tie plates in the foreground have cut into the broken crossties.

1.15.1 Point of Derailment and Rail Reconstruction

While on scene, NTSB investigators established the POD to be near MP 56.8 on the ballasted portion of track on the west approach of the bridge spanning Jack Creek, based upon the amount of damage to the rail infrastructure and the resting location of the tank cars.

NTSB investigators recovered, identified, and reconstructed the rails from the west approach and across the bridge spanning Jack Creek.[39] The total displaced track measured about 400 feet. About 15 feet of the south rail and 10 feet of the north rail were not recovered. The rails were identified by manufacturer, manufacture dates, and rail fracture characteristics and were pieced together to identify the first area of discontinuity. In the area of the derailment, the 90-pound rails were manufactured by Inland Steel Company and Illinois Steel Company. The majority of the rail was manufactured between 1925 and 1930; one rail section was manufactured in 1937; and another section was manufactured in 1957.

An inventory of all the recovered rail was made. The north and south rail pieces were labeled in sequential order, starting from the west and progressing east through the accident area.

As addressed in section 1.5, several wheels on the south side of the train exhibited fresh horizontal impact damage on the wheel tread that traveled over the south rail. As with the wheel impact damage on the wheel tread, when a rail vehicle's wheel encounters a rail discontinuity, the rail ends can become disfigured from the hammering effect of the wheel rolling over it. This disfiguration that occurs on the rail is referred to in the railroad industry as rail end batter. Consistent with the wheel's direction of travel, this rail end batter can be classified as either departing batter or receiving batter, meaning that the disfiguration will have unique characteristics when examined closely that are consistent with the direction of travel. Although rail end batter can serve as an indication of an existing discontinuity often associated with a preexisting broken rail, NTSB investigators were unable to recover any pieces of rail that displayed definitive rail end batter indicative of preexisting broken rail.

1.16 Hazardous Materials Information

1.16.1 Denatured and Undenatured Ethanol

The March 10, 2017, accident in Graettinger, Iowa, is the first derailment with breached tank cars and postaccident fire involving an HHFT transporting undenatured ethanol. The Graettinger fire chief was the first emergency responder to arrive on scene.[40] The fire chief told NTSB investigators that in sizing up the incident scene from a distance with binoculars, he observed "the fire seemed big, but could have been bigger." He said the released material was steadily burning, but there were no explosions. The fire chief said that he concluded the ethanol was not an explosive commodity, based on his past training in ethanol emergency response. The

[39] For more information, see "Materials Laboratory Factual Report" in NTSB Docket DCA17MR007.

[40] The fire chief was Fire Fighter 2 certified. He had additional training on the National Incident Management System (NIMS), a Fire Science Certificate from Iowa Lakes Community College, and completed UP-sponsored ethanol response safety courses, *Railroad Safety for Ethanol and Soy Diesel Shipments* and *Railroad Emergencies General Guide to Tank Cars.*

fire chief also said that given the 0.5-mile distance to nearest residences, the emergency response efforts could, therefore, be focused on separating undamaged tank cars from those that were burning.[41]

In 2014, the FRA compared data relating to thermal failures of tank cars involved in train derailments between 2006 and 2013 and concluded that denatured ethanol tank cars pose a greater risk of high-energy explosive events than tank cars carrying volatile crude oil grades when exposed to pool fires (Alexy 2014). Comparing empirical data for postaccident pool fire damage, such as thermal tears and tank fragmentation, the FRA found that the rate of tank car thermal failure in a pool fire was 15.5 percent for tank cars carrying denatured ethanol and 9.5 percent for crude oil.

In addition, the staff director for the FRA's Hazardous Materials division stated the following at an April 2014 NTSB Rail Safety Forum:

> When you look at the damage to the tank cars, and in this case, particularly tank cars that have had thermal ruptures, thermal tears, there have—and then, I'm going to distinguish between just the thermal tear where you – you know, it opens up partially, and an incident where there's enough energy to fragment the car. When we look at those, and of all the – I think there have been approximately 31 tank cars that have experienced some type of thermal damage, and there have been, I think, 7 or 8 that have had – that were violent ruptures or the ones where the tank car fragmented, all but one has been in ethanol service (NTSB 2014).

This investigation sought to understand the differences associated with the transportation of denatured and undenatured ethanol. Ethanol for use in motor fuel will generally be denatured with 2-5 percent gasoline or similar hydrocarbon. According to the Renewable Fuels Association (RFA), the addition of denaturant to ethanol depresses its flash point, providing significantly more volatile vapor for the product to ignite following the release (RFA 2017). In comparison, the National Institutes of Health, US National Library of Medicine, reports the flash point of undenatured ethanol to be 55°F, and denatured fuel ethanol typically has a flash point range between -5 and 19.4°F (NIH 2013).[42]

The Environmental Protection Agency (EPA) Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 amendments to the Clean Air Act.[43] It is a national policy that requires a certain volume of renewable fuel, such as ethanol, to replace or

[41] For more information, see "Emergency Response Factual Report" in NTSB Docket DCA17MR007.

[42] (a) The flash point of denatured fuel ethanol varies based upon the characteristics of the denaturing agent. (b) Noble Americas Safety Data Sheet, https://mansfield.energy/assets/uploads/NASBE_MSDS_Ethanol_2015-05-19.pdf. Accessed September 12, 2018; Valero Safety Data Sheet, https://www.valero.com/en-us/Documents/OSHA_GHS_SDS/SDS%20US%20-%20035-GHS%20Denatured%20Fuel%20Ethanol%205-14.pdf. Accessed September 12, 2018; Global Safety Data Sheet, http://www.globalp.com/documents/files/SDS%20Denatured%20Fuel%20Grade%20Ethanol%20Final.pdf. Accessed September 12, 2018.

[43] (a) Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594 (2005); (b) EPA implements the RFS program in consultation with the US Department of Agriculture and the US Department of Energy.

reduce the quantity of petroleum-based transportation fuel. The RFS was amended by the Energy Independence and Security Act of 2007 (EISA).[44]

Section 202 of the EISA includes annual target volumes (goals) and requires the EPA to establish compliance obligations that refiners and importers must meet each year. The statutory target volume for total biofuel use increases from 24 billion gallons annually in 2017 to 36 billion gallons annually by 2022. However, in its December 14, 2015, final rule, the EPA responded to marketplace constraints by establishing reduced, finalized, renewable fuel volumes for the years 2014 through 2016 (*Federal Register*, 2015, 77420). Nevertheless, the EPA final rule states that nearly all the estimated 139 billion gallons of gasoline used as domestic transportation fuel contains 10 percent ethanol. Railroads account for about 70 percent of ethanol transportation (AAR 2018a).

The director of regulatory affairs for the RFA told NTSB investigators that the ethanol industry has experienced significant recent growth in the shipment of undenatured fuel ethanol, as shown in figure 11. She explained that the growth in undenatured ethanol shipments is mostly due to foreign markets in Brazil and southeast Asia in which end users request the product without denaturant added. Unlike domestic ethanol producers, foreign ethanol producers typically do not denature their ethanol product (*Federal Register*, 2016, 80828).

[44] Energy Independence and Security Act of 2007, Pub. L. No. 110-140, 121 Stat. 1492 (2007).

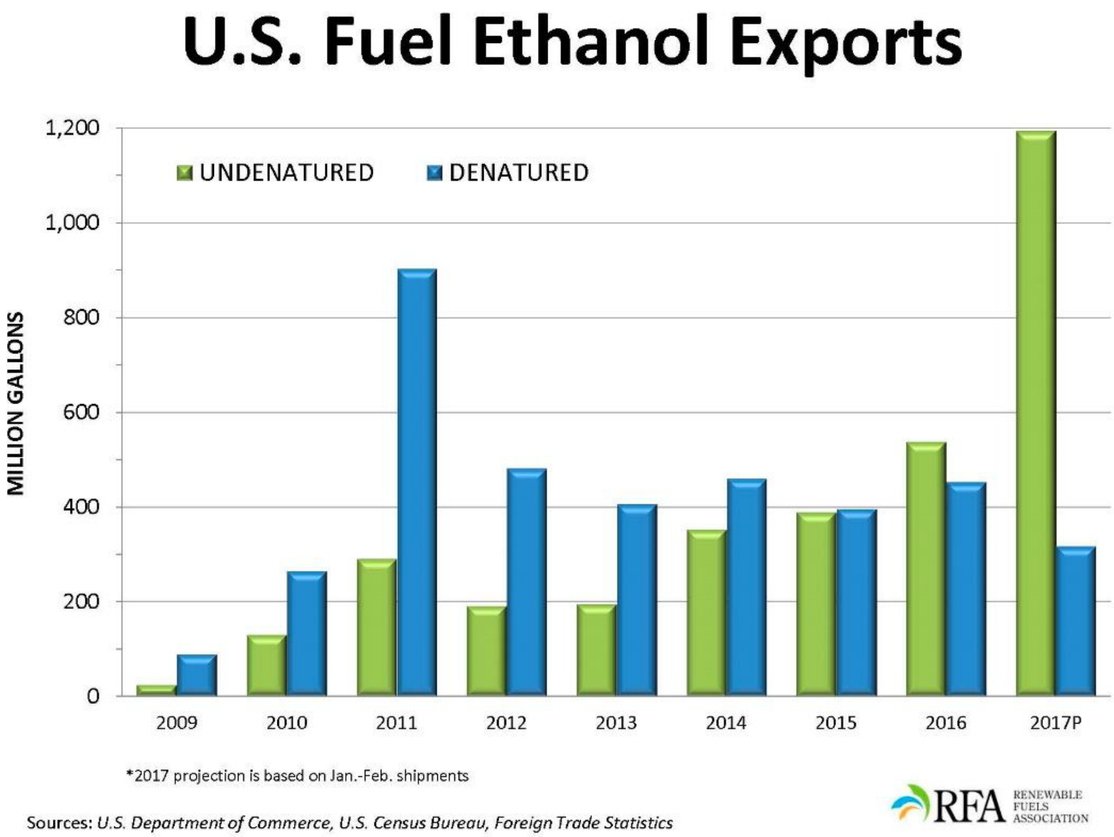

Figure 11. US 2017 export figures for denatured and undenatured ethanol. (Graphic courtesy of the RFA.)

The RFA director of regulatory affairs explained that any decision to ship ethanol as undenatured is not constrained by logistics, but rather by regulatory disincentives given the Alcohol and Tobacco Tax and Trade Bureau (TTB) beverage tax requirements. Federal law requires that ethanol produced at an alcohol fuel plant (AFP) be restricted for use exclusively as a motor fuel.[45] Before proprietors may withdraw distilled spirits from an AFP, the spirits must be rendered unfit for beverage use, otherwise the TTB requires payment of distilled spirits taxes if the ethanol is diverted to beverage use. The TTB defines fuel alcohol as having been made unfit for beverage use by adding materials to distilled spirits that will preclude beverage use without impairing their quality for fuel use.[46] Formulas for completely denaturing alcohol to make it undrinkable and thus not subject to the beverage alcohol tax are provided in 27 *CFR* Part 21, “Formulas for Denatured Alcohol and Rum.”

Under current RFS provisions, ethanol does not become a renewable fuel until a producer adds denaturant in accordance with TTB regulations at 27 *CFR* Parts 19-21. Only after a

[45] Title 26 *United States Code* (*USC*) Part 5181, “Distilled spirits for fuel use.”
[46] Rules for distilled spirits for fuel use are contained in 27 *CFR* Part 19, “Distilled Spirits Plants.”

renewable fuel producer has denatured the ethanol can they generate renewable identification numbers (RIN) for it.[47]

1.16.2 Shipping Paper Discrepancy

Placards displayed on each rail car listed United Nations (UN) Identification Number 1170, signifying undenatured ethanol. The shipping description used on the hazardous materials shipping papers that were in the train crew's possession was "UN1987, Alcohols, N.O.S., Class 3, PG II." This describes denatured fuel ethanol and is not the proper shipping description for undenatured ethanol. Emergency response information (required by 49 *CFR* 172.602, "Emergency response information") appended to the train consist described the hazards of UN1987 denatured fuel ethanol, not UN1170 absolute or undenatured ethanol.

The shipper confirmed that the lading on the accident train was undenatured ethanol UN1170. The Green Plains plant manager told investigators that the shipping documents were prepared at the company's headquarters in Omaha, Nebraska, and he could not explain the shipping name discrepancy in the train consist.

Protocols first responders follow differ based on the nature of the hazards. For example, flames of burning undenatured ethanol may be invisible in daylight and, therefore, may pose additional challenges to the first responders. Misidentified hazardous materials could cause inappropriate or delayed responses. NTSB investigators learned that when Green Plains Superior received an order for an ethanol shipment, the Green Plains corporate headquarters provided loading tracking numbers and the customer's chemical specification requirements. As the cars are loaded, an ETX Intellifuels system controlled the dispensing volumes, and reporting gross and net gallons with temperature correction. The system produced a metered ticket that displayed the shipping name in the old DOT shipping name format and identified the material by default as UN1987 denatured fuel ethanol.

The UN1987 shipping name was the only product description that was programmed into the ETX Intellifuels system 9 years ago and could not be changed by the operator. The meter tickets, which contained the wrong hazardous materials description and tank car inspection sheets which indicated the correct UN identification number for undenatured ethanol, were forwarded to the Green Plains headquarters office in Omaha, Nebraska. Once this information was received, the Green Plains logistics coordinator was then responsible for arranging shipments and preparing electronic data interchange documents for the railroad.

Following the accident, to eliminate confusion and prevent hazardous materials misdescription in future shipments, Green Plains disabled the ETX Intellifuels system function that printed the preprogrammed hazardous materials shipping name and description on its tank car loading tickets. The Green Plains headquarters uses the same coding for electronic data

[47] *RINs* are credits used for tracking compliance and are the "currency" of the RFS program. RINs are generated when a fuel is produced and may be bought, sold, and traded amongst obligated parties (refiners and importers of gasoline) and domestic and foreign market participants.

interchange documents and is used when their product order is sent to the Green Plains ethanol plant.[48]

1.16.3 Tank Car Regulations and Industry Standards

The HMR in 49 *CFR* Part 179, "Specifications for Tank Cars," outlines the federal requirements for tank cars. Subpart B of Part 179 contains general design requirements, while Subpart D contains the specifications for nonpressure tank car tanks. Additional tank car industry standards, incorporated in the HMR by reference, are found in the Association of American Railroads (AAR) *Manual of Standards and Recommended Practices*. Appendix C contains a chart describing the specifications for flammable liquids tank cars.

At the time the DOT-111 tank cars in the accident train were constructed, tank cars transporting ethanol could be fabricated of plate materials meeting the specifications that are outlined in 49 *CFR* 179.200-7, "Materials." The tank cars involved in this accident were constructed from carbon steel plates. DOT-111 tank cars must be fabricated from either TC 128 Grade B steel or A5l6-70 steel.[49] The specification requirement for DOT-111 requires a minimum plate thickness of 7/16-inch.[50] At the time these tank cars were constructed, federal regulations did not require thermal protection, tank-head puncture resistance systems such as jackets or head shields, or the use of tougher normalized steel.[51]

Pipeline and Hazardous Materials Safety Administration (PHMSA) regulation 49 *CFR* 179 (D) "Specifications for Non-Pressure Tank Car Tanks" requires that after October 1, 2015, new tank cars manufactured for use in a HHFT must be constructed to the specification DOT-117, or 117P performance standard as specified in that regulation. The regulation further required that DOT-111 tank cars used in ethanol service after May 1, 2023, and Casualty Prevention Circular Specification-1232 (CPC-1232) tank cars used in ethanol service after July 1, 2023, must be replaced with new specification DOT-117 tank cars, or existing tank cars that have been retrofitted to DOT-117R performance standards. The regulation mandates the use of DOT-117-compliant tank cars for the transportation of all Class 3 flammable liquids regardless of train composition and regardless of whether flammable liquids tank cars are assembled in a HHFT.

Retrofitted tank cars must be equipped with full height head shields, minimum 11-gauge jackets, thermal protection systems, top fittings protection, and an enhanced bottom outlet valve handle design to prevent unintentional opening in accidents.

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[48] *Electronic data interchange* is the computer-to-computer exchange of business documents in a standard electronic format between business partners.

[49] See 49 *CFR* 179.200-7, "Materials."

[50] See 49 *CFR* 179.201-1, "Individual specification requirements applicable to nonpressure tank car tanks."

[51] (a) See 49 *CFR* 179.201-1, "Individual specification requirements applicable to nonpressure tank car tanks," and 49 *CFR* 173.31 (b)(3) and (4) "Use of Tank Cars;" (b) In accordance with 49 *CFR* 173.31(b)(4), "Use of Tank Cars," the tank cars that were involved in this accident were not required to have thermal protection systems. Only tank cars that are used to transport Hazard Class 2 and poison inhalation hazard materials are required by the Hazardous Materials Regulations to have thermal protection that conforms to the specifications of 49 *CFR* 179.18, "Thermal protection systems."

Among the requirements for newly constructed DOT-117 tank cars are:[52]

- 9/16-inch normalized TC-128 steel minimum for heads and shells
- Full height 1/2-inch thick head shield
- Thermal protection system
- Minimum 11-gauge jacket
- Top fittings protective housing, minimum 1/2-inch thick
- Enhanced bottom outlet handle design to prevent unintended actuation during a train accident
- 286,000 pounds gross rail load (GRL) authorized

1.16.4 Flammable Liquids Tank Car Fleet

The Green Plains transportation and logistics vice president told NTSB investigators that the company selects tank cars according to market prices, which vary according to numbers leased and the lease duration. The lease agreements are full-service contracts in which the rail car retains the lessor's reporting mark and the lessor is responsible for most of the maintenance and administrative record keeping. Tank cars are assigned by availability, usability, and potential weight restriction for servicing the railroad at each of the Green Plains plants. He stated that tank cars constructed to 286,000 GRL, such as DOT-117 tank cars, may not be capable of full-capacity loading because of track infrastructure limitations on rail lines leading into some ethanol plants.[53]

The Green Plains transportation and logistics vice president told investigators that company management is fully aware of the applicable rules and the 2023 phase-out deadline for DOT-111 tank cars, and, thus, the logistics team is tasked with ensuring compliance on behalf of the company. He stated that to ensure the fleet remains compliant, Green Plains has been negotiating replacement plans and the movement of tank cars into and out of the fleet during repair periods arranged by the lessors. He further stated that Green Plains intends to adhere to the law.

NTSB investigators examined the UMLER database records for each of the seven rail car fleet owners that leased the tank cars used in the accident train to Green Plains. Table 3 provides the changes in the number of legacy DOT-111, CPC-1232, and DOT-117 tank cars in the respective overall fleets between January 2016 and April 2017.

[52] See 49 *CFR* 179.202, "Individual specification requirements applicable to DOT-117 tank car tanks."
[53] Legacy DOT-111 tank cars not constructed to CPC-1232 standards are limited to 263,000 pounds GRL.

Table 3. UMLER tank car statistics by owner, January 2016 vs. April 2017.

Car Owner[a]	Year	DOT-111	CPC-1232	DOT-117	DOT-117R
1	2016	3,397	200	0	0
	2017	2,975	200	0	0
	Change	-422	-	-	-
2	2016	10,022	12,325	930	4
	2017	9,352	11,710	2,549	270
	Change	-670	-615	+1,619	+266
3	2016	3,527	1,354	200	0
	2017	4,740	1,476	451	153
	Change	+1,213	+122	+251	+153
4	2016	4,761	4,916	100	0
	2017	5,868	4,926	100	8
	Change	+1,107	+10	-	+8
5	2016	698	0	0	0
	2017	673	0	0	0
	Change	-25	-	-	-
6	2016	16,174	9,154	100	114
	2017	16,096	8,958	3,390	612
	Change	-78	-196	+3,290	+498
7	2016	518	105	0	0
	2017	547	120	0	0
	Change	+29	+15	-	-

[a.] For the purposes of this report, the tank car fleet owners were not identified by name.

AAR ethanol tank car fleet utilization data indicated that about one-third of the tank cars shipping ethanol today are now DOT-117 compliant. (See figure 12.) First quarter 2018 AAR data for tank cars in ethanol service indicated there remains about 18,700 jacketed and nonjacketed DOT-111, 2,020 nonjacketed CPC-1232, and 1,000 jacketed CPC-1232 tank cars that must be replaced or retrofitted to DOT-117 specifications. AAR reported that about 350 tank cars a month would need to be replaced or retrofitted to achieve the 2023 deadlines for replacing legacy DOT-111 and CPC-1232 tank cars, and the 2025 deadline for replacing jacketed CPC-1232 tank cars (AAR 2018b).

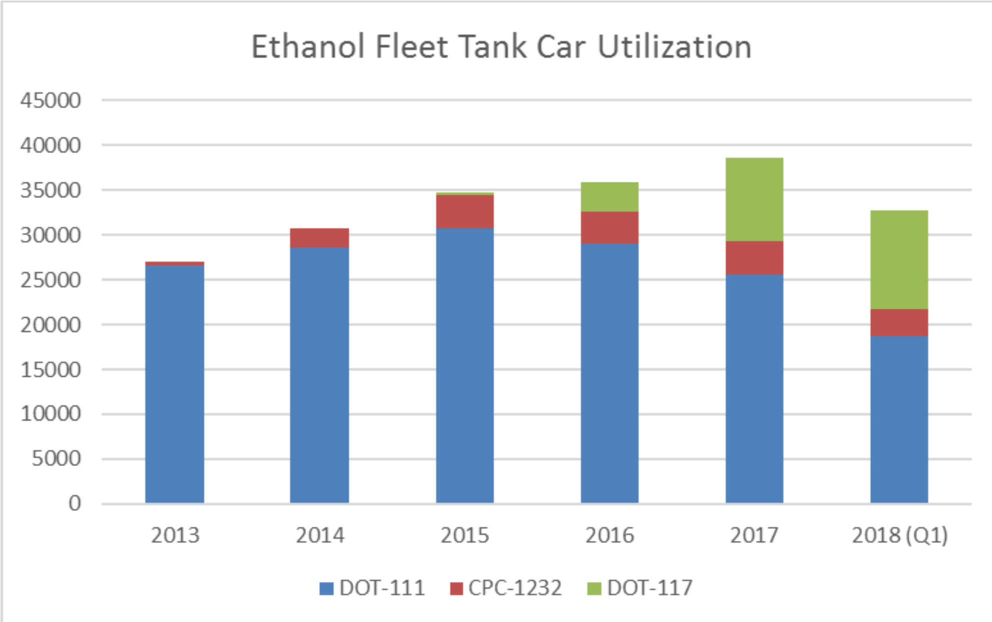

Figure 12. Ethanol shipments by tank car type, 2013 – Q1 2018. (Chart courtesy of AAR.)

1.17 Tests and Research

1.17.1 Examination of Recovered Rail

As discussed in section 1.15.1, NTSB investigators recovered about 390 feet of north rail and 385 feet of the south rail while on scene. This left about 10 feet of the north rail and 15 feet of the south rail unrecovered.

The recovered rail pieces were arranged on scene in their respective positions at the time of the derailment by matching up the fracture faces of the broken sections and cross-referencing features from UP track records on the Estherville Subdivision. The records described the locations of welds that joined two pieces of rail together and contained information on rail type, length, and milepost.

Many of the recovered rail pieces on scene exhibited prominent features, which included rail batter, wheel flange elevation (riding up), flakes, split webs, fire deposits, and recovery breaks.[54] These features were consistent with damage typical of a loaded freight train derailment.

Several rail pieces were sent to the NTSB Materials Laboratory for further examination. The tests included nondestructive visual examination, scanning electron microscopy, optical metallography, hardness testing, and material chemical composition testing.[55] The results of the examination are discussed in section 2.3.

[54] For more information, see “Materials Laboratory Factual Report 17-050” in NTSB Docket DCA17MR007.
[55] For more information, see “Materials Laboratory Factual Report 17-050” in NTSB Docket DCA17MR007.

1.17.2 Evaluation of Net Braking Ratio

In response to an NTSB request, investigators traveled to the Trinity rail tank car maintenance facility in Saginaw, Texas, to witness in-service tank car net braking ratio tests on three exemplar undamaged tank cars from the accident train. The brake systems performed within their design parameters.[56]

1.17.3 Finite Element Study

Finite element (FE) modeling was used to examine the effects of rail profile and track support conditions on the deformation and stresses in 90-pound rail under tank car wheel loads.[57] Two three-dimensional FE models of the 90-pound rail track were constructed. One model, based on drawings provided from UP, had a standard (unworn) rail profile and assumed stiff track support conditions. The other model had a worn rail profile based on measurements collected on rail profiles from the accident and assumed less stiff track support conditions.[58] Internal rail stresses and rail deformations from the two models were compared. (See figure 13.)

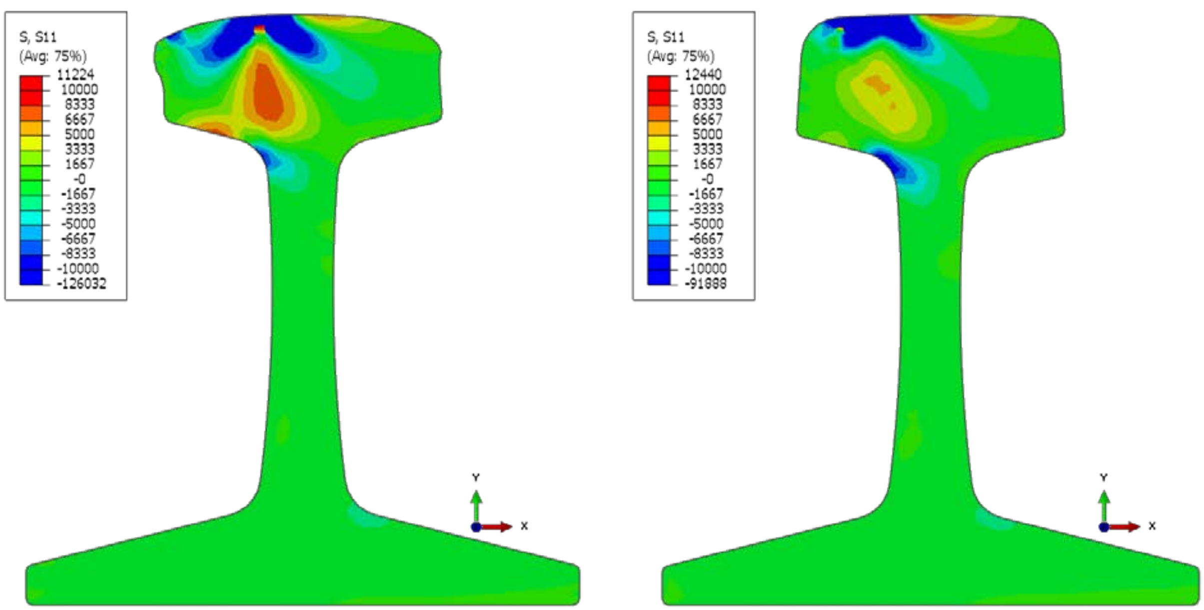

Figure 13. Comparison of the calculated internal transverse stresses of 90-pound rail supporting wheel loads using a worn rail profile with soft track support (left) and standard rail profile with stiff track support (right). In both illustrations, the gage side is on the left and the field side is on the right.

The model showed that the transverse stress in the rail head region was dependent on the head area of the rail cross-section and the track support conditions. A worn rail has less head area, which results in higher transverse stress in the head region. Comparing the two rail profiles

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[56] For more information, see "Mechanical – In-Service Tank Car Net Braking Ratio Testing" in NTSB Docket DCA17MR007.

[57] For more information, see "Finite Element Modeling Study Report" in NTSB Docket DCA17MR007.

[58] The model was derived from rail profile measurements using a MiniProf rail profile measurement system.

and track support conditions modeled in the study, the peak transverse stress was about 50 percent higher for the case with the worn rail profile and less stiff support. The area with relatively high transverse stress [greater than 5 thousand-pounds-per-square-inch (ksi)] was considerably bigger. The transverse stress in the head region is known to be related to a vertical split head failure since it has the potential to open up cracks in the vertical direction.

1.18 Postaccident Actions

FRA inspectors returned to the Estherville Subdivision in May 2017 and conducted walking and hi-rail inspections between MP 78.4 and MP 0.0; with the only exclusion being between MP 59.0 and MP 48.59. NTSB investigators requested records related to these inspections. As a result of these inspections, 78 defective track conditions were noted, of those, 51 were locations with defective crossties and 5 were locations with rail fasteners not maintaining track gage. The reports included no recommendations for civil penalties.

On November 13, 2017, UP officials informed NTSB investigators of the following postaccident actions on Estherville Subdivision and other nearby subdivisions since the accident:[59]

- Year-to-date [2017] regional work crews have installed about 8,600 crossties since the derailment in March 2017
- UP's 2018 capital program included the Grain Line crosstie program[60]
- UP's 2018 capital program included fortifying all bridge approaches on the aforementioned subdivisions with 10-foot approach crossties
- UP has reduced the maximum allowable speed on all Class 2 subdivisions on these Grain Lines from 30 mph to 25 mph
- UP has reduced maximum allowable speed on the portion of the subdivision that was 49 mph to 40 mph
- UP has increased the frequency of rail detector car tests on the Grain Lines from once per year to twice per year
- UP completed all of the requirements of the FRA compliance agreement by the end of 2017
    - Track inspections increased in accordance with the FRA compliance agreement, including additional track inspectors, GRMS testing, geometry car inspections, and rail detector car inspections

[59] For more information, see "UP Post-Accident Action Letter" in NTSB Docket DCA17MR007.
[60] The *Grain Line* is the name of UP's work effort.

  - Specifically, UP increased track inspections on Class 3 track by one additional test per year. Main line and siding inspections increased from twice annually to three times per year

UP officials provided NTSB investigators with an update on its postaccident actions on August 14, 2018:[61]

- UP anticipates over 600,000 crossties will be installed on the Grain Line by the end of 2018 and that the Grain Line crosstie program will be completed in 2019

- UP's 2018 capital program was approved for bridge approach crossties

- Year-to-date [2018], UP is in compliance with the testing and inspection requirements of the FRA compliance agreement

On November 16, 2017, FRA officials informed NTSB investigators of the following postaccident actions on the Estherville Subdivision since the accident:

- FRA conducted a comprehensive inspection of the track structure on UP's Estherville Subdivision, where the accident occurred. UP has corrected the conditions noted during that inspection

  - UP has put on a divisional work crew to correct the defects identified by FRA inspectors and added an additional 150 ties-per-mile under the 90-pound rail

- FRA continues to monitor UP's efforts to address the issues raised in the December 2016 compliance agreement related to deficiencies in UP's track inspection and maintenance programs

- UP completed all the requirements of the FRA compliance agreement that were due by the end of 2017 on time

  - UP has increased track inspections per the compliance agreement. Inspections include track inspectors, GRMS testing, geometry car inspections, and rail detector car inspections

FRA has scheduled its automated track inspection program car to inspect Estherville and surrounding subdivisions in October 2018.

[61] E-mail from a UP official to NTSB in response to written questions, August 14, 2018.

FRA officials provided NTSB investigators with an update on the status of the compliance agreement on August 21, 2018:[62]

- UP has been complying with all items in the compliance agreement
- UP is ahead of schedule in meeting the deliverables for the compliance agreement. Although the final deadline for these deliverables is the end of 2019, UP has the potential to exceed the required deliverables by the end of 2018
- UP continues to increase track inspections, GRMS testing, geometry car inspection, and rail detector car inspections

[62] E-mail from FRA official to NTSB in response to written questions, August 21, 2018.

2 Analysis

2.1 Introduction

The NTSB considered the following factors in the investigation of this accident: (1) the condition of the track and structure on the Estherville Subdivision, (2) the adequacy of UP's track maintenance and inspection program, (3) rail metallurgy, (4) the performance of 90-pound worn rail, (5) DOT-111 tank cars in ethanol service, (6) the transportation of fuel ethanol without denaturant, (7) ethanol product shipping paper discrepancy, (8) the mechanical condition of the train, (9) the performance of the train crew, (10) cell phone use by the train crew, (11) alcohol or other drugs by the train crew, and (12) the emergency response.

2.2 Estherville Subdivision

2.2.1 UP's Track Inspection Program

NTSB investigators determined that although UP track inspectors were identifying some defective crosstie conditions, not all defective conditions were reported or remediated. As an example, two defective conditions were identified and remediated by UP the day before the accident. However, both NTSB investigators and FRA inspectors identified more defects postaccident that had not been recorded during that UP inspection.

The adequacy of the UP's maintenance and inspection program has been addressed in previous NTSB investigations. On December 20, 1998, Amtrak (National Railroad Passenger Corporation) train 21 derailed while operating on UP track in Arlington, Texas. In that investigation, the NTSB determined that one element of the probable cause was "inadequate Union Pacific Railroad oversight of track maintenance work on this section of track." As a result of this investigation, NTSB made the following recommendation to UP:

> Revise your track maintenance policies and practices to establish quality control procedures for track repair and maintenance activities. These procedures should be designed to ensure that the type of maintenance to be performed is appropriate to address the specific problem and that the maintenance itself is performed correctly. (R-01-16)

In response to this recommendation, UP developed its *Engineering Track Maintenance Field Manual* and provided training to its employees. UP also developed an evaluation process for its managers to determine if these standards are being met. Therefore, on May 28, 2003, the NTSB classified Safety Recommendation R-01-16 as *Closed—Acceptable Action* (NTSB 2001).

On May 27, 2000, 33 cars of a UP freight train carrying hazardous materials derailed in Eunice, Louisiana. The derailment resulted in a release of hazardous materials with explosions and fire. About 3,500 people were evacuated from the surrounding area, which included some of the business area of Eunice. No one was injured during the derailment of the train or the subsequent release of hazardous materials. The NTSB determined the probable cause was "the failure of a set of joint bars that had remained in service with undetected and uncorrected defects because of Union Pacific Railroad's ineffective track inspection and inadequate management oversight." As a result of this investigation, the NTSB recommended that UP:

> Change your track inspection programs to ensure that managers are making use of all available information about track conditions, including railroad and Federal Railroad Administration track inspection reports, to identify trends or problem areas and to monitor the effectiveness of daily track inspections. (R-02-14)

In response to this recommendation, UP established a team of field managers to lead its quality assurance effort and developed and implemented an electronic track inspection reporting system. Therefore, on August 9, 2002, the NTSB classified Safety Recommendation R-02-14 as *Closed—Acceptable Action* (NTSB 2002).

The NTSB investigation noted the marginal crosstie conditions on the Estherville Subdivision, based on reviewed UP track inspection records, FRA track inspection records, and postaccident walking inspections. FRA regulations contain minimum safety standards that address defective crossties.[63] UP also has minimum safety standards that address crossties; however, the NTSB determined based on evidence that the track structure in the accident area was not consistently maintained to those standards (UP 2017). Table 4 shows the parameters for a crosstie to be considered defective.

Table 4. Comparison of UP vs. FRA defective tie standards.

UP Defective Crosstie Condition Standards	FRA Defective Crosstie Condition Standards
Broken through or hollow.	Broken through.
Split or otherwise impaired to the extent that ballast works through.	Split or otherwise impaired to the extent the crosstie will allow the ballast to work through or will not hold spikes or rail fasteners.
Unable to hold spikes or other rail fasteners.	Will not hold spikes or rail fasteners.
Deteriorated to the extent that the tie plate or base of the rail can move laterally 1/2 inch or more in relation to the tie.	So deteriorated that the crosstie plate or base of rail can move laterally 1/2 inch relative to the crosstie.
Cut by wheel flanges or dragging equipment, or damaged by fire or other sources to a depth of more than 2 inches within an area closer than 12 inches to the base of the rail, frog, or other load bearing component.	Cut by the crosstie plate through more than 40 percent of a crosstie's thickness.

FRA provided the following guidance regarding crossties and inspection of crossties in its *Track and Infrastructure Integrity Compliance Manual* (Volume 2), dated January 2017:

> Crossties are evaluated individually by the definitional and functional criteria set forth in the regulations. Crosstie "effectiveness" is naturally subjective and requires good judgment in the application and interpretation of this standard. The soundness and durability of a crosstie is demonstrated when a 39-foot track segment maintains safe track geometry and structurally supports the imposed wheel loads with minimal deviation. Key to the track segment lateral, longitudinal, and vertical support is a strong track modulus, which is a measure of

[63] FRA minimum standards are set forth in 49 *CFR* 213.109(c), "Crossties."

> the vertical stiffness of the rail foundation. Continuous superior superstructure (including rails, crossties, fasteners, etc.) and high-quality ballast characteristics that transmit both dynamic and thermal loads to the subgrade are also important. Proper drainage that is free from the presence of excess moisture is an apparent and crucial factor in providing added structural support (FRA 2017).

Crossties do not deteriorate in a matter of days—to the extent they are split, broken, and unable to hold rail fasteners—but do so over time. The useful service life of crossties varies greatly depending on track geometry characteristics, rail vehicle interaction, equipment axle loads exerted on the track, and environmental conditions. For this reason, the proper inspection of crossties requires visual inspection and performance-based measuring with accurate records to identify changes. Though the NTSB was not able to determine if the condition of the crossties at the POD contributed to the derailment, it is imperative that tracks are maintained in compliance with all minimum safety standards. The NTSB concludes that UP was not maintaining the track structure on the UP Estherville Subdivision in accordance with FRA minimum TSS or its own internal track maintenance standards.

An organization's oversight, in principle, provides assurance that front-line personnel ensure any system meets minimum safety requirements. In this case, the UP track supervisors were required to ensure their inspectors were identifying and remediating defects in accordance to UP internal track maintenance standards and FRA minimum TSS. As mentioned above, two defective crosstie conditions were identified and remediated by UP the day before the accident and NTSB investigators and FRA inspectors identified more defects that would have existed at the time of the prior UP inspection and were not recorded as part of that inspection. Therefore, the NTSB concludes that UP supervisors and managers were not ensuring defective crosstie conditions were being identified, reported, and remediated in accordance with UP track maintenance standards and FRA TSS. Therefore, the NTSB recommends that UP reexamine its track maintenance and inspection program standards to ensure those track inspection standards are complied with by both track inspectors and track supervisors.

2.2.2 Transition Regions

Bridge approaches are where there are changes in the vertical stiffness of the track structure, sometimes referred to as track transition regions. The American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* contains information regarding track transition problems, as well as track transition remedies and practices. The AREMA manual states:

> *Track Transition Problem*-stiffness transition regions are locations where railway track exhibits abrupt changes in vertical stiffness. They usually occur at abutments of open deck bridges, where concrete tie track changes to wooden tie track, at the ends of tunnels, at highway grade crossings, or at locations where rigid culverts are placed close to the bottom of ties. Abrupt changes in track stiffness result in increased dynamic wheel loading, accelerated track degradation etc., and poor ride quality. These locations have been seen to deteriorate significantly faster than regular track and require frequent maintenance.

> *Track Transition Remedies and Practices*-in practice, several methods have been developed to alleviate the problems associated with abrupt changes in vertical track stiffness. These methods all attempt to match vertical track stiffness whenever possible. Abrupt changes in vertical track stiffness have historically presented maintenance problems to railroads and empirical methods have been used to try to correct the problem. These include gradually stiffening the approaches entering or leaving a high stiffness zone and reducing the stiffness on the hard side (e.g. grade crossing) of the track (AREMA 2016).

Section 1.8 of the UP *Engineering Track Maintenance Field Handbook* discusses track transitions, and states:

> One of the highest maintenance issues for mainline track is maintaining track transitions. Typical problems are: bridge abutments; road crossing; turnouts; and tunnels. Where ballasted track changes to a structure there can be: accelerated track geometry and component degradation; increased maintenance; and chronic maintenance. Track transition maintenance issues can be attributed to the: abrupt change in vertical stiffness; ballasted track settling faster than structures; and the settlement of ballasted track is highly variable. The track transition maintenance issues can be found through track inspections; evaluation cars; and vehicle track interaction (UP 2017).

Section 3 of the UP *Engineering Track Maintenance Field Handbook* covers crossties and fastenings. In the handbook, table 3-I sets forth the requirement for 10 crossties of 10 feet each to be installed in the transition zone on the approach of open-deck bridges (UP 2017).

During FRA inspections conducted in May 2017, FRA inspectors documented conditions of track on the approaches of 12 bridges on the Estherville Subdivision. They reported five bridges had either fouled or had insufficient ballast at one or both bridge ends. In addition, the inspectors observed five bridges did not have 10-foot transition ties in the track transition regions. Based on the examination of aerial photographs of the postaccident condition of the ties in place up to the approach on the west side of Jack Creek Bridge, the 10-foot transition ties were not installed in the transition zone.

Based on available evidence, the investigation could not conclusively determine if there were vertical track transition issues on the Estherville Subdivision on the west approach to Jack Creek Bridge. However, the available evidence does show that there were no 10-foot transition ties on the west approach to Jack Creek Bridge that could mitigate risk of abrupt changes in vertical track stiffness, avoiding localized dynamic wheel loading, which could otherwise lead to a deteriorating track structure and rail failure.

Postaccident actions in this accident recognize that UP's 2018 capital program, that included a plan for replacing inferior crossties, contained elements for all bridge approaches on the aforementioned subdivisions to be fortified with 10-foot approach ties.

2.2.3 FRA Oversight

The NTSB considered the effectiveness of FRA's oversight on the Estherville Subdivision in this investigation. FRA track inspection records from 2015 through the day of the accident showed that inspectors had concerns with the crosstie conditions on the subdivision and near the derailment location. Two FRA inspections were completed in the area of the derailment of the Estherville Subdivision in 2015. These inspections were conducted in March and July by different inspectors. These reports documented 11 defective conditions with 9 of those being locations with defective crossties. In March 2015, one FRA inspection report contained a comment regarding marginal crosstie condition "approaching defective condition." In July 2015, an FRA inspector provided comment on an FRA inspection report about the marginal crosstie condition for the class of track being operated in the area. In addition, the inspector said that those crossties were close to the end of their life and another winter cycle would most likely put those areas in noncompliance. The inspector also emphasized that this was an ethanol route.

FRA inspection reports from MP 78.4 to MP 44.0 on August 10, 2016, documented 10 locations with crossties that did not meet the minimum requirements of FRA TSS. The inspector characterized the crosstie condition as being "marginal" and in many areas "defective," emphasizing in the report that this was an ethanol route and the risk was evident. No civil penalties were recommended in any of these inspection reports.

Although FRA track inspectors identified some defective crosstie conditions, others were documented as comments to the railroad, rather than defects subject to civil penalties. In May 2017, when the FRA returned to the Estherville Subdivision and conducted walking and hi-rail inspections, they documented 78 defective track conditions. Of those, 51 were locations with defective crossties and 5 were locations with rail fasteners not maintaining track gage—a clear demonstration that not all defective crosstie conditions were being reported by FRA inspectors. As previously mentioned, crossties do not deteriorate in a matter of days—to the extent they are split, broken, and unable to hold rail fasteners—but do so over time. Title 49 *CFR* 213.241, "Inspection records" requires the location and nature of any deviations from the requirements of FRA TSS to be specified on the inspection record. Although the crosstie conditions near the accident location were brought to the attention of UP in March 2015 and again in 2016, defective crossties remained on the track until after the derailment.

The NTSB concludes that FRA inspectors did not report all defective crosstie conditions on the UP Estherville Subdivision in the 2 years prior to the derailment. Furthermore, for those crosstie conditions that FRA inspectors identified as defective, the FRA did not use enforcement options, such as civil penalties, to compel UP to comply with safety regulations and to repair safety defects identified by FRA inspectors. Therefore, the NTSB further concludes that FRA inspectors were not using all available enforcement options, such as a recommendation for civil penalties, to require UP to comply with FRA minimum TSS on the Estherville Subdivision. Therefore, the NTSB recommends that the FRA provide additional training to all its track inspectors on regulatory track safety standards compliance and provide guidance of available enforcement options to obtain compliance with minimum TSS when defective conditions are not being properly remediated by railroads on all routes that carry high hazardous flammable materials.

When the FRA entered into a compliance agreement with UP in December 2016, the impetus was the derailment of an HHFT train in Mosier, Oregon, in June 2016. In that derailment, the FRA found that the train had derailed because of wide gage, a condition that occurs when the tracks are too wide to support normal wheel rail contact. According to the FRA's investigation, the wide gage resulted from the failure of the track's fasteners used to hold the tie plates in position. The FRA found that the fasteners could not adequately restrain the rail because they were worn, sheared, and in disrepair. The FRA also found evidence of other disrepair near the POD.[64] In subsequent inspections of UP crude oil routes on subdivisions located in Oregon, the FRA found 159 defects with 26 of those related to track fasteners.

The FRA has conducted other inspections on UP track which resulted from derailment investigations, which raised their level of concern of UP's track maintenance and inspection program. In January 2015, the FRA commenced a program called the Crude Oil Route Track Examination (CORTEX). This program involved a series of FRA inspections specifically targeted at railroad tracks where crude oil and/or ethanol was transported and was conducted in every FRA region for every Class I railroad across the country.

The FRA had been using some, but not all, of its available enforcement options to help UP improve compliance with federal TSS. The results of the CORTEX inspections demonstrated that more work is needed to improve the track conditions of UP's HHFT routes. The FRA sought out the compliance agreement as an alternate to a compliance order.

During his interview, NTSB investigators asked the RA how the 2016 Compliance Agreement between the FRA and UP affected the inspection activity on the Estherville Subdivision. The RA answered, "It has absolutely no bearing on the Estherville Subdivision." He said that it was his understanding that the compliance agreement applied to main track territory, not branch line territory. However, when NTSB investigators followed up with the FRA requesting a definition of a branch line, the FRA responded that there is no official definition of a branch line and the Estherville Subdivision was subject to the requirements of the compliance agreement. Had the FRA RA been aware that the requirements of the compliance agreement applied to the Estherville Subdivision, there may have been an increased regulatory presence identifying track defects in the area around the derailment. However, the compliance agreement had only been in place for 3 months prior to the accident; therefore, the NTSB is unable to determine the efficacy of the compliance agreement at the time of the accident.

After the postaccident inspections were completed, FRA officials informed NTSB investigators that UP corrected the defects identified by FRA inspectors and added an additional 150 crossties-per-mile under the 90-pound rail, thus increasing the strength of the track structure. As of August 2018, UP installed over 200,000 crossties since the derailment. According to the FRA, UP met all the requirements of the FRA compliance agreement by the end of 2017, but the FRA continues to monitor UP's efforts to address the deficiencies in its inspection and maintenance programs.

[64] For more information, see "FRA-UP Safety Compliance Agreement- Dated 12/22/2016" in NTSB Docket DCA17MR007.

As of December 2016, the CORTEX inspections revealed about 5,700 defects on UP's system and, as of that date, the FRA considered enforcement action for more than 800 documented violations. In addition, both prior to and following the Mosier derailment, the FRA repeatedly engaged with UP regarding its track maintenance and inspection program. UP willingly entered into the December 2016 compliance agreement with the FRA.

2.3 Rail Metallurgy

The fresh horizontal impact damage observed on the wheel tread of the 4th through the 20th nonderailed cars that moved over the bridge immediately prior to the derailment was consistent with rolling wheels contacting an exposed leading edge of a broken rail segment. The broken rail segment's leading edge impacted the wheels' treads as they rolled over the damaged area, leaving behind impact damage. NTSB investigators did not observe any horizontal impact damage to the wheel tread on the wheels that traveled over the north rail; however, they documented a total of 14 tank cars and locomotives that had traveled over the south rail which had fresh horizontal wheel damage to the tread. The observed wheel impact damage was more pronounced on the south side wheels of tank cars that were further from the locomotive consist, indicating that the broken rail sections of track became progressively worse until the south rail was no longer able to support the train.

NTSB's Materials Laboratory Factual Report includes examination details on a particular section of the broken rail—a section of the south rail measuring 3 feet, 4 inches—that was located near the Jack Creek Bridge.[65] (See figure 14.)

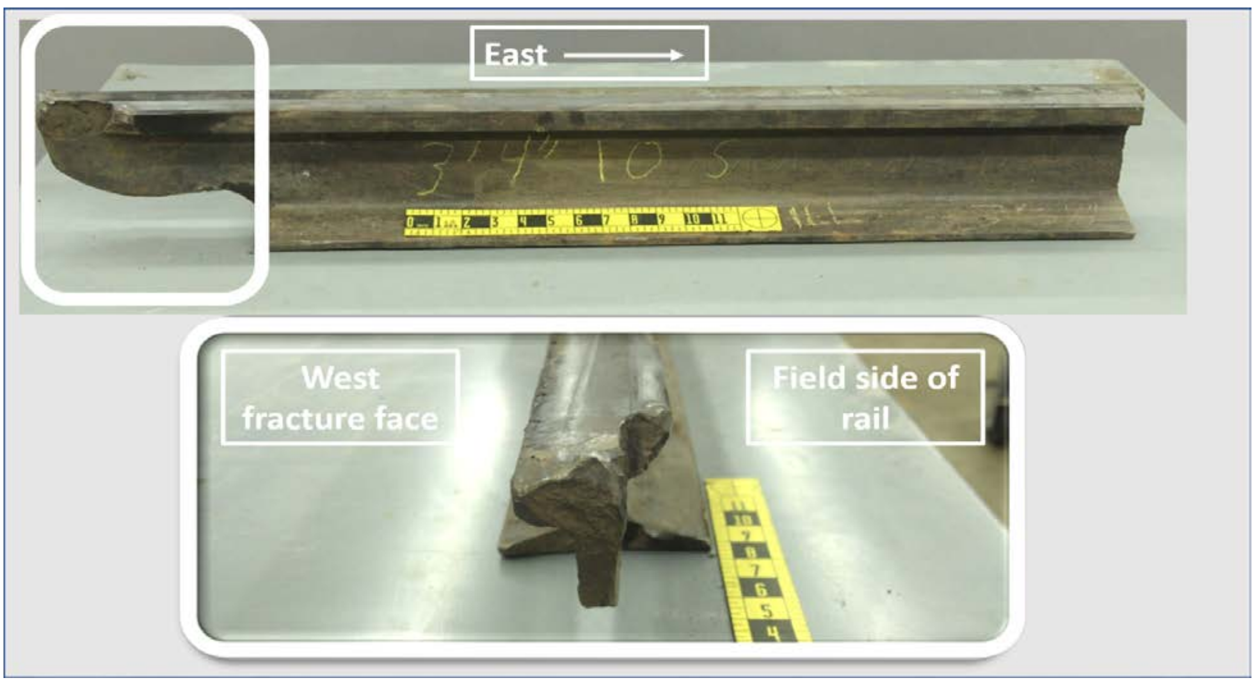

Figure 14. Section 10S from the south rail that was recovered from the accident, showing the field side and the west fracture face.

[65] Section 10S.

Longitudinal impact damage, also known as head batter, was present on much of the west fracture face, although it was generally angled facing the field side of the rail. In addition, the gage side (side opposite of the field side) of the rail exhibited features, or defects, consistent with rolling contact fatigue.[66]

Head checking, flaking, shelling, and rail head defects have been known to lead to progressive cracking (predominantly by fatigue) inward, which leads to rail fracture, and were all present on section 10S. It is possible that there may have been a critical preexisting material or mechanical defect on one of the unrecovered pieces of rail. However, there was no direct evidence to suggest this, and any possibility is speculative. Examination of the head wear and the other head damage was generally inconsistent with the widespread preexisting damage of section 10S. The most damaged rail heads were inspected using ultrasonic testing, and none of those inspected revealed crack indications consistent with internal cracking.

2.3.1 Rail Break

In its examination of the recovered pieces of rail, the NTSB Materials Laboratory determined all of the fracture surfaces of the examined rail from the accident exhibited features consistent with overstress fracture. Microscopic examination of these fracture surfaces revealed cleavage facets, consistent with overstress fracture of lower-ductility alloys. None of the rail fracture surfaces exhibited features consistent with preexisting cracks or defects that would have led to rail failure in this case.

The importance of proper maintenance to the track structure plays a significant role in the safe operation of a railroad. Proper maintenance assures that all the components of the track structure are performing as designed. In this investigation, NTSB investigators determined that UP was not maintaining its track structure on the UP Estherville Subdivision in accordance with FRA minimum TSS or its own internal track maintenance standards. In addition, NTSB investigators determined that not all defective crossties were being identified, reported, and remediated according to UP track maintenance standards and FRA TSS. NTSB investigators determined that the FRA did not report all defective crosstie conditions on the UP Estherville Subdivision in the 2 years prior to the derailment. In addition, they were not using all available enforcement options, such as a recommendation for civil penalties, to require UP to comply with FRA minimum TSS of the Estherville Subdivision. Based on the observation of the fresh horizontal impact damage observed on the wheel tread of the 4th through the 20th nonderailed cars, examination of the rail recovered from the accident, and the condition of the crosstie structure on the Estherville Subdivision, the NTSB concludes that the train likely derailed from a broken south rail that occurred prior to or at the 20th car of UP train UEGKOT-09 as it was traveling over the west approach of the Jack Creek Bridge, resulting from UP’s inadequate track maintenance and inspection program and the FRA’s inadequate oversight of the application of federal track safety standards.

[66] *Rolling contact fatigue* is defined as a failure or material removal driven by crack propagation caused by the near-surface alternating stress field.

2.4 Finite Element Analysis of 90-Pound Worn Rail

Finite element modeling was used to explore the effects of worn rail and possibly degraded track support conditions. NTSB investigators measured rail wear but track support stiffness values were derived from data reported in the literature.[67] A worst-case scenario with worn rail and less-stiff track support was compared to the best-case scenario of unworn rail and stiff track support. As expected, the degraded track exhibited higher stress levels under wheel loads compared with the best-case conditions, but the increased stresses in the assumed worst-case scenario were not sufficient by themselves to lead to track failure. It cannot be stated that any of the modeled track support conditions corresponded to the actual conditions at the accident site.

Based on the FE modeling results, the peak rail deflection and peak longitudinal stress were both about three times higher with worn rail and soft track support conditions than with standard (unworn) rail and stiff track support conditions.

The FE modeling results further showed that the transverse stress in the rail head region was dependent on the head area of the rail cross section and the support condition. A worn rail has less head area, which will result in higher transverse stress in the head region. Comparing the two rail profiles and track support conditions modeled in the study, the peak transverse stress was about 50 percent higher for the case with the worn rail profile and soft track support, and the area with relatively high transverse stress (greater than 5 ksi) was considerably larger. The transverse stress in the head region is known to be related to vertical split head failure because it has the potential to open up cracks in the vertical direction. However, in absence of evidence that the accident rail failed due to the vertical split head failure mode, it cannot be stated that the worn rail profile was responsible for the rail fracture during the accident.

Based on the results of this study, the NTSB concludes that a deteriorated track structure, such as worn rail and degraded track support conditions, will cause more track movement and higher stresses in the rail. In particular, the NTSB concludes the finite element study demonstrates that worn 90-pound rail on a degraded track support will result in higher transverse stress in the rail head region, exposing the rail to increased risks of failure due to a vertical split-head failure mode. However, the NTSB's FE study also showed no indications that the track was in danger of failure by overload, assuming that the loads, track, and support conditions in the model were representative of the actual conditions.

2.5 DOT-111 Tank Cars in Ethanol Service

The involvement of US DOT Specification-111 (DOT-111) tank cars in this accident further demonstrates the vulnerability of tank car heads and shells to breaching damage. FRA research relating to puncture performance suggests that several variables influence the ability of tank cars to resist puncture from impacting objects. This section describes why existing DOT-111 tank cars used to transport flammable liquids must be replaced expeditiously with newly available better-performing tank cars that are designed to resist lading release in derailment situations.

[67] For more information, see "Finite Element Modeling Study Report" in NTSB Docket DCA17MR007.

2.5.1 Tank Head Breaches

Fourteen of the 20 derailed tank cars released ethanol in this accident. Of those, 10 tank cars sustained mechanical impact damage causing punctures, fractures, and tears that breached tank heads and/or shells.[68] One tank car released product from a small thermal tear. Three tank cars released product only because of damage to top fittings and bottom outlet valves.

Although the calculated puncture resistance energies for tank car heads is greatest in the center of a head, this area on tank cars TCBX 198194 (24th) and TAEX 2909 (29th) were punctured.

Large-diameter rounded dents are evidence of head-to-head impacts between several tank cars. Such was the case with the 34th car, CTCX 731383, in which its B-end head sustained a deep rounded dent from impact with another tank car. Similar damage occurred to the 36th car, CTCX 731997, that caused an 8-inch crack in deeply folded material on the A-end head.

The NTSB investigated other accidents where tank head protection systems on nonpressure tank cars transporting flammable liquids successfully prevented tank breach and subsequent releases. For example, on April 30, 2017, a standing Canadian National Railway (CN) crude oil unit train was struck from behind at a speed of about 33 mph by a CN manifest train in Money, Mississippi. A crude oil tank car, CBTX 718470, constructed to new DOT-117 specifications with 9/16-inch normalized steel heads and shells, thermal protection, full-height 1/2-inch thick headshield, and tank jacket, sustained a head impact from the rear CPC-1232 tank car that was driven forward by the collision. NTSB investigators observed that the DOT-117 tank car head shield successfully intercepted the impacting CPC-1232 tank car head without transmitting breaching damage to the tank head.[69] The DOT-117 tank car did not release any crude oil in the accident.

Additional evidence demonstrating the value of tank head protection systems was found in the investigation of the February 16, 2015, derailment of nonjacketed CPC-1232 tank cars transporting crude oil in Mount Carbon, West Virginia.[70] Head shields successfully protected the heads of two tank cars that otherwise might have breached.

Head shields are designed to absorb and distribute an impact load over a greater surface area on the tank head. By doing so, the energy required to fracture or rupture the tank head is increased (Tyrell and others, 2007). A one-half-inch thick full-height head shield could have prevented, or at least mitigated some of the less-energetic punctures to the six breached tank heads in this accident. Although the speed of the train was 30 mph at the time of derailment, somewhat lesser car-to-car impact speeds would be expected in many cases from run-in and deceleration, frictional forces acting on derailed cars, and relative motions of tank cars in the same general direction. The tank-head puncture resistance performance standard in 49 *CFR* 179.16, “Tank-head puncture-resistance systems,” that specifies that a system capable of sustaining without any loss of lading a coupler-to-head impact at relative car speeds of 18 mph, might still have been an effective accident mitigation measure had the tank cars been so

[68] Some tank cars sustained multiple types of puncture damage and fittings damage.
[69] For more information, see “Materials Laboratory Factual Report 17-406” in NTSB Docket DCA17SH002.
[70] For more information, see “Tank Car Performance Factual Report” in NTSB Docket DCA15FR005.

equipped. The tank head puncture resistance performance standard is applicable to tank cars requiring such a system, such as the new specification DOT-117 and DOT-117R tank cars that are federally mandated to replace DOT-111 tank cars currently used to transport ethanol. Therefore, based on federal research and observed accident performance of tank car head protection systems in this accident, the NTSB concludes it is likely that had the legacy DOT-111 tank cars involved in this accident been replaced with DOT-117 tank cars equipped with head shields, breaches and punctures which resulted in the loss of hazardous material from six of the tank car heads could have been mitigated or prevented.

2.5.2 Tank Shell Breaches

While this accident again highlights a long history of unacceptable crashworthiness performance for DOT-111 tank cars, there is little empirical evidence with which to draw tank shell accident performance comparisons to new specification DOT-117 tank cars that are scheduled to replace the existing flammable liquids fleet. Nevertheless, such protective features used on DOT-117 tank cars have successful track records in pressure tank car service, including the DOT-112 and DOT-105 tank cars that are used to transport liquefied compressed gases and poison inhalation hazard materials.

While the available evidence is limited to the DOT-117 tank car in the Money, Mississippi, accident, NTSB investigators have observed many similar circumstances involving DOT-111 legacy tank cars that resulted in large shell fractures with total release of hazardous materials, such as the June 19, 2009, derailment in Cherry Valley, Illinois, which resulted in similar damage (NTSB 2012).[71]

The FRA tank car accident modeling research shows that more energy is needed to create punctures compared to the baseline DOT-111 car because of the stronger and tougher materials, increased thickness, and added jackets in the DOT-117 tank cars (FRA 2013). Although jacket material is less effective at resisting punctures than increased shell material thickness, adding tank thickness is not a practical option for retrofitting tank cars. FRA modeling suggests that adding a jacket to a DOT-111 tank car results in an almost 20 percent improvement in puncture resistance overall. The improvements were less for smaller contact-area impactors such as the end of a broken rail, and more for larger impactors such as couplers (FRA 2013).

In the Graettinger accident, two tank cars, TILX 197694 (26th) and DBUX 302834 (27th) were impacted in their centers at 90° by the head of oncoming car TAEX 2909 (29th), which fractured, crushed, and cleaved these cars in half to instantly release their entire contents. A third major shell breach in tank car CTCX 732108 (25th), that came to rest just behind the two fractured tank cars, occurred from the same impact. The 25th tank car sustained a 10-foot diameter hole in the center of the car that probably caused most of its contents to release instantly as well. The energetic spray of released ethanol from these three tank cars found a source of ignition and is the likely cause of the reported explosion during the first moments following the derailment.

[71] For more information, see "Materials Lab-Analysis Report 10-11A" in NTSB Docket DCA09MR006.

A fourth severely damaged tank car, WCHX 30078 (30th), was pinched between the heads of TAEX 2909 (29th) and TILX 199819 (32nd), forming a large shell tear at the point where the car was crushed. The severely damaged 32nd tank car impacted the 30th tank car, resulting in a 10-foot-wide hole in the shell. Most of the contents of these two tank cars emptied instantly and contributed to the initial fireball.

A sixth tank car with shell breaching damage, CTCX 731383 (34th), sustained a 24-inch fracture on the center-left side that was most likely caused by other impacting objects, such as truck frames and wheels that were scattered about the derailment scene. Although the physical evidence suggests that impacts to this car were less energetic than impacts further forward in the train, the shell and head breaches and an open bottom outlet valve led to complete lading loss.

In summary, damage to 5 of the 6 shell-breached tank cars was particularly severe and hazardous materials releases may not have been avoided in all cases, even if the tank cars had been equipped with the increased puncture resistance afforded by thicker normalized steel tank shells and 11-gauge jackets over a thermal protection blanket. Nevertheless, the NTSB concludes that tank car shell puncture resistance improvements required for new or retrofitted DOT-117 tank cars transporting flammable liquids that are scheduled to replace the existing fleet of DOT-111 ethanol tank cars by May 1, 2023, could have mitigated and might even have prevented some of the tank shell breaches from six of the tank cars involved in this accident.

2.5.3 Unprotected Valves and Fittings

The observed tank car valve and fittings damage that contributed to poor lading retention in this accident was typical of damages incurred by DOT-111 tank cars in other derailment accidents. Six of the derailed tank cars sustained top fittings and bottom outlet valve damage that resulted in ethanol releases. Because of the extensive tank head and shell breaching damages, ethanol releases in just half of these cases were caused only by damaged valves or fittings themselves.

Damage to top fittings can occur when a tank car rolls over and fittings that protrude from the tank (also referred to as discontinuities) strike the ground or another rail car. All of the DOT-111 tank cars involved in this accident were of pre-2010 vintage, equipped with a thinly constructed 0.119-inch-thick steel multihousing cover that served as little more than weather and vandalism protection. In contrast, top fittings protection for DOT-111 tank cars ordered after July 1, 2010, for transportation of Packing Groups I and II materials must be equipped with a protective structure capable of withstanding half the weight of a fully loaded car in the downward and lateral directions and the full weight of the car in the horizontal longitudinal direction (AAR 2018). If a DOT-111 tank car is retrofitted to specification DOT-117R standards, federal regulations require a top fittings protective housing not less than 0.5 inch in thickness with a tensile strength of not less than 65 kilo-pounds-per-square-inch (kpsi), and special allowance for the strength of the nozzle to tank or cover plate connection strength.[72] These more robust protective housings have been shown effective in reducing rollover and impact damage to top fittings that project outward from the tank shell. For example, the investigation of the Lac-Mégantic, Quebec, accident found of the 27 derailed DOT-111 tank cars equipped with

[72] Title 49 *CFR* 179.202-13(h), "Retrofit standard requirements (DOT-117R)."

robust top fittings protection that sustained impact damage, 4 of the tank cars had breached top fittings (TSB 2014). Conversely, of the 26 pre-2010 vintage derailed DOT-111 tank cars at Lac-Mégantic that were equipped with a thin multihousing cover, 16 sustained top fittings breaching damage (TSB 2014).

In this accident, the fragile multihousing cover of the 25th car failed to protect the liquid valve from an impact that crushed the housing and severed the fitting from its eduction pipe, which can be used to remove ethanol from the top of the tank car. The multihousing cover was also broken away from the 21st tank car and the threaded vapor valve was pulled from the multihousing fittings flange, leaving a 2-inch opening into the tank. Therefore, the NTSB concludes that if the tank cars involved in this accident had been retrofitted or replaced with DOT-117 compliant tank cars, the breaching damage to the top fittings of the 21st and 25th tank cars could have been avoided.

New bottom outlet valve design requirements have been adopted for all DOT-117 options in response to NTSB Safety Recommendation R-12-6, which resulted from the investigation into the Cherry Valley, Illinois, accident, that called for PHMSA to require that all bottom outlet valves used on newly manufactured and existing tank cars are designed to remain closed during accidents in which the valve and operating handle are subjected to impact forces. The bottom outlet nozzle adaptor attachment bolts have weakened cross sections to allow the adaptor to shear away on impact to avoid tank belly damage. Therefore, it is critical to prevent the operating handle from manipulating the bottom valve to an open position to avoid draining the tank contents. In derailments, valve operating handles frequently get caught in soil or debris as the tank rolls over and forces the valve to an open position. Federal regulations now require either the operating handle to be removed or designed to prevent unintended actuation during train accident scenarios.[73] Several designs for new and retrofitted tank cars have been developed, such as removable handles, handles that disengage from the operating shaft, and recessed valving.

Product released from the bottom outlet valves of four tank cars involved in this accident. None of the tank cars involved in this accident had the bottom outlet valve protective features prescribed by new federal regulations for specification DOT-117 tank cars.

The 22nd and 34th tank cars had open bottom outlet ball valves because the operating handles were moved to the open position by derailment forces and the nozzle adaptors had broken away. This had the effect of creating a 4-inch opening in the tanks from which their contents quickly drained out by gravity.

The bottom outlet ball valve remained closed on the 33rd tank car and the nozzle adaptor broke away at the fastening bolt shear sections as designed. However, the valve seals were damaged by pool fire exposure as evidenced by paint scorching over the bottom outlet area.[74] In this case, ethanol likely escaped from the tank as it flowed around the damaged valve seals.

In the 31st tank car, the valve operating handle was still in the closed position and the adapter nozzle had broken away. Because paint scorching was confined to the upper half of the

[73] Title 49 *CFR* 179.202-8, "Bottom outlets" and 179.202-13 (g), "Retrofit standard requirements (DOT-117R)."

[74] A *pool fire* is a turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel where the fuel has zero or low initial momentum.

tank, leakage from this valve probably occurred because of impact damage or mechanical deformation rather than fire damage. Thick mud caking on the bottom of the car including in and around the bottom valve was evidence of a hard ground impact that could explain the valve damage.

New valve operating handle closure protection features would not have prevented the releases of ethanol from the 31st and 33rd tank cars because these releases were not caused by the valve opening. In the case of the 34th tank car, it was extensively breached from head and shell damage and the bottom outlet valve failure had little effect on releases from that tank car. Therefore, the NTSB concludes that ethanol would not have released from the 22nd tank car had it been equipped with a bottom outlet valve operating mechanism that was designed to prevent actuation during an accident scenario.

2.5.4 DOT-111 Tank Car Fleet Replacement

PHMSA final rule HM-251, published on May 8, 2015, established new and safer specification DOT-117 tank car design criteria for nonpressure tank cars transporting flammable liquids, a performance standard DOT-117P, and a retrofit standard DOT-117R to which existing DOT-111 tank cars may be converted (*Federal Register*, 2015a, 26644). These new specifications were intended to address crashworthiness concerns NTSB raised in earlier investigations that cited poor DOT-111 tank car performance as a critical safety issue. The new specifications addressed NTSB Safety Recommendations R-12-5 and R-12-6 that called for enhanced puncture resistance and fitting and valve protection for tank cars transporting crude oil and ethanol that were issued as a result of the June 19, 2009, derailment of an ethanol unit train in Cherry Valley, Illinois (NTSB 2012). The new specifications also addressed NTSB Urgent Safety Recommendations R-15-14 and R-15-15 that stressed the importance of thermal protection systems for new and existing tank cars in flammable liquids service that were issued following the February 16, 2015, derailment of a crude oil unit train containing CPC-1232 tank cars in Mount Carbon, West Virginia.[75] In accordance with final rules HM-251 and HM-251C [as mandated by the Fixing America's Surface Transportation Act (FAST Act)], the HMR have established commodity-based deadlines for phase-out or retrofitting DOT-111 tank cars in continued flammable liquids service (*Federal Register*, 2016a, 53935).

PHMSA final rule HM-251 is not the first time that the DOT mandated a tank car safety enhancement and retrofit program. The DOT embarked on a similar effort in 1977, when it issued final rule HM-144, requiring that all new and existing specification 112 and 114 tank cars transporting flammable gases be equipped with thermal and tank head protection systems, and coupler restraint systems (*Federal Register*, 1977, 46306). In response to a 1978 NTSB public hearing on derailments and hazardous materials, the DOT amended the rule to require an accelerated retrofit schedule for existing flammable gas tank cars over a 2.5-year period (*Federal Register,* 1978a, 30057). The retrofit schedule required fleet owners to retrofit 20 percent of their existing fleets within 6 months, 65 percent by the following year, and their remaining tank cars by the following year.

[75] For additional information, see letter for NTSB Safety Recommendations R-15-14 through -17, which can be found through the NTSB website.

In September 1978, the DOT issued a supplementary final rule to address compliance reporting (*Federal Register*, 1978, 39792). At that time, the DOT recognized that it was not sufficient to simply mandate the retrofit program because neglect by a tank car owner or owners to establish an adequate pace of retrofit could have resulted in a failure to meet regulatory deadlines. The DOT was concerned that such a failure could have resulted in an accumulation of unequipped cars, which would have been prohibited from use in transportation. The NTSB has the same concerns today regarding the current ethanol fleet of DOT-111 tank cars. Because the ethanol fleet of legacy DOT-111 tank cars constitutes a substantially large percentage of the overall general service tank car fleet, the NTSB is concerned about the potential for critical short-term shortages of DOT-117-compliant tank cars for flammable liquids transportation if tank car owners fail to take adequate measures to assure the phased completion of the retrofits and replacements. Due to the high demand for general service tank cars to transport ethanol and other flammable materials, it is essential that tank car owners make careful plans to assure their fleets are converted in advance of applicable deadlines.

The accident tank cars were constructed between 2003 and 2009 and had the least crash-resistant features available for flammable liquids service. These legacy DOT-111 tank cars have the thinnest (7/16-inch thick) tank shells that are usually constructed of non-normalized steel, no head shields or puncture resistance system, no thermal protection system, and too little protection for top and bottom fittings. These shortcomings are responsible for the track record of poor accident performance for DOT-111 tank cars, especially since 2007 following their introduction into widespread use for flammable materials unit trains.

Federal regulations place the burden on the shipper to offer the hazardous material in a package that is authorized for transportation. Although safer tank cars such as the DOT-117 are available, Green Plains obtained the accident train tank cars that meet current federal minimum safety standards from seven different leasing companies based on availability and market prices. Since most shippers are not rail car fleet owners and generally obtain tank cars through full service lease terms, they must rely on third-party leasing companies to ensure that replacement tank cars are available before the regulatory deadline for replacing DOT-111 ethanol tank cars by May 1, 2023.

None of the tank cars in the accident train consist were constructed to DOT-117 specification requirements. At the time of this accident, three of the seven leasing companies that supplied tank cars used in the accident train had purchased significant numbers of DOT-117 tank cars. However, their rail car leasing fleets consisted predominantly of legacy DOT-111 and CPC-1232 tank cars.[76] At the time of this accident, three other leasing companies that supplied tank cars for the accident train had no DOT-117 tank cars in their fleets.

Prior to the publication of PHMSA final rule HM-251, the NTSB expressed concern about the lack of intermediate progress milestones for completing tank car modifications or replacements and the lack of transparency to hold the rail car owners accountable for progress

[76] According to the UMLER database, which is the industry's inventory of individual tank cars that are active or scheduled to be built.

toward implementing safer tank car fleets. This issue was addressed following the investigation of the Mount Carbon, West Virginia, accident with safety recommendations to PHMSA.[77]

> Require an aggressive, intermediate progress milestone schedule, such as a 20 percent yearly completion metric over a 5-year implementation period, for the replacement or retrofitting of legacy DOT-111 and CPC-1232 tank cars to appropriate tank car performance standards, that includes equipping these tank cars with jackets, thermal protection, and appropriately sized pressure relief devices. (R-15-16)

Safety Recommendation R-15-16 is currently classified *Open—Unacceptable Response* because PHMSA has not established a clear set of intermediate metrics that it could use to evaluate the safety improvement progress. The second recommendation, Safety Recommendation R-15-17, requested PHMSA:

> Establish a publicly available reporting mechanism that reports at least annually progress on retrofitting and replacing tank cars subject to thermal protection system performance standards as recommended in safety recommendation R-15-16. (R-15-17)

Safety Recommendation R-15-17 is classified *Open—Acceptable Response* because PHMSA, collaborating with its stakeholders, entered into an agreement with the Bureau of Transportation Statistics (BTS) to collect and report data about progress made in modifying or replacing DOT-111 tank cars. To encourage compliance with DOT-111 replacement deadlines, Section 7308 of the FAST Act required the secretary of transportation to implement a reporting mechanism to monitor industry-wide progress toward modifying tank cars and to report the aggregate results of its tank car data survey annually to Congress.

On September 22, 2017, the BTS submitted its first report to Congress detailing the fleet composition of rail tank cars transporting flammable liquids (BTS 2017). The BTS reported that as of the end of 2016, about 9 percent of the 81,000 tank cars used to transport Class 3 flammable liquids met new safety requirements. At that time, most of the flammable liquids fleet (53 percent) still consisted of nonjacketed DOT-111 tank cars, such as the tank cars that were involved in this accident. The number of nonjacketed DOT-111 tank cars used to transport ethanol has remained steady between 2014 and 2016 at about 26,000 to 28,000. However, during 2016, the BTS reported some progress with about 1,700 new DOT-117 and 1,200 retrofitted DOT-117R tank cars added to the ethanol fleet. However, the slow pace of ethanol fleet tank car conversions has prompted concern by the AAR and others in the industry about the availability of DOT-117 tank cars to service the flammable liquids fleet in years to come (Fronczak 2017).

PHMSA stated in the *U.S. Department of Transportation's Status of Actions Addressing the Safety Issue Areas on the National Transportation Safety Board's Most Wanted List: A Report to Congress and the National Transportation Safety Board* that it is working with the rail industry and tank car facilities to develop reporting mechanisms to monitor tank car replacement progress and provide Congress with an annual written report (DOT 2017). PHMSA stated it

[77] For additional information, see letter for NTSB Safety Recommendations R-15-14 through -17, which can be found through the NTSB website.

believes the transparency of the BTS report will help encourage industry to replace tank cars at a rate ahead of scheduled deadlines. However, in contrast to the earlier pressure tank car replacement regime mentioned above, the current regulatory scheme that responds to Section 7308(e) of the FAST Act requires DOT to redact tank car owners' identities from progress reports to Congress. It requires DOT to report data in industry-wide totals and to treat company-specific information as confidential business information; therefore, shielding individual fleet owners from public scrutiny of their tank car replacement progress, or lack of progress. Therefore, the report to Congress does not offer complete transparency.

Unlike the current regulatory system of assured anonymity and voluntary compliance that lacks targeted milestones, DOT chose to remedy potential failure of the earlier program in 1978 when it tasked FRA with closely monitoring the manner in which tank car owners complied with the deadlines. Thus, the 1978 rule required specification 112 and 114 tank car owners to file quarterly progress reports with the FRA, identifying the total number of tank car retrofits accomplished, as well as a declaration of intent concerning the remaining tank cars in their respective fleets. DOT stated that in the event any owner failed to establish a program leading to the timely completion of the retrofit tasks, the FRA could have instituted a compliance order or could have taken appropriate legal action under the provisions of 49 *CFR* Part 209, "Railroad Safety Enforcement Procedures." The flammable gas tank car retrofit program was completed in 1980, nearly 1 year earlier than originally anticipated, and the NTSB noted as a result, the frequency and severity of accidents with these tank cars had been significantly reduced.[78]

In its most recent quarterly report to the AAR Tank Car Committee in May 2018, the AAR stated, "Forty-three percent of the cars used to ship ethanol during the 1st quarter of 2018 were built since 2011 to new standards vs. less than 2 percent in 2013 [that were built after 2011 and met the new standards]."

In September 2018, the BTS sent its second report to Congress, *Fleet Composition of Rail Tank Cars Carrying Flammable Liquids: 2018 Report.* In this report, the BTS reported that nearly 20 percent of the tank cars used to carry Class 3 flammable liquids in 2017 met the new DOT-117 safety requirements—a significant increase from the 2 percent in 2015. The BTS further reported that nonjacketed DOT-111 tank cars, while carrying the largest share of flammable liquids, have decreased by 31 percent between 2014 and 2017. Furthermore, the number of both new and retrofit DOT-117 tank cars used in ethanol service more than doubled between 2016 and 2017 to over 6,000 tank cars (BTS 2018).

Newly available AAR flammable liquids fleet utilization figures indicate there was remarkable progress made in replacing DOT-111 cars to transport ethanol in 2017 and also during the first quarter of 2018. According to the AAR, almost 11,000 DOT-117 tank cars were used during the first quarter of 2018 to transport ethanol, while the number of DOT-111 tank cars used to transport ethanol dropped by the same amount between 2016 and 2018.

Despite recent tank car replacement progress, BTS and AAR fleet statistics indicate that still nearly one-half of the overall fleet of tank cars carrying flammable liquids were nonjacketed

[78] Letter to the FRA from NTSB closing Safety Recommendations R-74-33; R-75-19 and -30; R-78-20 through -22; R-79-23 and -28; R-79-65; R-81-74; and R-81-75, September 10, 1982.

DOT-111, and most of these were used to transport ethanol. However, the NTSB concludes that since PHMSA has not established a clear set of intermediate metrics for evaluating tank car conversion and replacements, achievement of the deadlines may be overly reliant on future market and economic conditions. Therefore, NTSB reiterates Safety Recommendation R-15-16, which requests tank car retrofitting and replacement progress milestones.

2.6 Transportation of Fuel Ethanol Without Denaturant

The Graettinger, Iowa, accident is the first unit train accident with release and fire that involved the transportation of undenatured fuel ethanol. While fuel ethanol is currently the most shipped hazardous material by railroad, the industry has experienced significant recent growth in the shipment of undenatured fuel ethanol to foreign markets. The foreign end-users generally request the product without denaturant added, which allows the ethanol to be used for other industrial purposes in addition to motor fuel. The RFA states that the 2017 undenatured ethanol export market in the United States is projected to amount to about 800 million gallons, and the transportation chain involves tank car originations mainly from Petroleum Administration for Defense Districts (PADD) 2 (Midwest) to Gulf and Northeast coast marine terminals.[79]

Domestically used ethanol is denatured for transport to discourage its use as a beverage. However, ethanol destined for export that is shipped from the same production facilities by the same tank cars and often on the same routes is not required to be denatured and is not treated to discourage use as a beverage. Denaturing agents, such as gasoline and benzene, may also increase both safety and environmental risks if a release occurs during an accident.

The NTSB believes that the need to denature the 23 billion gallons of fuel ethanol transported annually for domestic use with volatile organic compounds, merely to discourage its use as a beverage, potentially poses an unnecessary risk of death, injury, and environmental contamination when released in transportation accidents. In fact, transporting fuel ethanol without a denaturant could provide a real and measurable safety benefit.

The denaturant product typically used is 2 percent natural gasoline, which according to the RFA, lowers the flash point of denatured ethanol compared with undenatured ethanol, as described in section 1.16.1 (reported values between -5° and 19.4°F instead of between 45°F and 55°F) (RFA 2017) and (EERC 2017).[80] The purpose of adding denaturant to ethanol is to make the product completely unfit for beverage use, and the denaturants used must be nearly inseparable from the alcohol. A list of approved denaturants is specified in TTB regulations; however, natural gasoline is most commonly used to denature fuel ethanol. The addition of natural gasoline denaturant introduces volatile and toxic organic hydrocarbons into the product.

[79] During a November 15, 2017, meeting with NTSB investigators, the RFA director of regulatory affairs stated that the export figure was 800 million gallons in 2017. However, earlier projections published by the RFA suggested an export volume of 1.2 billion gallons for 2017. The United States is divided into five PADD that were created to organize the allocation of fuels derived from petroleum products.

[80] (a) Authorized denaturants are specified in 27 *CFR* 19.746, “Authorized Materials.” The most commonly used denaturants are 2 gallons or more of gasoline or natural gasoline per 100 gallons of ethanol. (b) *Natural gasoline* is a natural gas liquid with a vapor pressure intermediate between condensate and liquefied petroleum gas. This liquid hydrocarbon mixture is recovered at normal pressure and temperature and is more volatile and unstable than commercial gasoline.

Although the difference in flash point does not change the fact that denatured and undenatured ethanol are both Class 3 flammable liquids in Packing Group II, government and industry stakeholders have not studied what effect the absence of denaturant might have on the safety of transporting ethanol in unit trains. In particular, it is unknown the extent to which the absence of volatile constituents contained in natural gasoline denaturants could lessen the severity or probability of postaccident tank car shell thermal tears and energetic fireball eruptions.

NTSB investigators noticed the relatively mild postaccident fire damage following the Graettinger derailment does not compare with the observed outcomes from previous denatured fuel ethanol accidents. The derailment scene did not produce energetic high-pressure events, rocketing car parts, or significant thermal damage to the derailed tank cars. This is in stark contrast to the thermal tears and tank car separations observed following the February 2011 derailment of a denatured fuel ethanol unit train of identical tank cars in Arcadia, Ohio (FRA 2011).

The FRA has recognized that crude oil and denatured ethanol releases have a similar hazardous behavior, and that denatured ethanol even poses a greater hazard than crude oil on an equal tank car volume basis (Raj 2014). Moreover, the FRA has evaluated empirical tank car damage assessment data from accidents that occurred between 2006 and 2014, finding that denatured ethanol poses a greater risk to safety than the more volatile grades of crude oil (Alexy 2014). The FRA concluded that the tank car thermal failure rate for denatured ethanol was 1.5 times greater than for crude oil. The FRA opined that high energy events that result in tank cars completely separating are more likely to occur in tank cars transporting denatured ethanol. The accidents FRA examined all involved denatured fuel ethanol, which may have behaved differently than the undenatured fuel ethanol involved in this accident.

Furthermore, the presence of toxic organic hydrocarbons associated with denaturant have complicated environmental remediation efforts whenever denatured ethanol has been released in train derailments because of polluted surface and ground water and soil contamination. Because the undenatured ethanol in the Graettinger derailment did not contain toxic compounds, such as the human carcinogen benzene, the environmental consequences of this accident were much less severe than typically experienced following a denatured ethanol release. Water testing found no significant impact to aquatic life or the environment downstream of the derailment scene. The released ethanol only resulted in localized depression of surface water dissolved oxygen levels. The contaminated soils cleanup was much easier because the material could be disposed of at a sanitary landfill without the necessity of pretreating hazardous waste constituents. Furthermore, the absence of denaturants that typically infiltrate and pollute aquifers also eliminated the need for long-term groundwater monitoring and remediation efforts.

The NTSB, therefore, concludes that given the minimal thermal damage to tank cars, lack of energetic postaccident fireball eruptions, and less environmental impact observed in this accident compared with similar railroad accidents involving denatured fuel ethanol, it would appear a safety benefit may be derived from transporting ethanol without the use of volatile denaturant chemicals.

This accident shows there may be safety benefits for shipping ethanol in its undenatured form; however, information is only available for this occurrence. The NTSB concludes that more research should be conducted to determine whether operational changes to shipping ethanol in its undenatured form would improve safety. Therefore, the NTSB recommends that PHMSA sponsor research to study and publish the difference in characteristics between denatured and undenatured ethanol and the benefits that could be achieved by transporting fuel ethanol without the use of volatile organic chemical denaturants.

2.7 Factors Not Contributing to this Derailment

The NTSB determined that the factors in this section did not cause or contribute to the severity of this accident.

Among the requirements of 49 *CFR* Part 172 applicable to a person who offers a hazardous material for transportation, is certification that the hazardous material is properly classified and described on shipping papers. The erroneous hazardous materials shipping paper description conveyed to emergency responders that they were responding to a denatured ethanol release instead of an undenatured ethanol incident.

NTSB investigators found that the shipper's Intellifuels system, which generates meter tickets for each load, included a default DOT shipping description for denatured fuel ethanol. Green Plains, the shipper, claimed they were not able to change this description that the Intellifuels system manufacturer had programed into the unit when it was installed many years ago. This default description was established well before any consideration had ever been given to shipping ethanol as undenatured. Therefore, when the inaccurate description was forwarded to the Green Plains logistics coordinator at the company's headquarters in Omaha, Nebraska, the error was carried forward to the electronic data interchange documents for the accident train, which were used to produce the hazardous materials shipping paper. Under 49 *CFR* 172.204, "Shipper's certification," Green Plains, the offeror of the shipment, had a duty to certify that the hazardous material was properly classified, described, packaged, marked and labeled, and was in proper condition for transportation in accordance with applicable DOT regulations. Even though the shipping papers incorrectly identified the consist of 98 tank cars as denatured fuel ethanol (UN1987), tank cars correctly displayed Class 3 placards with the UN identification number for undenatured ethanol (UN1170).

When the train crew conducted a ground level acceptance inspection of the train as required by 49 *CFR* 174.26 (b), "Notice to train crews," they should have noticed the inconsistency between the UN identification numbers displayed on the placards and the UN identification numbers listed in the train consist. The train crew should not have accepted the tank cars into transportation until the train consist was corrected.

About 9 hours after the accident occurred, the logistics coordinator attempted to correct the error on the electronic data interchange system, but the system did not accept the correction because the shipment had already initiated. Therefore, the incorrect hazard communications were contained on the train consist that was available for emergency responder reference.

Although the Graettinger fire chief told NTSB investigators he was initially unaware of the inconsistency between the shipping documents and placards, the shipper's failure to properly identify the hazardous material in this case could have had significant safety consequences. For instance, emergency response personnel need to be aware that flames of burning undenatured ethanol may be invisible in daylight. Had it been necessary for a close-quarters urgent extrication or evacuation, inaccurate hazard communications have the potential of causing delays and confusion, or worse, even injury if first responders are misinformed about the nature of the hazards. The remote location of this accident allowed first responders to take a stand-off approach without having to try to attack the fire or risk injury to themselves or the public. Therefore, the NTSB concludes that the erroneous shipping documentation identifying the hazardous material as denatured alcohol, instead of undenatured ethanol, did not have any adverse impact on the emergency response to this accident.

As noted in section 1.10, the engineer tested positive for doxylamine in his urine, but not in his blood, which indicated that the level in his blood was below the reporting cut off level. Thus, it is unlikely the engineer was experiencing any effects of the drug at the time of the test. The blood was drawn at 5:12 a.m., about 4.5 hours after the accident. The half-life of the drug is between 6 and 12 hours. It is, therefore, impossible to determine if the level of the drug at the time of the accident was high enough that it could have caused any effects. However, the actions of the engineer throughout the trip and at the time of the accident were appropriate; there is no indication that he was impaired by his use of a sedating antihistamine at the time of the accident.

The NTSB concludes that none of the following were factors in this accident: (1) the mechanical condition of the train to include the train's braking system, (2) the performance of the train crew, (3) cell phone use by the train crew, (4) alcohol or other drugs by the train crew, and (5) the emergency response.

3 Conclusions

3.1 Findings

1. Union Pacific Railroad was not maintaining the track structure on the Union Pacific Railroad Estherville Subdivision in accordance with Federal Railroad Administration minimum track safety standards or its own internal track maintenance standards.

2. Union Pacific Railroad supervisors and managers were not ensuring defective crosstie conditions were being identified, reported, and remediated in accordance with Union Pacific Railroad track maintenance standards and Federal Railroad Administration track safety standards.

3. Federal Railroad Administration inspectors did not report all defective crosstie conditions on the Union Pacific Railroad Estherville Subdivision in the 2 years prior to the derailment.

4. Federal Railroad Administration inspectors were not using all available enforcement options, such as a recommendation for civil penalties, to require Union Pacific Railroad to comply with Federal Railroad Administration minimum track safety standards on the Union Pacific Railroad Estherville Subdivision.

5. Based on the observation of the fresh horizontal impact damage observed on the wheel tread of the 4th through the 20th nonderailed cars, examination of the rail recovered from the accident, the condition of the crosstie structure on the Union Pacific Railroad Estherville Subdivision, the train likely derailed from a broken south rail that occurred prior to or at the 20th car of the Union Pacific train UEGKOT-09 as it was traveling over the west approach of the Jack Creek Bridge, resulting from UP's inadequate track maintenance and inspection program and the FRA's inadequate oversight of the application of federal track safety standards.

6. A deteriorated track structure, such as worn rail and degraded track support conditions, will cause more track movement and higher stresses in the rail.

7. The finite element study demonstrates that worn 90-pound rail on a degraded track support will result in higher transverse stress in the rail head region, exposing the rail to increased risks of failure due to a vertical split-head failure mode.

8. Based on federal research and observed accident performance of tank car head protection systems in this accident, it is likely that had the legacy US Department of Transportation Specification-111 tank cars involved in this accident been replaced with US Department of Transportation Specification-117 tank cars equipped with head shields, breaches and punctures which resulted in the loss of hazardous material from six of the tank car heads could have been mitigated or prevented.

9. Tank car shell puncture resistance improvements required for new or retrofitted US Department of Transportation Specification-117 tank cars transporting flammable liquids that are scheduled to replace the existing fleet of US Department of Transportation Specification-111 ethanol tank cars by May 1, 2023, could have mitigated and might even have prevented some of the tank shell breaches from six of the tank cars involved in this accident.

10. If the tank cars involved in this accident had been retrofitted or replaced with US Department of Transportation Specification-117 compliant tank cars, the breaching damage to the top fittings of the 21st and 25th tank cars could have been avoided.

11. Ethanol would not have released from the 22nd tank car had it been equipped with a bottom outlet valve operating mechanism that was designed to prevent actuation during an accident scenario.

12. Since the Pipeline and Hazardous Materials Safety Administration has not established a clear set of intermediate metrics for evaluating tank car conversion and replacements, achievement of the deadlines may be overly reliant on future market and economic conditions.

13. Given the minimal thermal damage to tank cars, lack of energetic postaccident fireball eruptions, and less environmental impact observed in this accident compared with similar railroad accidents involving denatured fuel ethanol, it would appear a safety benefit could be derived from transporting ethanol without the use of volatile denaturant chemicals.

14. More research should be conducted to determine whether operational changes to shipping ethanol in its undenatured form would improve safety.

15. The erroneous shipping documentation identifying the hazardous material as denatured alcohol, instead of undenatured ethanol, did not have any adverse impact on the emergency response to this accident.

16. None of the following were factors in this accident: (1) the mechanical condition of the train to include the train's braking system, (2) the performance of the train crew, (3) cell phone use by the train crew, (4) alcohol or other drugs by the train crew, and (5) the emergency response.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the derailment was a broken rail that occurred as the train was traveling over the west approach of the Jack Creek Bridge resulting from Union Pacific Railroad's inadequate track maintenance and inspection program and the Federal Railroad Administration's inadequate oversight of the application of federal track safety standards. Contributing to the consequences of this accident was the continued use of US Department of Transportation Specification-111 tank cars.

4 Recommendations

4.1 New Recommendations

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

To the Federal Railroad Administration:

> Provide additional training to all your track inspectors on regulatory track safety standards compliance and provide guidance of available enforcement options to obtain compliance with minimum track safety standards when defective conditions are not being properly remediated by railroads on all routes that carry high hazardous flammable materials. (R-18-026)

To the Pipeline and Hazardous Materials Safety Administration:

> Sponsor research to study and publish the difference in characteristics between denatured and undenatured ethanol and the benefits that could be achieved by transporting fuel ethanol without the use of volatile organic chemical denaturants. (R-18-027)

To Union Pacific Railroad:

> Reexamine your track maintenance and inspection program standards on all routes that carry high hazardous flammable materials and ensure those track inspection standards are complied with by both track inspectors and track supervisors. (R-18-028)

4.2 Reiterated Recommendation

As a result of this investigation, the National Transportation Safety Board reiterates the following safety recommendation:

To the Pipeline and Hazardous Materials Safety Administration:

> Require an aggressive, intermediate progress milestone schedule, such as a 20 percent yearly completion metric over a 5-year implementation period, for the replacement or retrofitting of legacy DOT-111 and CPC-1232 tank cars to appropriate tank car performance standards, that includes equipping these tank cars with jackets, thermal protection, and appropriately sized pressure relief devices. (R-15-16)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

BRUCE LANDSBERG
Vice Chairman

EARL F. WEENER
Member

T. BELLA DINH-ZARR
Member

JENNIFER HOMENDY
Member

Adopted: October 30, 2018

Board Member Statement

Member Jennifer Homendy filed the following concurring statement on November 5, 2018. Chairman Robert L. Sumwalt, III, Vice Chairman Bruce Landsberg, and Members Earl F. Weener and T. Bella Dinh-Zarr joined in this statement.

The investigation of this accident highlighted significant deficiencies in Union Pacific Railroad's (UP) track maintenance and inspection program. National Transportation Safety Board (NTSB) investigators found that from 2015 through 2017, UP identified 102 track defects on the Estherville Subdivision, noting crossties that were either "marginal" or in "poor condition." Yet few of those track defects were remediated beyond the bare minimum.

As noted in the accident report, this is not the first time that we have raised concerns with UP's track maintenance and inspection program. Two previous NTSB accident investigations cited UP's ineffective track inspections and inadequate oversight of track maintenance work, resulting in the issuance of NTSB safety recommendations.

More recently, the UP accident in Mosier, Oregon, on June 3, 2016, in which 16 tank cars loaded with Bakken crude oil derailed (three of which ignited) was caused by track defects, specifically wide gage resulting from the failure of the track's lag screw fasteners utilized to hold the tie plates in position. Following the Mosier accident, the Federal Railroad Administration (FRA) found 159 defects on UP's Portland Subdivision, which runs between Troutdale, Oregon, and Hermiston, Oregon, and includes Mosier.

Preceding the accident, in January 2015, the FRA commenced a national program called the Crude Oil Route Track Examination (CORTEX), inspecting railroad track on which crude oil and/or ethanol was being transported in every FRA region for every Class I railroad across the country. In total, CORTEX revealed 5,700 track defects on UP's system.

Section 1.18 of the accident report discusses UP's postaccident actions on the Estherville Subdivision and other nearby subdivisions since the accident, which include installation of 8,600 crossties, reduction of maximum allowable speeds, and an increase in inspections. While I am encouraged by these safety improvements, it should not take a series of accidents for UP to take prompt action to address such serious deficiencies in their track maintenance and inspection program. A quick review of UP's data that it submits annually to the FRA shows that, over the last decade, the leading cause of all UP train accidents (not including grade crossings) is track defects.

While the deficiencies in UP's track maintenance and inspection program are problematic, they were intensified by the FRA's inadequate inspection regime. FRA inspectors from Region 6 identified numerous defects on the Estherville Subdivision but did little to nothing to address them. In fact, from 2015 through 2017, Region 6 inspectors identified 32 defective crosstie conditions, some of which were also identified by UP track inspectors. No enforcement actions were taken. Two months after the accident occurred on the Estherville Subdivision, the FRA again inspected the track and found 78 defective track conditions, 51 of which were locations with defective crossties and 5 were locations with rail fasteners not maintaining track gage. Again, no further enforcement action was taken.

Section 103 of Title 49, *United States Code*, states that the FRA "shall consider the assignment and maintenance of safety as the highest priority, recognizing the clear intent, encouragement, and dedication of Congress to the furtherance of the highest degree of safety in railroad transportation." In other words, the FRA is the authority for ensuring safety on our nation's rail network. If the railroads fail to address safety, it's the FRA's responsibility to take appropriate action. In this case, the regional administrator and Region 6 inspectors could have mandated speed restrictions, issued civil penalties, or required UP to report back to the FRA when repairs to the track were completed. None of that happened.

Fortunately, there were no fatalities or injuries in this accident, but if the DOT-111 tank cars contained denatured ethanol, there could have been a different outcome. As noted in the report, denatured ethanol poses a greater hazard than crude oil in rail transportation. According to the FRA, the failure rate (due to thermal damage) of tank cars containing denatured ethanol is 1.5 times greater than that of tank cars transporting crude oil. The FRA also found that ethanol vapors are about nine times more hazardous than Bakken crude vapors at normal temperatures, and that ethanol poses "a greater fire ball hazard" than crude oil in tank car wall breaches.

These hazards highlight the importance of considering the safety benefits of transporting undenatured ethanol in lieu of denatured ethanol; the urgent need to replace DOT-111 tank cars as required by existing regulations and the Fixing America's Surface Transportation Act of 2015 (P.L. 114-94), and the need to ensure emergency responders are properly trained to react and respond to accidents involving hazardous materials.

According to the National Fire Protection Association's Fourth Needs Assessment of the U.S. Fire Service, dated November 2016, 39 percent of emergency responders are trained at the basic general awareness level (trained to initiate a response sequence by notifying proper authorities); another 14 percent have no training whatsoever. Only 41 percent of emergency responders are trained at the higher operations level (those who are part of an initial response to protect person, property, or the environment), and 7 percent are trained at the technician level (those who respond with the purpose of stopping the release). Additional training at the operations level, at a minimum, for emergency responders is needed.

The Pipeline and Hazardous Materials Safety Administration of the U.S. Department of Transportation (US DOT) provides grants to states for training emergency responders. As a condition for receiving a grant, a state must train its emergency responders at the operations level. Funding is also provided for a train-the-trainer program at the operations level. These US DOT programs, and those offered by the rail industry through TRANSCAER (Transportation Community Awareness and Emergency Response), are critical for helping fire departments that may not otherwise be able to afford appropriate training for their personnel.

Appendixes

Appendix A: Investigation

The National Transportation Safety Board was notified on March 10, 2017, that a Union Pacific Railroad unit ethanol train derailed 20 loaded tank cars releasing product and fueling a postaccident fire on the Union Pacific Estherville Subdivision in Graettinger, Iowa. The National Transportation Safety Board launched Chairman Robert Sumwalt, who was a Board Member at the time, an investigator-in-charge, and 17 team members to investigate the accident.

Parties to the investigation included the Federal Railroad Administration; Union Pacific Railroad; the Brotherhood of Locomotive Engineers and Trainmen; the International Association of Sheet Metal, Air, Rail and Transportation Workers; the Brotherhood of Railroad Signalmen; TrinityRail; the Brotherhood of Maintenance of Way Employes; and the Iowa Emergency Management of Palo Alto County.

Appendix B: Summary of Federal Railroad Administration and Union Pacific Railroad Inspections

The following charts note results of the Federal Railroad Administration (FRA) and Union Pacific Railroad (UP) track inspections on the Estherville Subdivision in the 2 years prior to the accident. (See tables 5 and 6.) This is selected information and illustrates findings on crosstie conditions only.

Table 5. Results of FRA inspections regarding crossties prior to the accident.

Date	Location (Milepost)	Findings	Notification to FRA of Remedial Action	Violation
March 11, 2015	77.75	Crossties not effectively distributed to support a 39-foot segment of track-5 in a row defective causing small profile approximately 100 feet west of crossing.	Optional	No
March 11, 2015	71.85	Insufficient fasteners in a track segment-6 ties in a row not fully holding causing gage to shove out to almost 57 1/2".	Optional	No
March 11, 2015	51.75	Crossties not effectively distributed to support a 39-foot segment of track-5 in a row defective causing small profile.	Optional	No
March 11, 2015	51.20	Crossties not effectively distributed to support a 39-foot segment of track-5 in a row defective just west of point of tangent.	Optional	No
March 11, 2015	50.13	Crossties not effectively distributed to support a 39-foot segment of track-5 in a row defective causing profile just [to the] east end of private crossing.	Optional	No
March 11, 2015	46.13	[Rail] Head and web separation-2 inches breaking out in joint on 90lb. Side of comp [compromise joint bar] joint on south rail just west of turnout.	Optional	No
March 11, 2015	48 - 78	Tie condition between MP 48 and 78 is in poor condition and approaching defective condition for intend class in many areas.	Optional	No
July 29, 2015	76.35	Crossties not effectively distributed to support a 39-foot segment of track, several ties defective in a row.	Optional	No
July 29, 2015	76.34	Crossties not effectively distributed to support a 39-foot segment of track, several ties defective in a row with one inch profile.	Optional	No
July 29, 2015	73.45	Crossties not effectively distributed to support a 39-foot segment of track with deflection.	Optional	No
July 29, 2015	66.10	Crossties not effectively distributed to support a 39-foot segment of track, seven ties defective in a row with deflection.	Optional	No
July 29, 2015	62.52	Crossties not effectively distributed to support a 39-foot segment of track, eight ties defective in a row with deflection.	Optional	No
July 29, 2015	70 - 49	**Comment to Railroad Company** Tie condition is marginal for the FRA class of track being operated in areas. Many areas where these ties are very close to the end of their life and another winter cycle will most likely put these areas in non-compliance. This is also a major ethanol hauling route.	Optional	No

Date	Location (Milepost)	Findings	Notification to FRA of Remedial Action	Violation
August 10, 2016	77.90	Failure to maintain the minimum number of crossties per FRA track class for each 39-foot segment of track as indicated in table in this section. (20 out of 25 defective)	Optional	No
August 10, 2016	76.50	Crossties not effectively distributed to support a 39-foot segment of track, seven ties defective in a row.	Optional	No
August 10, 2016	72.90	Crossties not effectively distributed to support a 39-foot segment of track, 15 ties in a row with plate movement and maximum gage of 57 5/8-inches.	Optional	No
August 10, 2016	70.80	Crossties not effectively distributed to support a 39-foot segment of track, eight ties defective in a row.	Optional	No
August 10, 2016	68.70	Crossties not effectively distributed to support a 39-foot segment of track, nine ties defective in a row.	Optional	No
August 10, 2016	62.49	Crossties not effectively distributed to support a 39-foot segment of track, five ties defective in a row.	Optional	No
August 10, 2016	62.48	Crossties not effectively distributed to support a 39-foot segment of track, 12 ties defective in a row.	Optional	No
August 10, 2016	61.10	Crossties not effectively distributed to support a 39-foot segment of track, seven ties defective in a row.	Optional	No
August 10, 2016	52.60	Crossties not effectively distributed to support a 39-foot segment of track, 10 out of 12 ties defective with one inch of profile.	Optional	No
August 10, 2016	52.05	Crossties not effectively distributed to support a 39-foot segment of track, 7 out of 8 defective ties with profile.	Optional	No
August 10, 2016	49 - 78	Crosstie condition marginal from MP 49 Emmetsburg to MP 78 Superior. Within this area some very marginal tie conditions exist from MP 60 Graettinger to MP 70 south end of Estherville. Numerous areas with 5-10 or more ties in a row defective or nearly so. FRA class 2 speeds exist from MP 72 to 78. FRA class 3 speeds exist from MP 72 to the worst of the marginal ties extending to MP 49. This is an ethanol route with higher risk, especially on the most marginal area for ties and it being operated at FRA class 3 speeds.	Optional	No
December 13, 2016	44.5 – 78.40	No defects noted, snow cover. We also had a discussion about marginal tie conditions that exist between Superior, Iowa and Emmetsburg. Especially the hill and curves west of Estherville and between Emmetsburg and Estherville. FRA report 67 dated August 10th, 2016 listed 10 areas of defective tie conditions. This condition can only get worse going into the next year. Railroad will need to monitor this tie condition and take proper remedial action if necessary	Optional	No
March 10, 2017	49.09 – 69.34	Made a hi-rail inspection to look at the overall condition of the track in each direction of Jack Creek (MP 56.72) and to rule out any additional broken rails that could have occurred under the	Optional	No

Date	Location (Milepost)	Findings	Notification to FRA of Remedial Action	Violation
		derailing train prior to Jack Creek in the event of a flattened rail wheel. No broken rail were found. The inspection east of the derailment was from MP 54.53 to MP 49.09, while the inspection west was from MP 58.0 to MP 69.34. The portion in between was not inspected because of equipment occupying the track. Overall condition of this portion was: 90lb CWR; anchoring was good with no longitudinal movement, surface is fair for intended FRA Class 3 track; no gage issues were identified; tie condition is poor in many areas.		
March 11, 2017	56.98	Crossties not effectively distrubuted to support a 39-foot segment of track-6 in a row defective, with plate cutting and tight gage 56 1/16".	Optional	No
March 11, 2017	56.95	Failure to maintain the minimum number of crossties per FRA track class for each 39-foot segment of track as indicated in table in this section. - only 7 effective ties in 39' causing 7/8" profile and tight gage (56 1/8").	Optional	No
March 11, 2017	56.94	Crossties not effectively distributed to support a 39-foot section of track, 4 in a row defective causing 3/4" profile.	Optional	No
March 11, 2017	56.62	Crossties not effectively distributed to support a 39-foot section of track, 4 in a row defective causing 3/4" profile just west of curve on tangent.	Optional	No
March 11, 2017	56.58	Crossties not effectively distributed to support a 39-foot section of track, 4 in a row defective causing 1 1/4" profile and 57 1/8" gage at west end of curve.	Optional	No
March 11, 2017	56.50	Insufficient fasteners in a track segment. - 8 ties in a row with either no spikes or raised spikes causing 2" profile on south rail and 2 1/4" profile on north rail.	Optional	No

Table 6. Results of UP inspections regarding crossties prior to the accident.

Date	Location (Milepost)	Findings	Repair Date
March 18, 2015	65.50	Crossties not effective	March 31, 2015
March 18, 2015	67.40	Crossties not effective	March 31, 2015
March 18, 2015	71.65	Crossties not effective	March 25, 2015
March 31, 2015	51.70	Crossties not effective	March 31, 2015
April 7, 2015	39.30	Crossties not effective	April 30, 2015
April 7, 2015	42.40	Crossties not effective	April 30, 2015
April 7, 2015	43.75	Crossties not effective	April 30, 2015
April 11, 2015	60.95	Crossties not effective	April 24, 2015
April 11, 2015	61.63	Crossties not effective	April 24, 2015
April 23, 2015	63.20	Crossties not effective	May 1, 2015
April 23, 2015	63.30	Crossties not effective	May 1, 2015
April 30, 2015	61.90	Crossties not effective	May 8, 2015
April 30, 2015	70.43	Crossties not effective	May 5, 2015
May 9, 2015	50.75	Crossties not effective	May 20, 2015
May 12, 2015	47.27	Crossties not effective	June 10, 2015

Date	Location (Milepost)	Findings	Repair Date
May 16, 2015	69.52	Crossties not effective	May 22, 2015
May 21, 2015	58.70	Crossties not effective	June 19, 2015
June 2, 2015	1.77	Crossties not effective	June 18, 2015
June 2, 2015	34.87	Crossties not effective	June 30, 2015
June 6, 2015	49.00	Crossties not effective	June 30, 2015
June 6, 2015	77.77	Crossties not effective	June 26, 2015
June 12, 2015	62.60	Crossties not effective	July 1, 2015
June 12, 2015	68.50	Crossties not effective	July 1, 2015
June 27, 2015	54.06	Crossties not effective	July 24, 2015
June 27, 2015	54.17	Crossties not effective	July 24, 2015
July 3, 2015	68.30	Crossties not effective	July 29, 2015
July 3, 2015	68.35	Crossties not effective	July 29, 2015
July 3, 2015	68.45	Crossties not effective	July 29, 2015
July 11, 2015	40.40	Crossties not effective	July 31, 2015
July 22, 2015	69.07	Crossties not effective	July 31, 2015
July 25, 2015	73.68	Crossties not effective	August 18, 2015
August 11, 2015	49.17	8-defective ties in 39' segment	September 2, 2015
August 11, 2015	49.49	8-defective ties in 39' segment	August 25, 2015
September 11, 2015	58.12	Crossties not effective	September 18, 2015
September 11, 2015	73.60	Crossties not effective	September 18, 2015
September 12, 2015	38.08	Crossties not effective	September 21, 2015
October 1, 2015	64.80	Crossties not effective	October 20, 2015
October 1, 2015	65.20	Crossties not effective	October 29, 2015
October 13, 2015	2.39	Crossties not effective	November 11, 2015
March 15, 2016	69.01	Crossties not effective	April 13, 2016
March 15, 2016	69.02	Crossties not effective	April 13, 2016
March 15, 2016	69.07	Crossties not effective	April 12, 2016
March 15, 2016	71.35	Crossties not effective	April 12, 2016
March 29, 2016	61.07	Crossties not effective	April 27, 2016
March 29, 2016	61.15	Crossties not effective	April 27, 2016
March 29, 2016	68.06	Crossties not effective	March 29, 2016
March 29, 2016	68.08	Crossties not effective	March 29, 2016
April 5, 2016	0.25	Crossties not effective	April 27, 2016
April 19, 2016	42.50	Crossties not effective	May 19, 2016
May 10, 2016	48.58	2-defective crossties	May 12, 2016
May 10, 2016	48.59	2-defective crossties	May 12, 2016
June 1, 2016	57.64	Crossties not effective	June 29, 2016
June 1, 2016	58.24	Crossties not effective	June 28, 2016
June 24, 2016	71.84	Crossties not effective	July 15, 2016
June 24, 2016	73.10	Crossties not effective	July 15, 2016
June 24, 2016	73.11	Crossties not effective	July 21, 2016
July 7, 2016	32.82	Crossties not effective	July 18, 2016
July 7, 2016	32.80	Crossties not effective	July 18, 2016
July 7, 2016	32.81	Crossties not effective	July 18, 2016
July 15, 2016	73.12	Crossties not effective	July 29, 2016
July 29, 2016	73.13	10-defective crossties	August 5, 2016
August 5, 2016	73.12	10-defective crossties	September 2, 2016
August 27, 2016	44.36	Crossties not effective	September 7, 2016
August 31, 2016	63.65	Crossties not effective	September 9, 2016
August 31, 2016	63.74	Crossties not effective	September 9, 2016
September 3, 2016	38.09	Crossties not effective	September 28, 2016
September 3, 2016	39.85	Crossties not effective	September 6, 2016
September 8, 2016	70.28	Crossties not effective	October 5, 2016
September 10, 2016	76.90	Crossties not effective	October 5, 2016
September 10, 2016	77.13	Crossties not effective	October 5, 2016
September 15, 2016	32.33	Crossties not effective	October 10, 2016
September 15, 2016	39.74	Crossties not effective	October 10, 2016

Date	Location (Milepost)	Findings	Repair Date
September 20, 2016	77.63	Crossties not effective	October 7, 2016
September 20, 2016	77.70	Crossties not effective	October 7, 2016
September 20, 2016	77.71	Crossties not effective	October 7, 2016
September 23, 2016	62.56	Crossties not effective	October 19, 2016
September 23, 2016	62.58	Crossties not effective	October 19, 2016
September 23, 2016	70.36	Crossties not effective	October 19, 2016
September 23, 2016	70.41	Crossties not effective	October 19, 2016
September 23, 2016	70.55	Crossties not effective	October 12, 2016
September 27, 2016	67.32	Crossties not effective	October 21, 2016
September 27, 2016	68.46	Crossties not effective	October 21, 2016
September 27, 2016	69.73	Crossties not effective	October 21, 2016
September 27, 2016	69.77	Crossties not effective	October 21, 2016
September 27, 2016	70.02	Crossties not effective	October 21, 2016
September 28, 2016	59.70	Crossties not effective	October 25, 2016
September 28, 2016	59.71	Crossties not effective	October 25, 2016
September 28, 2016	70.43	Crossties not effective	October 12, 2016
October 1, 2016	50.29	Crossties not effective	October 10, 2016
October 1, 2016	74.44	5-defective crossties	October 18, 2016
October 4, 2016	57.55	Crossties not effective	October 10, 2016
October 5, 2016	76.72	Crossties not effective	October 7, 2016
October 12, 2016	67.58	Crossties not effective	October 21, 2016
October 12, 2016	75.40	Crossties not effective	October 18, 2016
October 12, 2016	77.85	Crossties not effective	October 18, 2016
October 12, 2016	77.90	Crossties not effective	October 18, 2016
October 12, 2016	77.21	Crossties not effective	October 18, 2016
October 15, 2016	49.57	Crossties not effective	October 25, 2016
October 19, 2016	69.93	Crossties not effective	October 19, 2018
October 26, 2016	63.59	Crossties not effective	October 28, 2016
October 26, 2016	63.70	Crossties not effective	October 28, 2016
November 4, 2016	58.44	Crossties not effective	November 9, 2016

Appendix C: Tank Car Specifications

There are three primary types of tank cars used to transport flammable liquids: DOT-111, CPC-1232, and DOT-117.

- DOT-111: Referred to as "legacy" DOT-111 nonpressure tank cars, the tanks have thinner heads and shells (7/16 inch) than what is now required for newly manufactured DOT-117 tank cars. These tank cars are not required to have head shields to protect the tank from impact damage. The top fittings are vulnerable to impact damage and bottom outlet valve operating mechanisms are not designed to prevent releases in accident scenarios. These tank cars do not have a pressure relief device that is sufficiently sized to protect against tank shell rupture from severe fire exposure.

- CPC-1232: An industry-sponsored specification for more robust DOT-111 tank cars used to transport crude oil and ethanol was applicable to tank cars ordered after October 2011. These tank cars have a thicker head and shell (1/2-inch nonjacketed, and 7/16-inch jacketed) constructed of normalized steel, with a full-height head shield for jacketed tank cars and half-height head shield for nonjacketed cars. These tank cars have more extensive top fittings protection than legacy DOT-111 cars and must be equipped with a reclosing pressure relief device.

- DOT-117: A nonpressure tank car constructed of normalized steel with a minimum head and shell thickness of 9/16 inch, a jacket, full head shields, top fittings protective housing, and a bottom outlet valve operating mechanism designed to prevent opening during accident scenarios. These tank cars must have a thermal protection system and appropriately sized pressure relief device designed to protect the tank from exposure to a 100-minute pool fire and a 30-minute torch fire. DOT-117R tank cars are DOT-111 or CPC-1232 tank cars that have been retrofitted to meet the specifications for DOT-117.

The features of these various types of tank cars are noted in the table below. (See table 7.)

Table 7. Flammable liquids tank car specifications.

Tank Car Specification	Phaseout or Replacement?	Head and Shell Thickness (inches)	Normalized Steel?	Head Shield?	Jacket?	Thermal Protection?	Top Fittings Protection?	Bottom Outlet Valve Handle Modification?
DOT-111[a] Legacy Nonjacketed	Phaseout	0.4375	No	No	No	No	No	No
DOT-111 Legacy Jacketed	Phaseout	0.4375	No	No	Yes	Fiberglass insulation	No	No
CPC-1232 Jacketed	Phaseout	0.4375	Yes	Full	Yes	Fiberglass insulation	Yes	No
CPC-1232 Nonjacketed	Phaseout	0.5	Yes	Half	No	No	Yes	No

Tank Car Specification	Phaseout or Replacement?	Head and Shell Thickness (inches)	Normalized Steel?	Head Shield?	Jacket?	Thermal Protection?	Top Fittings Protection?	Bottom Outlet Valve Handle Modification?
DOT-117R Legacy DOT-111 Retrofit	Replacement	0.4375	No	Full	Yes	Fiberglass insulation	Modified	Yes
DOT-117R CPC-1232 Jacketed Retrofit	Replacement	0.4375	Yes	Full	Yes	Fiberglass insulation	Yes	Yes
DOT-117R CPC-1232 Nonjacketed Retrofit	Replacement	0.5	Yes	Full	Yes	Yes	Yes	Yes
DOT-117J	Replacement	0.5625	Yes	Full	Yes	Yes	Yes	Yes

[a] Specification for all tank cars involved in the Graettinger, Iowa, accident.

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