December 12, 2023 Railroad Investigation Report RIR-23-15

Derailment of Washington Metropolitan Area Transit Authority Train Near Rosslyn Station

Arlington, Virginia
October 12, 2021

Abstract: This report discusses the October 12, 2021, derailment of Washington Metropolitan Area Transit Authority train 407, which derailed in a tunnel while traveling from Rosslyn Station toward Arlington Cemetery Station on the Blue Line in Arlington, Virginia. All railcars remained upright and in-line. All 187 passengers and the train operator were evacuated to Arlington Cemetery Station, and no injuries were reported. The safety issues identified in this report include a wheelset design that allowed wheel migration and a lack of trend analysis at the Washington Metropolitan Area Transit Authority, which hindered an effective response to the wheel migration. One recommendation is made to the Washington Metropolitan Area Transit Authority and one is made to the Washington Metrorail Safety Commission.

Contents

Figures

Tables

Acronyms and Abbreviations

ACFD	Arlington County Fire Department
AREMA	American Railway Engineering and Maintenance-of-Way Association
CAP	corrective action plan
CMOR	WMATA Chief Mechanical Officer, Rail
ESC	WMATA Executive Safety Committee
FTA	Federal Transit Administration
NTSB	National Transportation Safety Board
ROCC	WMATA Rail Operations Control Center
RTC	rail traffic controller
SSOA	state safety oversight agency
WMATA	Washington Metropolitan Area Transit Authority
WMSC	Washington Metrorail Safety Commission

Executive Summary

What Happened

On October 12, 2021, about 4:49 p.m. local time, Washington Metropolitan Area Transit Authority (WMATA) train 407, consisting of 8 railcars and carrying 187 passengers and the operator, derailed while traveling from Rosslyn Station toward Arlington Cemetery Station on the Blue Line in Arlington, Virginia. The derailment occurred in a tunnel south of the Rosslyn Station platform. All railcars remained upright and in-line. The passengers and operator were evacuated to Arlington Cemetery Station. No injuries were reported; one passenger was transported to the hospital, treated, and released.

What We Found

The derailment occurred because the wheels of one wheelset had migrated outward on their axle, resulting in a width larger than the design specification. The wheel migration happened over time, eventually causing the wheelset to exceed its maximum design width. When this wheelset traveled over a turnout (a type of special track work that allows a train to change tracks), the out-of-specification wheelset width caused a wheel to leave the rail, derailing a railcar.

We found that one department within WMATA was aware of wheel migration in its railcar fleet and attempted to mitigate the associated safety risks, but the department did not conduct a trend analysis to monitor the incidence of wheel migration or how effective its mitigations were. A trend analysis would have shown the increasing incidence of wheel migration and made an effective response more likely. WMATA has since made improvements to its safety management systems and has plans to expand its use of trend analysis and related tools to identify and mitigate safety risks before accidents occur. The oversight of the Washington Metrorail Safety Commission is vital to supporting and monitoring these ongoing improvements.

The National Transportation Safety Board determines that the probable cause of the derailment of Washington Metropolitan Area Transit Authority train 407 south of Rosslyn Station was an out-of-specification wheelset that caused a wheel to depart the rail at a turnout; the wheelset was out of specification because the wheelset's design allowed the wheels to migrate outward and eventually exceed the maximum permitted back-to-back measurement.

What We Recommended

We recommended that WMATA implement processes and resources to expand its use of trend analysis to identify and mitigate safety risks. We also recommended that the Washington Metrorail Safety Commission develop a program to support and monitor WMATA's expanded use of trend analysis, both to ensure that it remains compliant with federal guidelines and to assess its effect on safety.

1 Factual Information

1.1 Derailment Description

On October 12, 2021, about 4:49 p.m. local time, Washington Metropolitan Area Transit Authority (WMATA) train 407, consisting of eight 7000-series railcars, was traveling from Rosslyn Station toward Arlington Cemetery Station on track 2 of the Blue Line in Arlington, Virginia, when the last wheelset on the fourth railcar (wheelset #4 on railcar 7200) derailed.[1] The derailment occurred at a turnout within a tunnel south of Rosslyn Station.[2] (See figure 1.) The train was traveling about 37 mph before the derailment. The train decelerated after the derailment, traveling about 430 feet before the operator stopped it within the tunnel. All railcars remained upright and in-line.

Train 407 had 187 passengers and 1 operator on board. All were evacuated onto the track bed and escorted south to Arlington Cemetery Station, which is an aboveground platform. No injuries were reported. One passenger was transported to the hospital and treated and released. WMATA estimated the damage to the track and equipment was about $690,000.

[1] (a) All times in this report are local times. (b) Visit ntsb.gov to find additional information in the public docket for this National Transportation Safety Board (NTSB) accident investigation (case number RRD22LR001). Use the CAROL Query to search safety recommendations and investigations.

[2] A *turnout* is a type of special track work that guides trains to or from a diverging track.

Figure 1. Map showing the Rosslyn derailment.

Train 407 was traveling on main track 2 on the Blue Line from Rosslyn Station toward Arlington Cemetery Station when, about 4:49 p.m., the train began to decelerate south of the Rosslyn Station platform. Data from an inward-facing image recorder in railcar 7200 showed the railcar moving laterally relative to other railcars at 4:49:22 p.m. and a shower of sparks visible through a window on the right side.

In an interview with the National Transportation Safety Board (NTSB), the train operator said that the operating compartment console sounded an audio alert and indicated a stuck brake on railcar 7200. Based on event recorder data, the operator stopped the train about 430 feet after it began to decelerate. The train operator attempted to release the stuck brake by cycling the power on the train's control system. The train operator contacted the WMATA Rail Operations Control Center (ROCC) at 4:51 p.m. and reported that the train had a stuck brake. A student rail traffic controller (RTC) working under the supervision of another RTC (the radio RTC) attempted to assist the train operator in troubleshooting the problem. At 4:52 p.m., the train operator told the RTCs that he had received passenger intercom communications describing "a brake odor" coming from the train.[3]

In the radio RTC's interview with the NTSB, he described continuing the troubleshooting process with the train operator based on the odor, believing it may have come from the stuck brake; a stuck brake can overheat the brake pads and create smoke and an odor. The radio RTC advised the train operator to perform a "brake power knockout."[4] The train operator performed the brake power knockout about 4:56 p.m. and, based on the NTSB's review of event recorder data, was able to move the train about 1,200 feet before coming to a stop on a slight up-grade.

After the train stopped, the train operator walked back through the train, where he encountered what he described in interviews as "light smoke." He observed that the fourth railcar, railcar 7200, was "shifted" and concluded that it had derailed. He reported the derailment and smoke to the radio RTC. Following the radio RTC's instructions, the train operator moved passengers toward the front of the train. A WMATA Rail Transportation supervisor, dispatched by the ROCC, reached train 407 on foot from Arlington Cemetery Station about 5:05 p.m. and radioed to the ROCC that the "rear trucks" (the truck containing axles #3 and #4) on railcar 7200 had derailed.[5]

A third RTC was responsible for tunnel ventilation and line management, including setting signals and communicating with train operators on the Blue, Silver, and Orange Lines. The third RTC was working from the same desk as the student RTC and radio RTC, and he heard the train operator report a stuck brake and smoke in the train. He did not initially realize that the train was in a tunnel.[6] In an interview with the NTSB, he indicated that other than personally riding the Metro, he had no knowledge of whether a location in the Metro system (as specified by an alphanumeric code or distance from a station) was within a tunnel. About 5:03 p.m., the radio RTC suspended Blue Line service between Pentagon Station and Foggy Bottom-GWU

[3] Each railcar has an intercom for emergency communication with the operator.

[4] A *brake power knockout* is a procedure intended to release a stuck brake.

[5] A *truck* is the assembly housing a railcar's wheelsets. On WMATA railcars, each truck contains two wheelsets. A wheelset consists of an axle with two wheels.

[6] Part of the Blue Line between Rosslyn Station and Arlington Cemetery Station is above ground.

Station and remotely de-energized the third rail on main track 2 between Rosslyn Station and Arlington Cemetery Station. Personnel from the Metro Transit Police Department and Arlington County Fire Department (ACFD) arrived at Arlington Cemetery Station about 5:12 p.m. At 5:13 p.m., the third RTC remotely de-energized the third rail on main track 1 between Rosslyn Station and Arlington Cemetery Station. The ACFD began evacuating passengers to Arlington Cemetery Station along main track 2 about 6:20 p.m. After Metro Transit Police called the ROCC and communicated an intent to approach the derailment from Rosslyn Station, the third RTC realized that the derailment may have occurred in a tunnel and activated the exhaust fan at Rosslyn Station to clear smoke from the tunnel about 6:44 p.m. The ACFD completed the evacuation about 7:16 p.m. See table 1 for a timeline of events.

Table 1. Timeline of events.

Time	Event
4:49 p.m.	Train 407 derails south of Rosslyn Station
4:51 p.m.	Accident train operator reports stuck brake to radio RTC
4:56 p.m.	Operator moves train about 1,200 feet toward Arlington Cemetery Station; train stops permanently
5:03 p.m.	The third RTC suspends Blue Line service between Pentagon Station and Foggy Bottom-GWU Station
5:05 p.m.	WMATA Rail Transportation supervisor arrives on-scene and confirms derailment of railcar 7200
5:12 p.m.	ACFD arrives at Arlington Cemetery Station
6:20 p.m.	ACFD begins evacuating passengers to Arlington Cemetery Station
6:44 p.m.	The third RTC activates the exhaust fan at Rosslyn Station
7:16 p.m.	Evacuation complete

1.2 WMATA

WMATA is a public transit agency that operates bus and rail services in Washington, DC, and suburbs in Virginia and Maryland. Its rail services, branded as "Metrorail," operate over about 129 miles of WMATA-owned track, including the Blue Line where the derailment took place. WMATA falls under the regulatory authority of the Federal Transit Administration (FTA). WMATA's Metrorail operations are also overseen by a state safety oversight agency (SSOA), the Washington Metrorail Safety Commission (WMSC).

1.2.1 WMATA Blue Line Track

At the time of the Rosslyn derailment, WMATA's Blue Line extended from Largo Town Center Station to Franconia-Springfield Station. AREMA 115RE rail is standard across the WMATA rail system, including all Blue Line track.[7] The track between Rosslyn Station and Arlington Cemetery Station is exclusive to the Blue Line. Near the Rosslyn derailment, the speed limit was 59 mph and set by WMATA's Metrorail Safety Rules and Procedures Handbook.

1.2.2 Accident Train

The accident train, designated train 407 at the time of the derailment, consisted of eight 7000-series railcars owned and operated by WMATA. The 7000-series fleet, manufactured by Kawasaki Rail Car, Inc., entered revenue service in April 2015. A total of 748 7000-series railcars were delivered to WMATA between 2015 and 2020. All 7000-series railcars are joined into pairs with semi-permanent couplers, and a normal consist is made up of four pairs.

Railcar 7200 was the only railcar in train 407 to derail. It was an A-car paired with B-car 7201.[8] Its last maintenance and physical inspection before the derailment occurred on July 28–29, 2021.[9] After this inspection, the railcar was approved to continue in service.

The accident train underwent its daily visual inspection in the morning on the day of the derailment. The inspection report did not include any defects that would have kept the train from revenue service. The train entered revenue service as train 405 at 4:47 a.m., departing New Carrollton Station on the Orange Line. At that time, the train was being operated by a different operator than the one who was operating the train during the derailment.

[7] AREMA stands for American Railway Engineering and Maintenance-of-Way Association. AREMA 115 RE rail is a common specification of rail that weighs about 115 pounds per yard and conforms to specific dimensions.

[8] Each pair of 7000-series railcars consists of an A-car (with an operator cab) and B-car (with a simplified set of controls for railyard movement).

[9] This inspection included physical examination of the railcar's wheelsets. For more details about WMATA physical inspections, see section 1.7.

1.3 Personnel Information

1.3.1 Train Operator

The train operator was hired by WMATA in October 2000 as a bus operator. He completed train operator training in March 2009 and transitioned from bus to train operations on the Blue, Orange, and Silver Lines. His last recertification before the derailment was in May 2020, and he completed his last refresher training in November 2020. At the time of the derailment, he had about 11 years of experience as a train operator.

On the day of the derailment, the accident train operator went on duty at 5:45 a.m. He assumed control of a train (not the accident train) and made several trips on the Blue Line between Largo Town Center Station and Franconia-Springfield Station. These trips were uneventful. He assumed control of train 407 before departing Largo Town Center Station at 4:11 p.m. In an interview with the NTSB, he reported that he did not experience anything unusual while operating train 407 before the Rosslyn derailment.

1.3.2 Toxicology

After the Rosslyn derailment, the train operator took a breathalyzer test for alcohol and submitted specimens for postaccident toxicological testing as required by the FTA under Title 49 *Code of Federal Regulations* Part 655. The results were negative for all tested-for substances.[10]

1.4 Track Examinations and Surveillance Camera Data

The NTSB's on-scene investigation identified wheel flange departure marks on rail switches and damage to track infrastructure at the derailment site south of Rosslyn Station. Wheel flange departure marks are a unique scar on the surface of a rail due to increased weight concentration at a spot where railcar wheel flanges ride directly

[10] FTA postaccident toxicology testing screens for urinary metabolites of amphetamine, methamphetamine, cocaine, codeine, morphine, heroin, phencyclidine (PCP), methylenedioxymethamphetamine (MDMA), methylenedioxyamphetamine (MDA), methylenedioxyethylamphetamine (MDEA), tetrahydrocannabinol (THC), oxycodone, oxymorphone, hydrocodone, and hydromorphone.

on the surface of a rail rather than their intended position at the inner edge of the rail. (See figure 2.) Investigators use these marks to identify points of derailment.

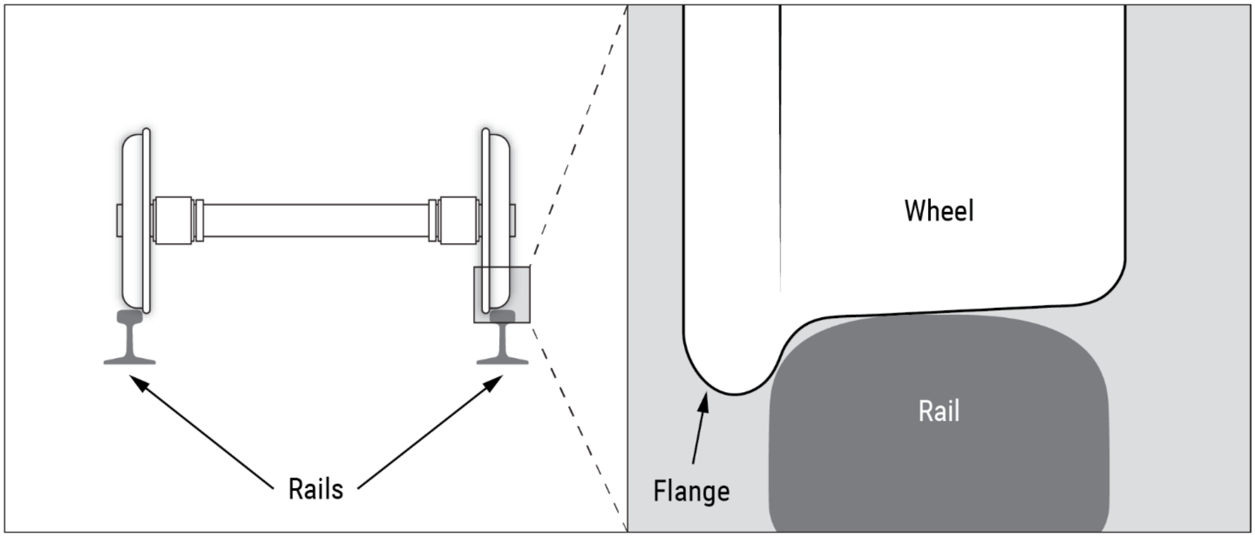

Figure 2. Diagram of wheelset on rails (left) and wheel profile (right).

A rail switch (usually called a switch) is a part of some types of special track work that allows trains or railcars to be diverted to other tracks, such as at a turnout or crossover.[11] Rail switch components relevant to this investigation include switch points, switch heels, frogs, and frog points. (See figure 3.) The switch point is the moveable rail within a switch, and the switch heel is the component that connects the switch point to the rail that runs to the frog. The frog is the component at the intersection of two rails that supports wheels and provides a passageway for flanges when a wheel passes over an intersecting rail. The frog point is the pointed end of the frog.

[11] *Special track work* refers to features such as turnouts, crossovers, diamond crossings, restraining guard rails, expansion or sliding rail joints, and restraining devices. Special track work is distinct from the ordinary track that makes up most miles of a rail system.

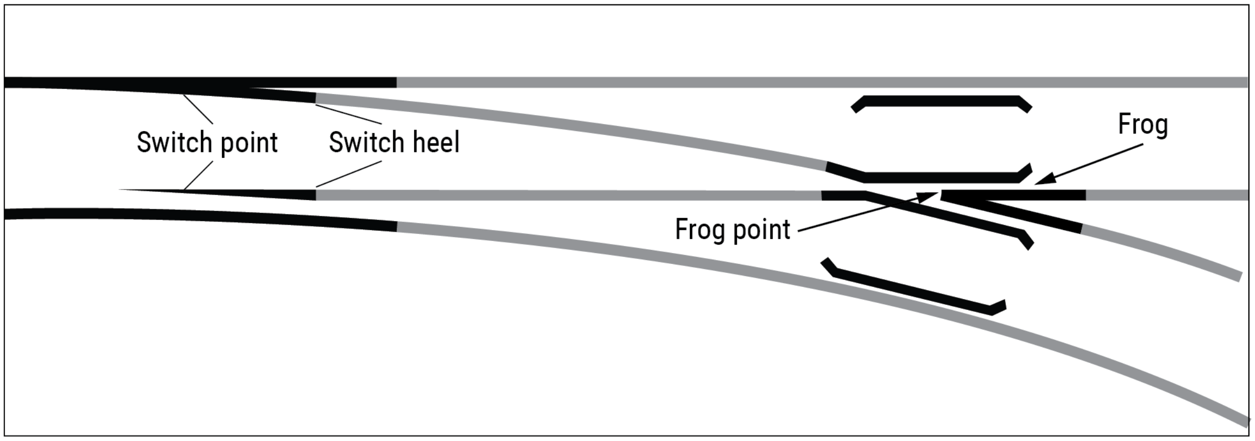

Figure 3. Simplified diagram of a railroad turnout containing a rail switch and a frog.

The NTSB also directed WMATA to examine the tracks traveled by the accident train on the day of the derailment for signs of other derailments that could have occurred before the Rosslyn derailment. During this examination, WMATA personnel identified physical evidence consistent with a train derailment—wheel flange departure marks and pieces of brake discs—at two locations on the Blue Line: north of Arlington Cemetery Station and west of Largo Town Center Station.

The NTSB examined the physical evidence and reviewed data from platform surveillance cameras at these two additional locations to determine whether other derailments had occurred and whether train 407 was involved. The surveillance cameras recorded train 407 exhibiting unusual motion north of Arlington Cemetery Station about 3:24 p.m. and west of Largo Town Center Station about 4:13 p.m. on the day of the Rosslyn derailment. The train's motion at both locations was consistent with derailment and re-railment. (See figure 4.) No reviewed camera data indicated that another train could have derailed at these locations. The physical evidence and surveillance camera data are discussed below in chronological order as determined by the surveillance camera timestamps.

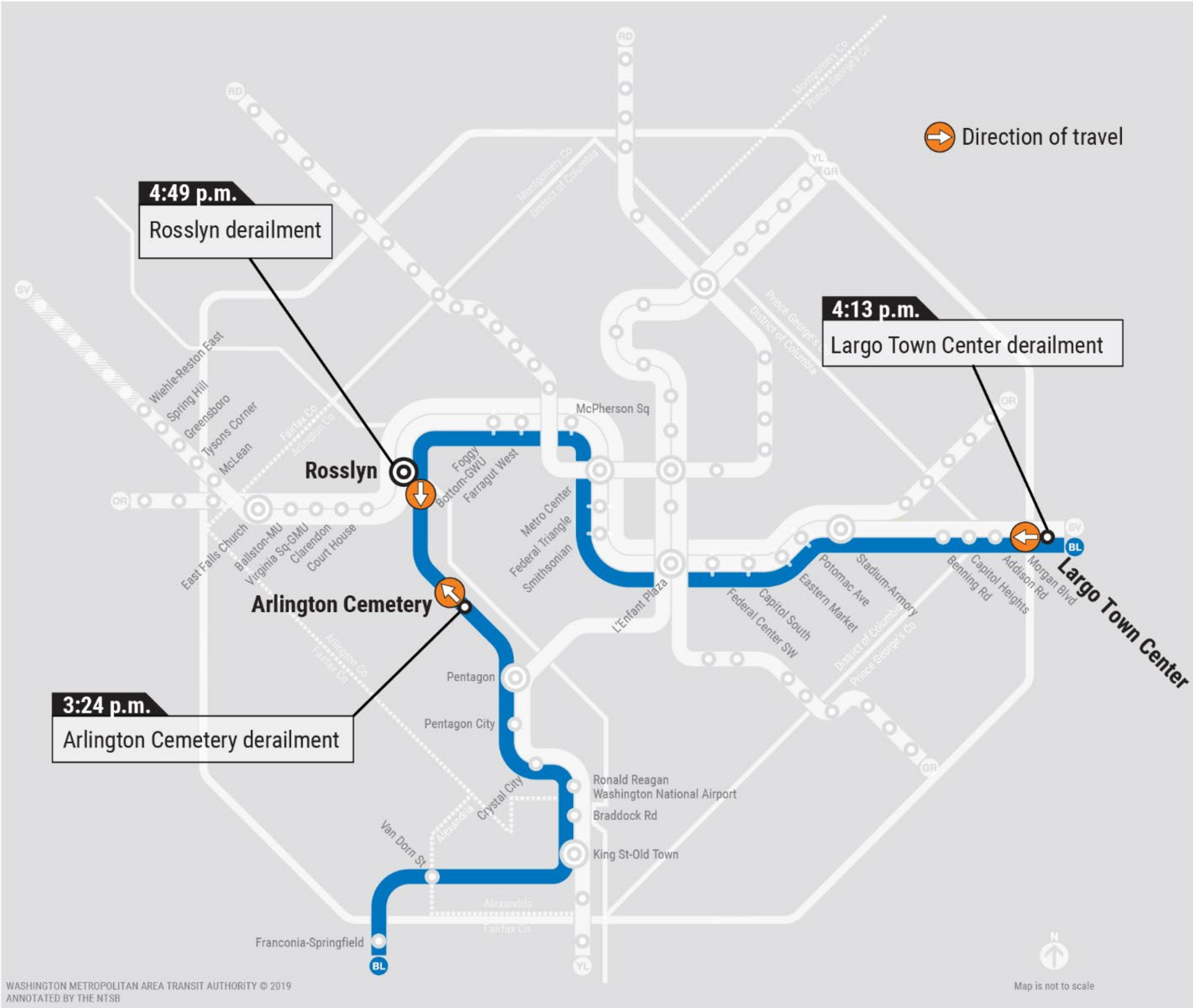

Figure 4. Map of all three derailment locations.

1.4.1 Arlington Cemetery Station

As a result of the investigation into the Rosslyn Station derailment, WMATA employees discovered damage to switches 1A and 3A chain marker 187+25 on main track 1 in a crossover north of Arlington Cemetery Station, including wheel flange departure marks near the switch point (across a switch point guard) of switch 1A.[12] (See Figure 5.) While examining the track between switch 1A and switch 3A, the NTSB noted damage to two switch heel blocks, bolts, ties, and automatic train control

[12] (a) WMATA designates locations with *chain markers*; 187+25 indicates a distance of 18,725 feet (187×100 feet+25 feet) from the middle of the Metro Center Station platform. (b) A *switch point guard* is a device used by some transit railroads to protect switch points from wheel flanges. It resembles a third running rail and moves with the switch point.

equipment consistent with one or more derailed wheels running along the ground and re-railing as they approached switch 3A. (See figure 6.) WMATA employees also found broken sections of brake disc in this area, which the NTSB matched to the right-side brake disc on wheelset #4 of railcar 7200.[13]

Figure 5. Wheel flange departure mark on the switch point guard near the heel of 1A switch.

[13] Each pair of 7000-series railcars has a front and back, which do not always correspond to the train's direction of travel. When this report discusses railcar components, left and right are based on the front of the railcars (which is constant) and not the head end of the train (which changes depending on direction of travel).

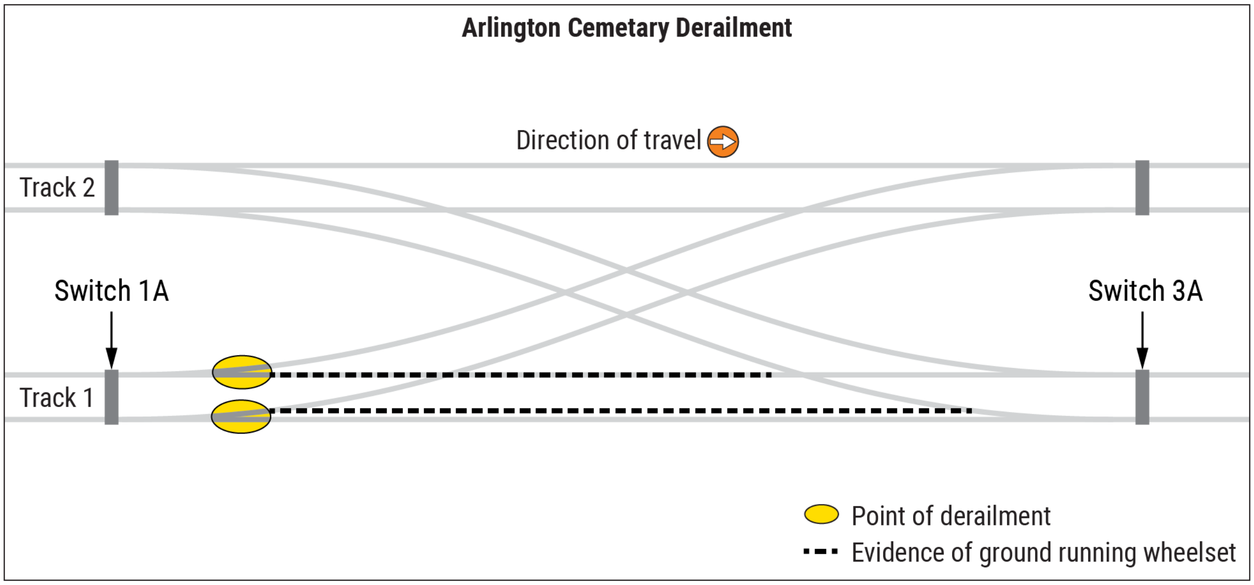

Figure 6. Diagram of Arlington Cemetery derailment site.

The NTSB reviewed data from WMATA's platform surveillance cameras. About 3:24 p.m. on the day of the derailments, a camera at the north end of the Arlington Cemetery Station platform recorded railcar 7200 in train 407 moving up, down, and side-to-side in a manner consistent with derailment as the train departed the station and railcar 7200 traversed the C06 crossover. The camera also recorded a dust plume beneath railcar 7200, consistent with a railcar component disturbing track bed material (ballast). Railcar 7200 resumed normal motion after about 4 seconds. No other railcars exhibited unusual motion.

1.4.2 Largo Town Center Station

The NTSB also identified wheel flange departure marks on the tread portion of the track (the tread portion carries the wheel tread) on switches 1B and 3B at crossover G05 west of Largo Town Center Station at chain marker 621+98 on main track 2. (See figure 7.) In addition, the NTSB identified wheel marks on the ground, broken ground pads, and damaged automatic train control equipment between switch 1B and switch 3B. The damage was consistent with one or more derailed wheels running along the ground and re-railing as it neared switch 3B. The NTSB found fragments of brake disc at the crossover.[14]

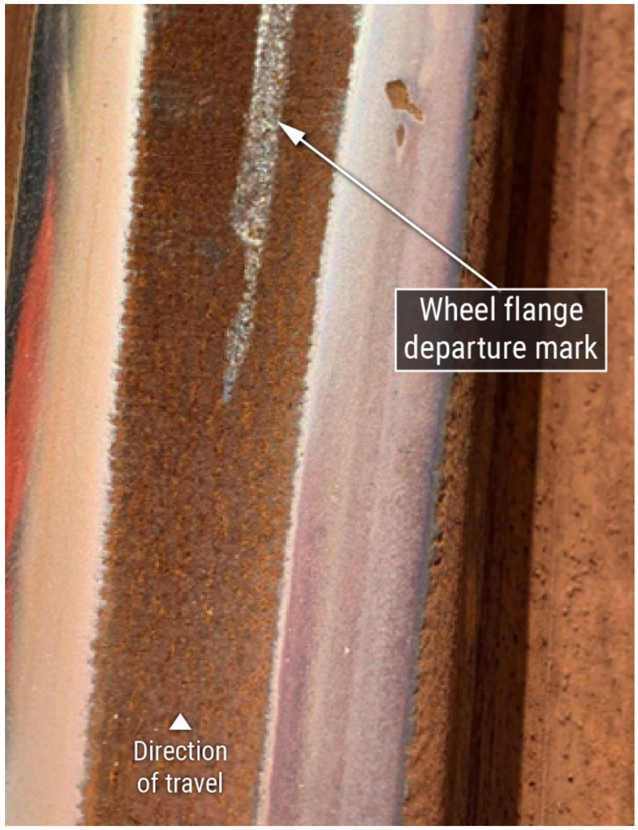

Figure 7. Wheel flange departure mark on the tread portion of a frog point at the 1B switch.

[14] The NTSB did not repeat the laboratory analysis for fragments of brake disc recovered at the Largo Town Center crossover. Laboratory analysis of the brake disc fragments from the Arlington Cemetery derailment site matched the fragments to wheelset #4 of railcar 7200. The evidence collected by the NTSB had focused the investigation on railcar 7200 and did not suggest that other railcars had derailed.

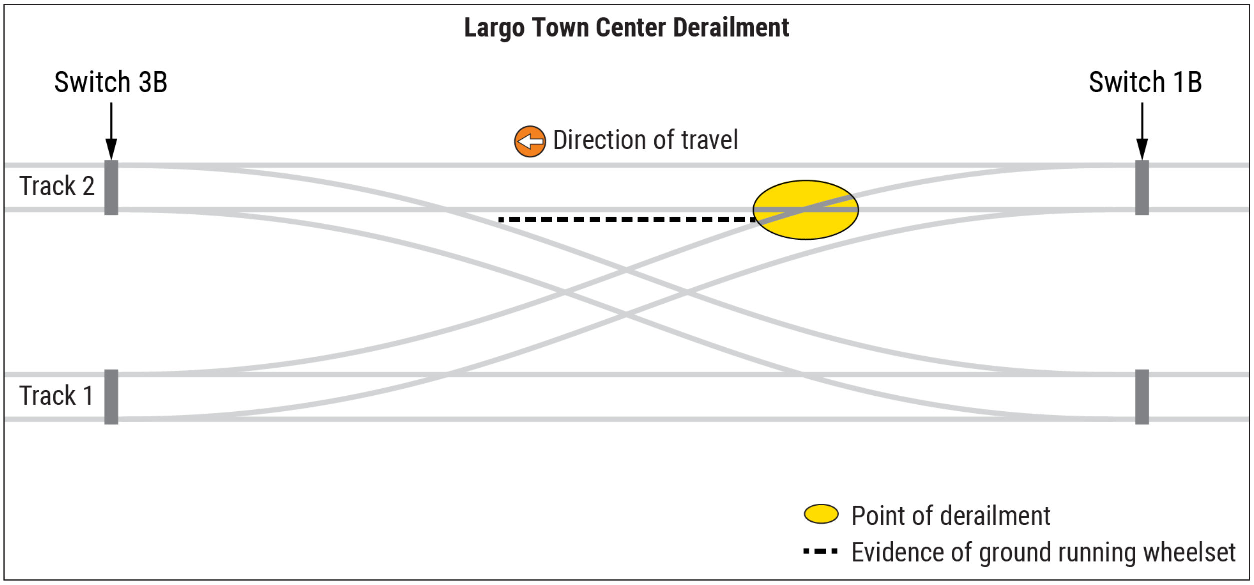

Figure 8. Diagram of Largo Town Center derailment site.

About 4:13 p.m., a camera at the southwest end of the Largo Town Center Station platform recorded railcar 7200 moving side-to-side in a manner consistent with derailment as the train departed the station and railcar 7200 traversed crossover G05. The camera also recorded a dust plume beneath railcar 7200, consistent with a railcar component contacting the concrete beneath the rails. Railcar 7200 resumed normal motion after about 5 seconds. No other railcars exhibited unusual motion.

1.4.3 Rosslyn Station

The NTSB identified wheel flange departure marks in the turnout at the frog of the switch in the C05 turnout at chain marker 146+70, about 166 feet south of Rosslyn Station. (See figure 9 and figure 10.) Investigators also found wheel departure marks on other track components nearby. This turnout was the final point of derailment.

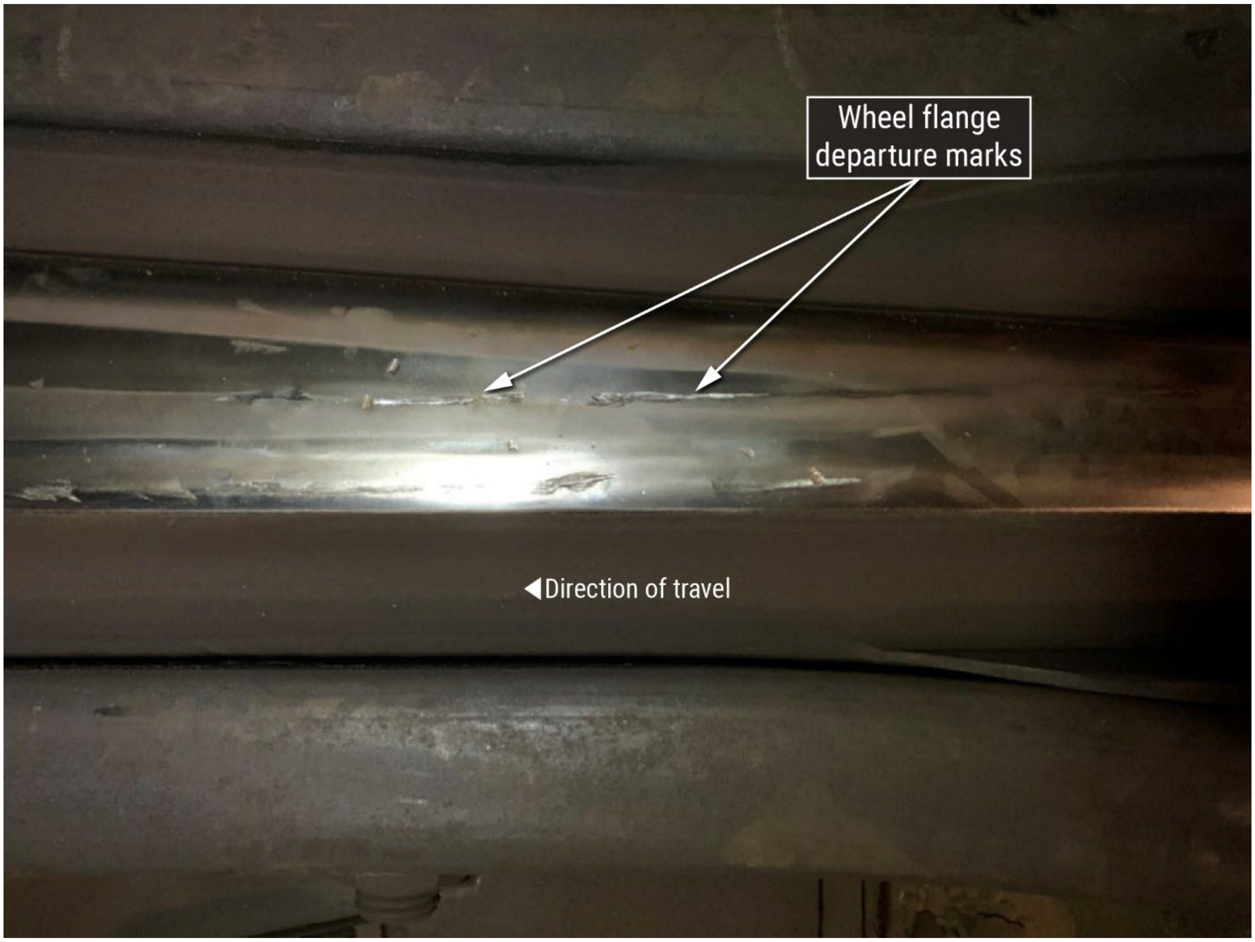

Figure 9. Wheel flange departure marks on the tread portion of the frog point at the C05 turnout.

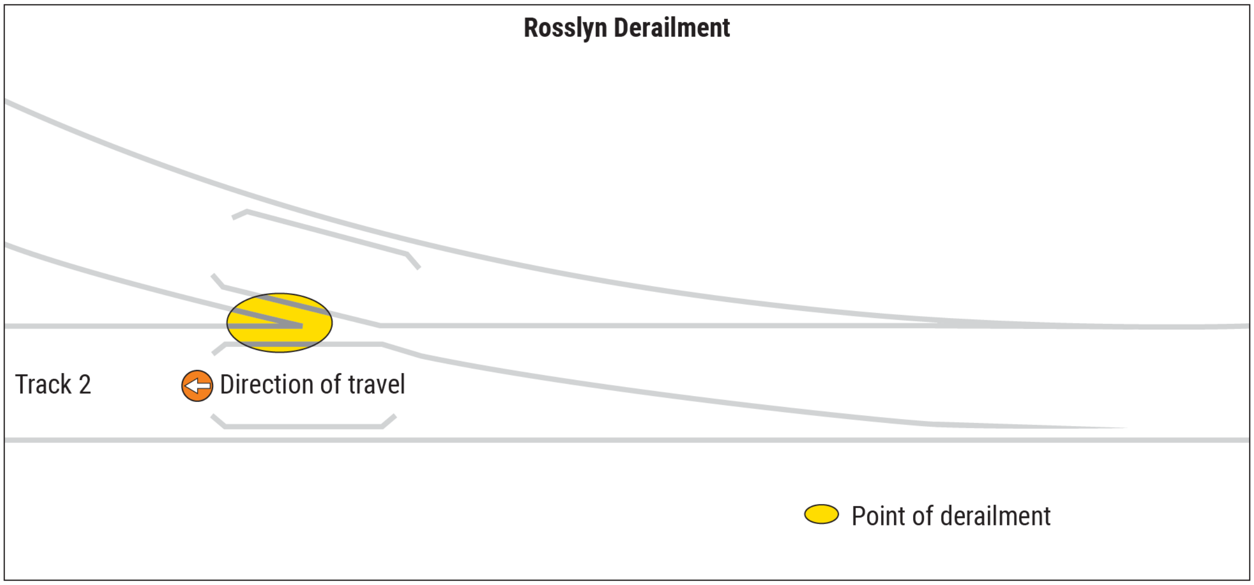

Figure 10. Diagram of Rosslyn derailment site.

1.4.4 WMATA Track Conditions

WMATA provided data and survey reports from a geometry car to the NTSB for the Blue Line track.[15] Track geometry refers to the gage, surface, and alinement of the track structure.[16] The most recent surveys that included the three derailment locations were conducted on September 19 and 23, 2021. The surveys showed that track conditions at or near these locations were within WMATA's design specifications. The NTSB reviewed track and turnout inspection records from WMATA for the identified derailment locations, all of which were within WMATA tolerances. The NTSB did not identify any track-related risk factors for derailment.

The NTSB also examined signal equipment and switch function near the derailment locations on October 13-14, 2021. The NTSB did not identify any defects or issues with signal equipment or switch function.

1.5 Post-derailment Railcar Inspections and Examinations

On October 16, 2021, the NTSB worked with WMATA technicians to inspect the lead truck (containing wheelsets #3 and #4) on railcar 7200. All inspected components were within WMATA's design specifications except for wheelset #4, which had an out-of-specification back-to-back measurement as described below. A back-to-back measurement is the distance between the inner faces of the wheels on a single axle. (See figure 11.)

[15] *Geometry cars* measure track to determine compliance with maintenance standards and provide data to inform planning of routine maintenance.

[16] (a) *Gage* is the distance between rails. (b) *Alinement* is a measure of track uniformity.

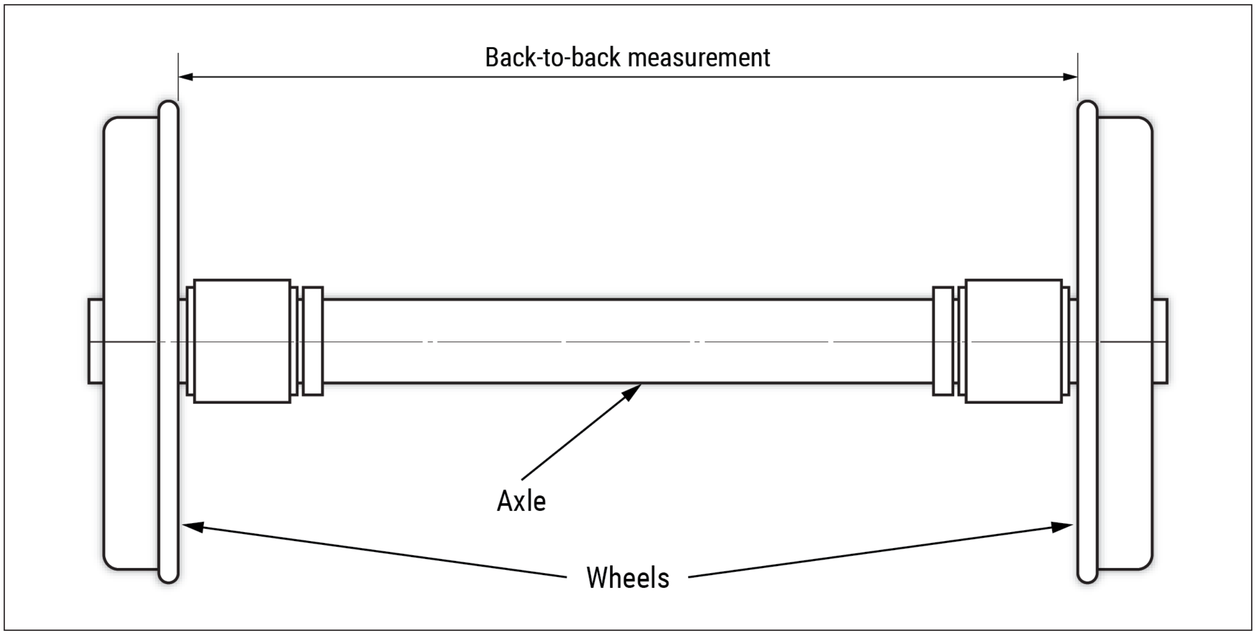

Figure 11. Diagram of a back-to-back measurement.

1.5.1 7000-Series Wheelset Specifications

Each 7000-series railcar has two trucks, each with two wheelsets. Both wheels on each axle are flanged (see section 1.4) and, when new, have a minimum specified flange thickness of 1.1563 inches. Flanges wear over time, and the minimum acceptable flange size for wheel in service, which is measured during 90-day physical inspections, is 0.9375 inches (15/16 inches as measured using an Association of American Railroads flange gauge). WMATA's specified back-to-back measurement is greater than or equal to 53.25 inches and less than 53.375 inches.[17]

These wheelsets are assembled by press-fitting (also known as interference-fitting) wheels onto 5.620-inch-diameter axle wheel seats at either end of a hollow axle. An interference fit is created by pressing an axle wheel seat into a bore (the opening in the wheel hub) with a slightly smaller diameter than the axle seat. The resulting joint is held together by friction. When used as a measurement, interference refers to how much larger the axle wheel seat is than the bore.[18]

[17] The original specification and some WMATA inspections considered a back-to-back measurement equal to 53.375 inches acceptable; inspections conducted after April 2022 with higher-precision digital instruments require a back-to-back measurement of less than 53.375 inches.

[18] Interference is commonly given in inches or mils (thousandths of an inch) but is technically a dimensionless quantity because it expresses inches of excess diameter per inch of bore.

When wheelsets are assembled, the amount of force required to press the wheel onto the axle is measured and recorded for each wheel. A higher mounting force tends to indicate a greater amount of interference. A mounting force specification is a means of confirming that the desired interference has been achieved.

WMATA observed cases of wheels migrating outward on their axles over time in the pre-7000-series fleet (the legacy fleet) in 2014 and responded by increasing the interference specification for the 7000-series, which was then in production. As a result, at the time of the derailments, the 7000-series fleet included wheelsets assembled under two different interference specifications: 0.0035-0.0060 inches (original) and 0.0045-0.0065 inches (after June 16, 2017, when WMATA approved revised design drawings from Kawasaki). These specifications resulted in wheelsets with mounting forces of 55-80 tons (original) and 65-95 tons (after revision).[19]

According to WMATA's records, axle #4 on railcar 7200 was assembled under the original specification on April 8, 2016. The interference for both wheels was 0.0044 inches, resulting in a mounting force of 64 tons for the right wheel and 58 tons for the left wheel.

1.5.2 Wheel Positions

The NTSB observed the inspection and disassembly of wheelset #4 from railcar 7200 at the WMATA Greenbelt maintenance facility on October 20, 2021. In accordance with wheelset design, each wheel should have been flush against its bearing when mounted. Before disassembly, the inspection identified gaps between both wheels and their respective bearings: about 0.63 inches for the right-side wheel and about 1.10 inches for the left-side wheel. (See figure 12 and figure 13.) The back-to-back measurement was about 55.375 inches, or about 2 inches wider than the maximum design specification.[20]

[19] Mounting force correlates imperfectly with interference; factors such as bore finish and lubrication can lead to different mounting forces for wheelsets assembled with the same interference.

[20] The measurement recorded in the inspection discrepancy sheet was "55 3/8 inches" and should be taken as approximate; the wheels were loose on the axle and no longer perpendicular, meaning that the exact point and circumstances of the measurement could introduce variation.

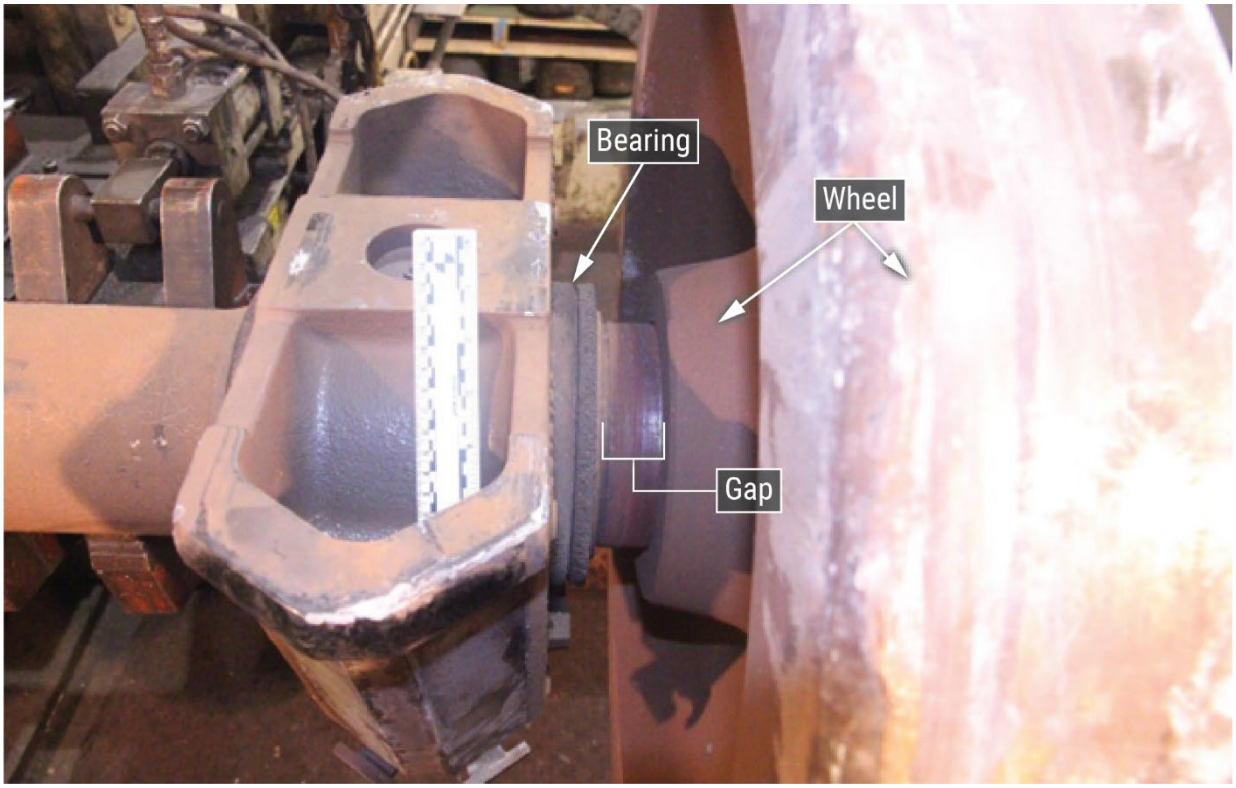

Figure 12. Gap between the right-side wheel and bearing on wheelset #4.

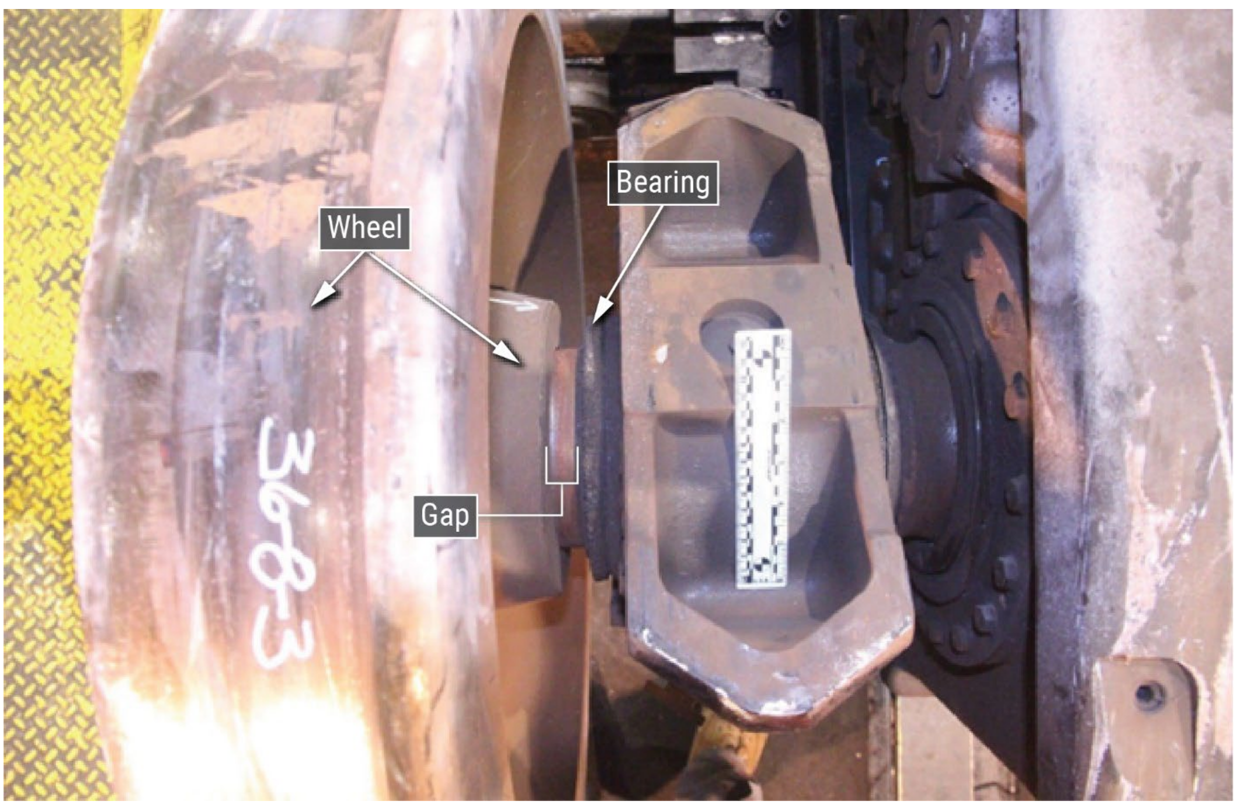

Figure 13. Gap between the left-side wheel and bearing on wheelset #4.

1.5.3 Rust Patterns

After disassembly, the axle and the unmounted wheels from wheelset #4 were provided to the NTSB for further examination. The NTSB Materials Laboratory examined the axle and found oxidation (rust) on the surface of the axle wheel seats within the gaps between the wheels and bearings. The rust was more pronounced inboard (toward the center of the axle).

1.5.4 Wear Patterns

After cleaning the axle to remove obscuring surface oxidation and to allow further examination, the NTSB Materials Laboratory identified circumferential bands consistent with fretting wear on the axle wheel seat surface. Fretting wear results from small oscillations between two bodies in contact. Fretting wear tends to roughen surface finishes, leading to oxidation and reducing the strength of the connection between components. In axles, fretting wear can be a sign of ratcheting extrusion, in which an axle under simultaneous bending and lateral stresses will experience movement between the wheel bore surface and the axle wheel seat (Nishimura, Sakatmoto, and Kawashima 2001).

The most severe observed region of fretting damage, located on the right-side axle wheel seat surface, exhibited parallel wavy and linear features oriented perpendicular to the axle's long axis. The features exhibited a reddish-brown color consistent with oxidation (rust). (See figure 14.)

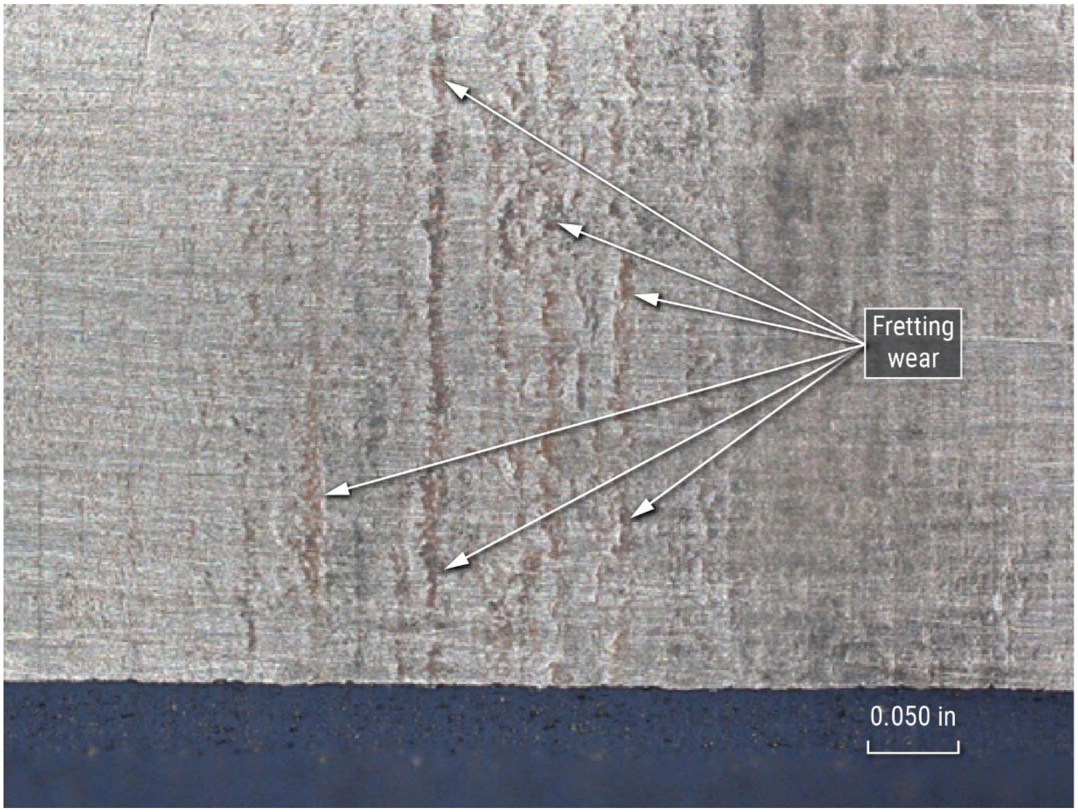

Figure 14. Close-up of the most severe fretting wear on the right-side axle wheel seat.

1.5.5 Wheel Flange Wear

The NTSB Materials Laboratory examinations of the wheels removed from wheelset #4 identified thin flanges on both wheels: the left wheel flange had thinned to a minimum of 0.76 inches, and the right wheel flange had thinned to a minimum of 0.91 inches.[21] WMATA considers a flange thinner than 0.9375 inches to be out-of-specification.

1.6 Federal and State Oversight

1.6.1 FTA

The FTA issues grants and exercises safety oversight authority over transit systems under Title 49 *United States Code* Chapter 53. As part of that authority, the

[21] Flanges extend below the tread of the wheel and can contact the edges of rails. This causes flanges to thin over time. See figure 2 for an illustration of a flange.

FTA developed a National Public Transportation Safety Plan. The first version of this plan was published in 2017.

The National Public Transportation Safety Plan includes a framework for transit agencies to implement safety management systems. Under this framework, a rail transit agency's safety management system is intended to improve safety by providing information to senior leadership, creating accountability for safety decision making to promote a proactive safety culture, and identify safety trends and manage hazards before they result in accidents (FTA 2017). The National Public Transportation Safety Plan also includes guidance on how to set safety performance measures for fatalities, injuries, safety events, and system reliability. The plan recommends analyzing data over time to assess safety performance and identify trends, but it does not directly set performance measures.

The Moving Ahead for Progress in the 21st Century Act (Public Law 112-141), enacted in 2012, required the FTA to establish certification requirements for state safety oversight agencies (SSOAs). In 2016, the FTA published the State Safety Oversight final rule at 49 *Code of Federal Regulations* Part 674, requiring all states with rail transit systems to establish an FTA-certified State Safety Oversight program by April 15, 2019. Under these requirements, SSOAs establish minimum safety standards for public rail transit agencies, review and approve public transportation agency safety plans, oversee rail transit agencies' execution of these plans, and investigate both accidents and allegations of transit agencies' noncompliance with public transportation agency safety plans. Public transportation agency safety plans must be consistent with the FTA's National Public Transportation Safety Plan.

1.6.2 WMSC

The WMSC serves as the SSOA for WMATA's rail operations. It was established in August 2017 and certified in March 2019 by the FTA. The WMSC replaced the Tri-State Oversight Committee, whose inadequate safety oversight contributed to two fatal accidents investigated by the NTSB: a train-to-train collision near Fort Totten Station and the L'Enfant Plaza Station electrical arcing and smoke accident (NTSB 2010 and 2016). The WMSC is responsible for reviewing and approving WMATA's public transportation agency safety plans, auditing safety plans to monitor execution, investigating allegations of noncompliance, and investigating rail accidents. The WMSC also reviews and approves corrective action plans (CAPs) developed by WMATA and monitors CAP progress through inspections or other means as appropriate.

At the time of the derailments, WMATA was operating under the WMSC-approved 2020 WMATA Transit Agency Safety Plan, which was effective from December 2020 through December 2021 (WMATA 2020c). This plan described the structure, purpose, and requirements of WMATA's safety management system, including responses to safety risks.

1.7 WMATA Railcar Inspection Procedures

WMATA set its own railcar inspection schedules and procedures as described in its WMSC-approved public transportation agency safety plan (WMATA 2020c). WMATA's maintenance program included daily visual inspections and physical inspections of railcars at 90-day intervals (WMATA 2020a and 2020b). WMATA's daily visual inspection for 7000-series railcars was intended to "identify problems that cannot wait until the next inspection, as well as problems that may impact passenger safety and comfort" (WMATA 2020a). The visual inspection procedure included looking for unusual wear patterns and other damage on visible portions of wheels. Railcar 7200 was visually inspected the morning before the derailments.

Physical inspections conducted at 90-day intervals included back-to-back wheelset measurements and examination of wheels for defects (WMATA 2020b). Depending on the measuring tool used, these inspections resulted in a recorded back-to-back measurement or a pass-fail check. The last physical inspection of railcar 7200 occurred on July 28-29, 2021, about 75 days before the Rosslyn derailment, and resulted in a passed back-to-back measurement, and the railcar was approved to continue in service.

1.8 Wheel Migration on WMATA Railcars

1.8.1 Wheel Migration in the Legacy Fleet

In March 2014, wayside monitoring equipment detected unusual performance in several railcars in the pre-7000-series fleet, known as the "legacy fleet." WMATA's inspections of these railcars found out-of-specification back-to-back measurements, which prompted WMATA to inspect its entire legacy fleet and retain LTK Engineering Services to conduct a study of wheel migration. As documented in the resulting 2015 report, WMATA examined all in-service railcars and identified more than 30 railcars with wheelsets with out-of-specification back-to-back measurements.[22] The report

[22] The report is available in the docket for this investigation.

recommended increasing the interference specification to prevent wheel migration; the increased interference would require increasing wheel mounting forces from 55–80 tons to 65–95 tons. No 7000-series railcars were yet in service, but many 7000-series wheelsets had already been assembled under the interference specification shared with the legacy fleet's wheelsets. In June 2017, after the 2015 LTK Engineering Services report, WMATA increased the interference specification for 7000-series wheelsets. (See section 1.5.1.) Based on WMATA's wheel press records for the 7000-series fleet, 493 railcars went into service with wheelsets assembled under original specification, including railcar 7200, and 255 railcars went into service with wheelsets assembled under the new specification.[23]

1.8.2 Wheel Migration in the 7000-series Fleet

According to the NTSB's interview with the senior program manager for the 7000-series program and WMATA's deputy chief mechanical officer, the Office of the Chief Mechanical Officer, Rail (CMOR) first observed wheel migration resulting in an out-of-specification back-to-back measurement in a 7000-series wheelset in March 2017. The Office of the CMOR responded by disassembling the wheelset for examination but was already considering increasing interference because of the 2015 report on wheel migration in the legacy fleet as described in section 1.8.1, and WMATA revised the interference specification in June 2017.

Between 2017 and the date of the derailments, physical inspections of 7000-series railcars performed at 90-day intervals identified 31 wheelsets with out-of-specification back-to-back measurements. The number of deployed 7000-series railcars increased over this period, reaching a maximum of 748 railcars (and 2,992 in-service wheelsets).[24] Out-of-specification 7000-series wheelsets per year are shown in table 2. The Office of the CMOR did not know what was causing the wheel migration.

[23] WMATA retains press records for their wheel and axle assemblies.

[24] Over the same period, physical inspections of the legacy fleet identified two wheelsets (one 2000 series and one 6000 series) with out-of-specification back-to-back measurements. The number of legacy railcars in service was decreasing as WMATA deployed the 7000-series fleet, which makes a direct comparison of wheel migration in the two fleets difficult.

Table 2. Yearly number of wheelsets with out-of-specification back-to-back measurements.

Year	Out-of-Specification 7000-series Wheelsets
2017	4
2018	1
2019	4
2020	4
2021 (through October 12)	18

In his interview with the NTSB, the senior program manager for the 7000-series characterized wheel migration falling within the class of "small or infrequent reliability issues" typically addressed through WMATA's Failure Reporting and Corrective Action System meetings, which were held weekly between Office of the CMOR staff and Kawasaki Rail Car. The Office of the CMOR did not conduct or obtain a trend analysis for wheel migration. Affected wheelsets were replaced by Kawasaki Rail Car under warranty.[25]

Beginning in 2018, and unrelated to the wheelset issue, WMATA used a "Hot Issues" list to resolve problems with high failure rates of any component that could affect service or safety. In interviews, the senior program manager for the 7000-series fleet characterized this list as an informal process involving a weekly meeting between the Office of the CMOR and the Offices of Quality Assurance, Internal Compliance, and Oversight. According to the senior program manager, the CMOR monitors vehicle reliability and evaluates any defect or failure for inclusion on the Hot Issues list. However, the senior program manager said he did not know about the increasing incidence of 7000-series wheel migrations until after the derailment. He also said that there was no formal process or set criterion for including a failure or defect on the Hot Issues list; including an item on the list was a "judgment call," and although wheelset migration was "very important," it was not added to the Hot Issues list because of a low occurrence rate and the use of inspections to mitigate safety concerns.

In December 2020, WMATA adopted (and WMSC approved) the version of its public transportation agency safety plan that would remain in effect until after the derailments. The plan required that each department participate in the Executive Safety Committee (ESC), the primary group responsible for providing the rest of WMATA guidance on risk acceptability, the allocation of resources to address risks,

[25] Based on WMATA maintenance records, all 7000-series wheelsets replaced after adoption of the new specification conformed to it.

and the implementation of WMATA's safety management system. Participation involved sharing safety data with other departments, including hazard and risk management, safety and failure trends, and asset and resource management. The plan highlighted trend analysis as part of "actively seeking to identify hazards and mitigating them effectively before adverse events occur" (WMATA 2020c). The plan also required each WMATA office to maintain a safety risk register to document risks and mitigations and ensure that corrective actions were developed, approved, and implemented as required by the WMSC (WMATA 2020c). The safety risk register was also to include tracking of whether and how mitigations reduced risks.

Under the plan, individual departments retained the responsibility for using hazard and data analysis to identify when

> unacceptable or undesirable risk exists that cannot be mitigated with existing resources; and [t]hese risks must be documented and addressed through the respective area's EVP Executive Safety Committee (ESC) participation or the hazard management process.… (WMATA 2020c)

The NTSB did not find evidence that the Office of the CMOR was conducting a trend analysis of wheel migration based on inspection results or otherwise monitoring the effectiveness of its wheel migration mitigation. Based on interviews with WMATA officials, awareness of wheel migration in the 7000-series did not exist outside the Office of the CMOR until after the derailment. The NTSB did not identify any post-2017 measures taken by the CMOR other than 90-day physical inspections to address the potential safety risk.

1.9 WMATA Emergency Response Procedures

In interviews with the NTSB, the ROCC Director said that the presence of smoke in a railcar should have taken priority over troubleshooting the apparent stuck brake. WMATA uses checklists to guide personnel through emergency procedures. The ROCC's after-action review identified the smoke response checklist that applied to the derailment: Standard Operating Procedure #6 (Fire and Smoke on the Roadway), which directed ROCC personnel to take two steps:

- Initiate tunnel ventilation fan procedures (to clear smoke from tunnels).
- Direct train operators near reported smoke to shut down railcar ventilation systems (to prevent smoke in tunnels from entering railcars and affecting occupants).

The after-action review noted that this checklist was not completed during the Rosslyn derailment response. As the train operator described in his interview with the NTSB, the radio communications between the operator and radio RTC did not mention railcar ventilation. The third RTC, who was responsible for tunnel ventilation, did not activate a tunnel ventilation fan (the exhaust fan at Rosslyn Station) until about 2 hours after the derailment.

WMATA Permanent Order T-15-01 (effective January 21, 2015) authorized train operators to independently shut down railcar ventilation if they observed any smoke in their immediate area. The train operator did not independently shut down railcar ventilation in response to the light smoke he observed within the train.

1.10 Revisions to Emergency Procedures and Training

WMATA has made revisions to its emergency procedures, training for train operators and ROCC personnel, and technologies since the derailment that led to this investigation. However, several of these changes began as part of wider series of revisions that began with the January 12, 2015, electrical arcing and smoke accident on WMATA's Yellow Line near L'Enfant Plaza in Washington DC, in which 91 people were injured and 1 passenger died (NTSB 2016). The NTSB's L'Enfant Plaza investigation revealed a lack of knowledge among train operators about how to shut down railcar ventilation systems, smoke response requirements and practices that exposed passengers to risk, and a lack of ROCC compliance and proficiency with standard operating procedures related to smoke. The WMSC issued a series of CAPs (corrective action plans) and the NTSB made safety recommendations (discussed below) to WMATA related to emergency procedures and training.[26] WMATA's responses to NTSB safety recommendations and WMSC CAPs included hiring a new ROCC Director, revising procedures, and beginning an overhaul of the ROCC safety and organizational culture.

As part of these broader safety reforms, WMATA updated its ROCC training and procedures. These changes were in response to Safety Recommendations R-16-25 and R-16-26:

[26] These efforts began with the WMSC's predecessor agency, the Tri-State Oversight Committee, and with direct oversight from the FTA.

> Develop and incorporate a comprehensive program for training Rail Operations Control Center control operators in emergency response procedures including regular refresher training. (R-16-25)[27]

> Conduct regular emergency response drills and develop a program to test the efficiency of the Rail Operations Control Center to ensure that standard operating procedures are properly followed during emergencies. (R-16-26)[28]

As described in a WMATA correspondence to the NTSB dated May 12, 2023, at the time of the October 2021 derailments, WMATA had begun a series of emergency response training activities. Immediately after the October 2021 derailments, the ROCC Director instructed ROCC managers to use existing checklists while in-progress checklist updates continued. Between the derailments and May correspondence, the ROCC conducted four emergency drills or exercises; ROCC personnel participating in these activities were required to select and use the correct guidance documents to navigate the drill or exercise. In changes to ROCC operations and software responding specifically to the Rosslyn derailment, WMATA transferred responsibility for operating tunnel ventilation fans from RTCs to maintenance operations center personnel with training specific to the use of tunnel ventilation fans, added tunnel location information to ROCC consoles, and continued existing efforts to revise standard operating procedures for fans. These changes are intended to eliminate delays in activating tunnel ventilation fans in response to emergencies. On September 18, 2023, the NTSB replied that these activities were positive steps towards implementing Safety Recommendation R-16-26, but an important aspect of this recommendation was that the drills and efficiency testing be part of a continuing program. The NTSB asked WMATA to supply information on the scheduling for upcoming training. Pending that information, Safety Recommendation R-16-26 was classified Open—Acceptable Response.

WMATA has also made changes to its train operator qualification processes and requirements to emphasize railcar ventilation. After the investigation in the L'Enfant Plaza accident, the NTSB issued Safety Recommendations R-16-19 and R-16-20 to WMATA:

[27] Safety Recommendation R-16-25 is classified Open—Acceptable Response.

[28] Safety Recommendation R-16-26 is classified Open—Acceptable Response.

> Ensure that all train operators are trained and regularly tested on the appropriate procedure for emergency shutdown of railcar ventilation. (R-16-19)[29]
>
> Incorporate a specific test in your efficiency testing program to ensure that train operators understand the procedure for emergency shutdown of railcar ventilation. (R-16-20)[30]

WMATA's letter to the NTSB dated March 17, 2023, described changes to train operator qualification, certification, and recertification intended to ensure train operators know when and how to shut down railcar ventilation. The letter also described a program of audits and evaluations intended to ensure ongoing proficiency. A February 2023 audit of all train operators due for recertification found that these operators were compliant with WMATA's operating rules covering railcar ventilation shutdown. On August 10, 2023, the NTSB classified Safety Recommendations R-16-19 and R-16-20 Closed—Acceptable Action.

1.11 Post-derailment Actions

1.11.1 FTA

On November 1, 2021, the FTA issued a Safety Advisory, SA-21-1, requiring SSOAs to report information about out-of-tolerance wheel gages to the FTA within 30 days (FTA 2021).[31] The FTA did not receive any reports of out-of-tolerance wheel gages from SSOAs other than the WMSC. SA-21-1 also advised SSOAs to require fleetwide inspections of wheel gages on all rail transit vehicles in revenue service.

1.11.2 WMSC

On October 17, 2021, the WMSC ordered WMATA to remove the 7000-series fleet from revenue service, develop a response to wheel gage anomalies in 7000-series railcars, and implement a plan for safely returning 7000-series railcars to revenue service (WMSC 2021b). On December 29, 2021, the WMSC issued an additional order, setting criteria for WMATA to meet before returning the 7000-series

[29] Safety Recommendation R-16-19 is classified Closed—Acceptable Action.

[30] Safety Recommendation R-16-20 is classified Closed—Acceptable Action.

[31] In this context, *wheel gage* is synonymous with back-to-back measurement.

fleet to revenue service. These criteria included internal oversight practices, data-driven revision of inspection frequency, and WMSC approval of WMATA's return-to-service plan (WMSC 2021a).

The WMSC also required WMATA to develop and implement CAPs related to the 7000-series fleet and to emergency response. These plans are intended to improve accountability, risk management, and the efficacy of train operators and ROCC personnel in handling emergencies.

1.11.3 WMATA

1.11.3.1 Safety Management System

The current version of WMATA's public transportation agency safety plan (Public Transportation Agency Safety Plan, Release/Version 3.0, adopted after the Rosslyn derailment) includes additional criteria for when departments must perform trend analyses, along with clarified standards on reporting risks to the ESC and internal oversight. These changes are intended to ensure that risk mitigations are being followed and are working as intended. WMATA has also undertaken changes to its maintenance program, including revising existing processes and implementing new processes to identify safety critical items for all assets, setting system-wide criteria for reporting and tracking risks, automating trend reports, and establishing triggers for informing executives of adverse safety trends. WMATA plans to finalize organizational changes and begin recruiting staff to support the new processes and tools in early 2024.

1.11.3.2 Ongoing Monitoring and Removal of Railcars from Service

After the derailment, WMATA complied with WMSC's order and removed all 7000-series railcars from revenue service and developed a return-to-service plan. The plan included gradual increases in the number of 7000-series railcars in revenue service, regular collection and analysis of wheel migration data, collection of vehicle performance data and back-to-back measurements from new trackside vehicle monitoring equipment, and the recording of any resulting corrective actions. WMATA also developed a plan to address wheel migration in the 7000-series fleet, which is discussed in more detail in section 1.11.3.3.

1.11.3.3 Post-derailment 7000-series Fleet Inspection

After the Rosslyn derailment, WMATA inspected all 2,992 wheelsets in the 7000-series fleet, finishing in November 2022. These inspections identified about 50 wheelsets that had exhibited outward wheel migration reaching or exceeding the 53.375-inch maximum specification, bringing the total number of affected wheelsets in the 7000-series fleet to about 80. None exhibited wheel migration as pronounced as the 2-inch exceedance measured on wheelset #4 of railcar 7200 after the Rosslyn derailment.

WMATA also hired Hatch LTK to conduct a study of all known WMATA 7000-series wheelsets with out-of-specification back-to-back measurements identified from 2017 through 2022.[32] The resulting report included calculated failure rates (incidence of wheel migration beyond specification) for wheels pressed on with different amounts of interference. These calculations considered only out-of-specification wheelsets whose inspection records identified the wheel or wheels that migrated. Additional wheelsets failed, but not all records provided details about specific wheels.[33] The failure rate decreased with greater interference as shown in table 3. Two wheels failed at 0.0058 inches; none failed at greater interferences (Hatch LTK 2023).[34]

Table 3. Failure rate by interference.

Interference (inches)	Failure Rate
≤0.0040	6.7%
0.0041-0.0045	2.3%
0.0046-0.0050	1.4%
0.0051-0.0055	0.6%
0.0056-0.0060	0.4%
0.0061-0.0065	0%

The report also found that the failure rate decreased with greater mounting forces, which are a result of greater interferences. A single wheel failed at 78 tons and none failed at higher mounting forces. Failures were more common among wheels assembled under the original specification; among wheels known to have migrated,

[32] In 2020, LTK Engineering Services, creator of a 2015 report on wheel migration, merged with Hatch to become Hatch LTK, which conducted the newer study. The resulting 2023 Hatch LTK report is available in the docket for this investigation.

[33] Out of 76 records of failed original-specification wheelsets referenced in the Hatch LTK report, 36 did not indicate the wheel or wheels that moved. Out of three records of failed new-specification wheelsets, one did not indicate the wheel or wheels that moved.

[34] The Hatch LTK report describes these results in a bar graph; the precise numbers are included in the docket for this investigation report.

41 original-specification wheels failed (out of a population of 3,970 wheels) and 2 new-specification wheels failed (out of a population of 2,020 wheels).

Based on the Hatch LTK report, and on related reports WMATA obtained from MxV and Kawasaki Rail Car, WMATA's wheelset replacement program for the 7000-series fleet calls for increasing the interference specification to 0.0065-0.0080 inches (resulting in a mounting force of 80–120 tons) to correct insufficient interference fits, which WMATA assessed as the reason for the wheel migration. WMATA began replacing wheelsets on July 31, 2023. The replacement process for the entire fleet is scheduled to take 3 years. WMATA has been physically inspecting 7000-series wheelsets at 30-day intervals and plans to continue this practice for non-replaced wheelsets. Replaced wheelsets will be physically inspected at 60-day intervals. WMATA is also deploying automated wayside inspection systems to monitor back-to-back measurements to supplement these physical inspections.

WMATA's Public Transportation Safety Plan, Release/Version 3.0 was approved by the WMSC in November 2022 and became effective in December 2022. This plan added criteria and listed potential sources for identifying safety-relevant trends and reporting them to the ESC (WMATA 2022). Specifically, the plan states that executive vice presidents "are expected to be familiar with safety-related data and performance information for each ESC meeting so that deficiencies and lapses may be appropriately addressed in terms of risk and resources system-wide."

2 Analysis

2.1 Introduction

On October 12, 2021, about 4:49 p.m., WMATA train 407, consisting of eight 7000-series railcars and carrying 187 passengers and 1 operator, was traveling on track 2 of the Blue Line from Rosslyn Station toward Arlington Cemetery Station in Arlington, Virginia, when one wheelset on the fourth railcar derailed. This derailment occurred at a frog in a turnout within a tunnel about 166 feet south of Rosslyn Station. The operator observed light smoke in a railcar, and passengers were evacuated along the track to Arlington Cemetery Station. No one was injured, but one passenger was transported to a local hospital. Two derailments involving the same train occurred earlier that day, but the train rerailed both times; the third and final derailment, the Rosslyn derailment, resulted in the NTSB's investigation.

This analysis discusses the following safety issues:

- Wheelset design that allowed wheel migration and caused the train to derail.
- Lack of trend analysis, which hindered effective response to a safety hazard.

The NTSB established that the following factors did not contribute to its cause:

- *Defects in railroad track and infrastructure*: the condition of special track work, other track components, and the track geometry at the three identified derailment locations did not show any defects. The damage to the track at the derailment locations was caused by the derailments.
- *Signals and train control systems*: the signal and train control systems were tested and the systems functioned as designed.
- *The train operator's readiness for duty*: the operator showed no risk factors for fatigue, had no relevant medical conditions, and tested negative for alcohol and other drugs.
- *The train operator's train handling*: the train operator was obeying speed restrictions at the time of each derailment, and the NTSB found no evidence of noncompliant or unusual train handling.

Therefore, the NTSB concludes that none of the following issues contributed to the derailment of WMATA train 407: defects in the track or infrastructure; signals and train control systems; the train operator's physical readiness for duty; and the train operator's train handling.

2.2 The Derailments

The derailment of WMATA train 407 near Rosslyn Station followed two other derailments in which the train derailed then re-railed and continued moving: the Arlington Cemetery derailment (which occurred about 3:24 p.m.) and the Largo Town Center derailment (which occurred about 4:13 p.m.).

Each derailment is discussed below, followed by a summary.

2.2.1 Arlington Cemetery Station Derailment and Re-railment

Railcar 7200 derailed and rerailed north of Arlington Cemetery Station. During the on-scene investigation on October 13–14, 2021, the NTSB found wheel departure marks at the derailment site that placed the point of derailment at special track work. Video from a WMATA surveillance camera indicated that railcar 7200 was the only railcar in train 407 to derail.

The brake discs on WMATA railcars are positioned outboard of the wheels, where they are likely to strike rails or other track equipment during a derailment. WMATA personnel found a piece of disc brake from the derailment site and provided it to the NTSB for analysis; the NTSB matched the piece to the fractured right-side brake disc on wheelset #4. The damage to the right-side brake disc was consistent with a derailment, and the match to the piece of brake disc recovered from the track confirms that wheelset #4 derailed near Arlington Cemetery.

2.2.2 Largo Town Center Station Derailment and Re-railment

Train 407 derailed and rerailed near Largo Town Center Station before the Rosslyn derailment. The NTSB found wheel departure marks at the derailment site that placed the point of derailment at special track work. Video from a WMATA surveillance camera indicated that railcar 7200 was the only railcar in train 407 to derail.

WMATA personnel found pieces of a disc brake at the derailment site, but the NTSB did not recover these pieces for laboratory analysis. The NTSB's later laboratory examination of wheelset #4 from railcar 7200 did, however, identify a fractured brake disc on the left side of wheelset #4 that was missing material. As with the right-side disc brake, the damage was consistent with derailment.

2.2.3 Rosslyn Station Derailment

The NTSB found wheel departure marks at the Rosslyn derailment site—the final derailment, in which the train did not rerail—that placed the point of derailment at special track work. Video from an inward-facing image recorder showed railcar 7200 moving laterally relative to other railcars, which is consistent with derailment, and the operating compartment console alerted the train operator to a "stuck holding brake on railcar 7200," as the train operator described in interviews with the NTSB. The train operator and a WMATA supervisor both confirmed after the train came to a stop that railcar 7200 had derailed; the WMATA supervisor further reported to the ROCC that the truck containing wheelset #4 had derailed.

2.2.4 Summary

All three derailments occurred at special track work. However, the NTSB's examination of the track near the derailments identified no track defects. All three derailments also involved railcar 7200, and the NTSB found no evidence that any other railcar in train 407 derailed.

The NTSB and WMATA physically inspected the truck containing wheelsets #3 and #4 of railcar 7200 on October 16, 2021. All truck components were within specification and undamaged except for wheelset #4. Wheelset #4 showed damage consistent with derailment, including damage to both brake discs. Combined with the video and physical evidence from all three derailment sites, the presence of derailment damage on wheelset #4 but not wheelset #3 indicates that wheelset #4 was likely the only wheelset on train 407 to derail.

The NTSB's and WMATA's joint physical inspection of wheelset #4 identified an out-of-specification back-to-back measurement: the wheelset was about 2 inches wider than the maximum design specification. In the year following the accident, WMATA performed its own physical inspections of all wheelsets in the 7000-series fleet, including all the wheelsets on the accident train. While WMATA's inspections identified additional wheelsets with out-of-specification back-to-back measurements, the NTSB's review of WMATA's records found no wheelsets as far out of specification as wheelset #4.

The NTSB's laboratory examination of wheelset #4 identified worn flanges on both wheels. Worn flanges can result from elevated and ongoing lateral forces between wheels and rails. Wheelsets that are too wide tend to exert greater than normal outward lateral force on rails, and wheel flanges subjected to these elevated forces tend to wear over time.[35] The wheels from wheelset #4 exhibited significant flange wear; the Materials Laboratory examination found that both wheels' flanges had worn to below the minimum acceptable in-service specification and would have failed a physical inspection. The wear patterns on the wheel flanges from wheelset #4 therefore suggest that wheelset #4 was applying greater than normal outward lateral force to the rails.

Elevated lateral forces create derailment risk at special track work because of differences between ordinary track, which makes up most miles of track, and special track work, such as crossovers and turnouts. On ordinary track, outward lateral forces cause rails to tilt slightly outward, a phenomenon called rail cant. Rail cant increases with increased outward lateral force. Special track work, however, is less prone to rail cant because it is more rigidly fixed. When passing over ordinary track, wheelset #4 would have applied greater than normal lateral force between the rail and wheels because of its out-of-specification back-to-back measurements, causing rail cant and additional flange wear. When wheelset #4 encountered special track work, however, the special track work could not cant as much and instead forced a wheel upward, resulting in derailment and the wheel departure marks observed at all three derailment sites. At the Rosslyn derailment site, wheelset #4's wheels never returned to the rails, eventually preventing the train from moving. Therefore, the NTSB concludes that the derailment of train 407 south of Rosslyn Station was caused by the out-of-specification widened wheelset #4 on railcar 7200 and its interaction with special track work.

2.3 Wheel Migration

The NTSB's examination of wheelset #4 indicated that the wheels were out of position because they had migrated outward. Post-derailment inspections identified a 0.63-inch gap (right side) and a 1.10-inch gap (left side) between the wheels and bearings. This resulted in a back-to-back measurement of more than 55 inches, about 2 inches wider than the maximum specification of 53.375 inches. Examination of the axle wheel seats within the gaps revealed rust on the surface. The rust was more pronounced inboard, toward the center of the axle. This is consistent with the inboard area of each gap being exposed to ambient air and humidity (water) longer than the outboard area. The different levels of exposure indicate that the wheels migrated

[35] The rate of wear depends on factors such as the amount lubrication between the rails and wheels, the number and radius of curves in the track, speed, and railcar weight. In general, higher lateral force on a flange will produce a higher the rate of wear.

outward over time, exposing progressively more of the axle wheel seats and incrementally increasing the back-to-back measurements of wheelset #4.

The NTSB's examination of wheelset #4 also identified fretting wear on the axle, which can indicate a phenomenon called ratcheting extrusion, in which a wheelset under simultaneous bending and lateral stresses will experience movement between the wheel bore surface and the axle wheel seat. This movement tends to accelerate over time as the interference fit between the wheel bore and axle wheel seat covers less surface area and therefore becomes less secure. Sources of stress on axles include restraining and guard rails, and additional bending loads can result from out-of-specification back-to-back measurements. The fretting wear and rust on wheelset #4 are both consistent with incremental wheel migration. Therefore, the NTSB concludes that the out-of-specification back-to-back measurement on wheelset #4 was caused by incremental wheel migration over time. However, the amount of time over which this migration occurred could not be determined. Wheelset #4 passed its last physical inspection on July 28-29, 2021, about 75 days before the Rosslyn derailment.

The NTSB supported WMATA's studies of how wheel migration could have occurred in the 7000-series fleet.[36] One product of these studies was a 2023 report published by Hatch LTK, which reviewed data from all out-of-specification wheelsets identified in the 7000-series fleet. The study identified a correlation between wheel migration and reduced interference (and therefore lower mounting forces) in 7000-series wheelsets—that is, wheelsets with less interference experienced a higher incidence of wheel migration (Hatch LTK 2023).

To determine whether wheelset #4 was more likely to exhibit wheel migration because of its interference fit, the NTSB reviewed wheel press records for wheelset #4 and the two specifications for interference used by WMATA on 7000-series railcars (0.0035-0.0060 inches (original, resulting in mounting forces of 55-80 tons), and 0.0045-0.0065 (after mid-2017, resulting in mounting forces of 65-95 tons)). Wheelset #4 was assembled with an interference of 0.0044 inches and mounting forces of 64 tons (right wheel) and 58 tons (left wheel). The amount of interference and the resulting mounting forces are below the midpoint of the original 7000-series specification and are below the minimum values of WMATA's 2017 replacement specification. The interference specification under which wheelset #4 of car 7200 was fabricated was also used for wheelsets on 492 other railcars. Although no other axles

[36] WMATA's efforts involved MxV, Kawasaki Rail Car, and Hatch LTK as contractors. Each contractor produced a report. WMATA summarized the findings in its party submission.

exhibited wheel migration leading to derailment, WMATA's post-derailment physical inspections have identified additional cases of wheel migration, mostly concentrated among wheelsets fabricated under the original specification.

Following the derailment, NTSB investigation, and orders from the WMSC, WMATA removed the 7000-series fleet from service and developed a return-to-service plan that includes replacement of all wheelsets in the 7000-series fleet with wheelsets assembled with an interference of 0.0065-0.0080 inches and a mounting force of 80–120 tons. This is intended to eliminate wheel migration; in the Hatch LTK study and associated 2023 report, no wheels pressed on with an interference greater than 0.0058 inches or a mounting force greater than 78 tons exhibited wheel migration beyond specification. The WMSC has approved this plan, and WMATA began replacing wheelsets on July 31, 2023. WMATA intends to finish the process in 3 years.

2.4 Trend Analysis

The NTSB's investigation, including interviews with WMATA's senior leadership, found that knowledge of wheel migration affecting the 7000-series fleet existed before the Rosslyn derailment but was confined to the Office of the CMOR, which was responsible for railcar engineering and maintenance. In March 2017, the Office of the CMOR observed the first known case of a 7000-series wheelset exhibiting wheel migration severe enough to cause an out-of-specification back-to-back measurement. At the time of this observation, the Office of the CMOR was already planning to revise the interference specifications for 7000-series wheelsets because of a 2015 study that documented wheel migration in the legacy fleet. WMATA approved the new wheel specification in June 2017. However, because the 7000-series was already being delivered to WMATA and deployed before approval of the new specification, 493 railcars went into service under the original specification. This meant that about two-thirds of the 748-railcar 7000-series fleet went into service with the original specification, including railcar 7200.

Although the Office of the CMOR had not determined the root cause of wheel migration, it did not bring the issue to the attention of other departments or WMATA's senior leadership. Nor did the Office of the CMOR add wheel migration to the "Hot Issues" list, a list started in 2018 as a means of addressing problems affecting train service or safety. When interviewed by the NTSB, personnel from the Office of the CMOR said that they chose not to take further actions because of a low failure rate. The office expected the new wheel specification approved in 2017 to reduce the incidence of wheel migration and its existing program of physical inspections at

90-day intervals to identify individual cases of wheel migration. The Office of the CMOR considered the safety risks resulting from wheel migration to be mitigated by these measures. After the Rosslyn derailment, WMATA determined that physical inspections identified 13 instances of 7000-series wheelsets exhibiting wheel migration out of about 3,000 wheelsets in service in 2017–2020.

While the Office of the CMOR considered the safety risk mitigated, the office was not conducting a trend analysis to determine the rate of wheel migration over time or monitor the rate for changes at the time of the derailment. After the derailment, WMATA reviewed its railcar inspection records, which revealed an increase in the incidence of wheel migration in 2021 compared to the numbers in previous years: in the first 10 months of 2021, 90-day physical inspections identified 18 out-of-specification 7000-series wheelsets, compared to 4 in 2020, 4 in 2019, and 1 in 2018. After October 12, 2021, when the 7000-series fleet was not in service, additional physical inspections performed in response to the derailment identified about 50 more cases of wheel migration.

Wheel migration was most common in wheelsets assembled under the original specification. The 2023 Hatch LTK report found that out of 3,970 original-specification wheels, available records showed that at least 41 wheels had migrated, indicating a minimum failure rate of about 1%. The same report found that out of 2,020 new-specification wheels, at least 2 had migrated, indicating a minimum failure rate of about 0.2%.[37] The NTSB was unable to determine whether wheelset #4 was out-of-specification during its last 90-day physical inspection on July 28–29, 2021, or whether the wheel migration that led to the accident occurred mainly during the 75 days between this inspection and the accident. Since the Rosslyn derailment, WMATA has begun using higher-precision instruments to take back-to-back measurements and recording the resulting values during regular physical inspections.

Had the Office of the CMOR monitored the efficacy of its mitigations through trend analysis, WMATA would have become aware of a sharp increase in the rate of wheel migration in 2021—an increase that eventually resulted in about 50 railcars operating with out-of-specification back-to-back measurements, including one severe

[37] These wheel counts do not account for all out-of-specification wheelsets. About 80 wheelsets exhibited wheel migration, but the Hatch LTK report analyzed only the subset whose records identified the wheel or wheels that migrated. Because about half the inspection records for failed original-specification wheelsets did not identify a specific wheel, the report's analysis supports only a minimum failure rate and likely understates the failure rate for original-specification wheelsets. A similar but less severe limitation applies to the records for failed new-specification wheelsets; one of the three available records did not identify a specific wheel.

enough to cause a derailment. The concentration of wheel migration among original-specification wheelsets would have indicated, as WMATA concluded in its post-derailment studies, that greater interference was necessary to prevent wheel migration. In the absence of this trend analysis, the Office of the CMOR continued to assume its original mitigations were sufficient. The NTSB therefore concludes that had WMATA used trend analysis to assess the efficacy of its risk mitigation strategies for wheel migration, WMATA would have identified the increasing incidence of wheel migration in time to adopt more effective mitigation measures.

The NTSB has previously investigated rail accidents related to risk identification and mitigation at WMATA. In 2009, the NTSB investigated a collision between two WMATA trains near Fort Totten Station in Washington, DC, that resulted in nine deaths (NTSB 2010). During the investigation, the NTSB identified a track circuit that did not reliably detect trains and therefore could not maintain train separation. The NTSB determined that this safety risk was known to individual WMATA engineers, technicians, and managers before the accident.

At the time of the Fort Totten collision, WMATA had developed but not implemented a test procedure to verify the proper functioning of track circuits. The NTSB believes that if this test procedure had been used, it could have helped WMATA fully diagnose and address the track circuit failure before the Fort Totten collision. However, despite awareness of a safety hazard and the availability of a test procedure that could have mitigated it, WMATA did not prioritize implementing the test procedure or address anomalous track circuit behavior by other means. The NTSB's investigation found shortcomings in WMATA's internal communications, recognition of hazards, and implementation of corrective actions—all evidence of an organization unprepared to proactively protect safety.

In 2015, the NTSB investigated an electrical arcing and smoke accident that occurred in the tunnel between L'Enfant Plaza Station and the Potomac River bridge in Washington, DC, in which 91 people were injured and 1 passenger died (NTSB 2016). The NTSB identified a series of engineering studies from the 1980s that identified capacity problems with WMATA's tunnel ventilation system. These studies concluded that improvements would be necessary to manage airflow and evacuate smoke from tunnels. WMATA failed to address these problems before the accident.

The NTSB also determined that the Public Radio Service System, a communications system maintained by WMATA and used to support emergency response operations, depended on a signal too weak to support reliable below-ground communications. On the day of the accident, emergency responders found the system unreliable and resorted to using runners to convey information. The

NTSB found that the Public Radio Service System had problems that were identified but not remediated before the accident. In its investigation report, the NTSB concluded that WMATA had not effectively used past safety investigations and studies to enhance safety and that, while WMATA had "taken steps to improve its organizational safety since the 2009 Fort Totten accident, significant safety management deficiencies still exist within the organization" (NTSB 2016).

In the Rosslyn derailment, the lack of a trend analysis in response to wheel migration and resulting ineffectual mitigations indicate continuing failures of communication, hazard identification, and risk mitigation within WMATA. For most of the period from 2017 to October 2021, WMATA did not have formal requirements for when to conduct trend analyses. However, WMATA had begun implementing a safety management system under WMSC oversight as required by federal regulations. The first version of this safety management system was documented in the WMSC-approved 2020 WMATA public transportation agency safety plan, which was effective from December 2020 through December 2021. While this plan required sharing of trend analyses across departments (including through the ESC, or Executive Safety Committee), responsibility for determining whether to conduct a trend analysis still resided with individual departments (WMATA 2020c). It is unclear whether the Office of the CMOR would have independently adopted a different approach if it had reconsidered wheel migration under the requirements of the safety plan when the plan went into effect in December 2020. The Office of the CMOR approached wheel migration in the belief that it was a rare event reliably detected by 90-day physical inspections. This approach was consistent with research suggesting individuals have difficulty accurately evaluating risks they perceive as low-likelihood (Kunreuther, Novemsky, and Kahnman 2001).

Since the Rosslyn derailment, WMATA has continued to develop its safety management system. The current version of WMATA's public transportation agency safety plan (Public Transportation Agency Safety Plan, Release/Version 3.0) includes additional criteria for creating trend analyses and reporting them to the ESC, along with revised internal oversight intended to ensure that risk mitigations are being performed and are effective (WMATA 2022). WMATA's post-derailment actions also include plans to establish system-wide criteria for departments to follow when identifying safety issues, and plans to automate trend reports, including a list of safety-critical items for all assets and triggers to inform executives of adverse safety trends. The NTSB acknowledges these plans as positive steps toward improvements in WMATA's safety procedures and concludes that while WMATA has a history of safety lapses related to risk identification and mitigation, its proposed additional processes and resources for expanding the role of trend analysis in identifying safety risks would, if implemented, increase the likelihood of WMATA successfully identifying and mitigating safety risks before accidents occur. The NTSB believes that successfully implementing these plans would improve the efficacy of WMATA's safety management system and address a significant reason that wheel migration eventually led to the Rosslyn derailment: an individual department's discretion in whether to monitor both a safety issue and the success of its mitigations. Therefore, the NTSB recommends that WMATA implement processes and resources to expand the role of trend analysis in identifying and mitigating safety risks.

Under 49 *Code of Federal Regulations* Part 674, SSOAs are responsible for ensuring that rail transit agencies adopt and comply with public transportation agency safety plans consistent with the FTA's National Public Transportation Safety Plan. The FTA's plan includes guidance on both safety management systems in general and trend analysis as a specific tool. As the SSOA with oversight authority over WMATA's rail operations, the WMSC is responsible for ensuring that WMATA's use of trend analysis complies with WMATA's public transportation agency safety plan and therefore with federal requirements.

WMATA's planned improvements, such as refined and automated trend analysis and its list of safety critical items, involve significant changes to how WMATA has historically assessed risks and risk mitigations. Challenges should be expected as these improvements are implemented and evaluated. Refining the use of trend analysis and its successful integration into WMATA's safety management system will be an ongoing process. The NTSB therefore concludes that WMSC oversight of WMATA's planned implementation of trend analysis is necessary to ensure that WMATA's operations remain compliant with the safety management system documented in its public transportation agency safety plan, and that the as-implemented changes to trend analysis support continuing improvements in identifying and mitigating risks. Therefore, the NTSB recommends that the WMSC develop and implement a program to support and monitor WMATA's use of trend analysis within its safety management system.

3 Conclusions

3.1 Findings

1. None of these issues contributed to the derailment of Washington Metropolitan Area Transit Authority train 407: defects in the track or infrastructure; signals and train control systems; the train operator's physical readiness for duty; and the train operator's train handling.

2. The derailment of train 407 south of Rosslyn Station was caused by the out-of-specification widened wheelset #4 on railcar 7200 and its interaction with special track work.

3. The out-of-specification back-to-back measurement on wheelset #4 was caused by incremental wheel migration over time.

4. Had the Washington Metropolitan Area Transit Authority (WMATA) used trend analysis to assess the efficacy of its risk mitigation strategies for wheel migration, WMATA would have identified the increasing incidence of wheel migration in time to adopt more effective mitigation measures.

5. While the Washington Metropolitan Area Transit Authority (WMATA) has a history of safety lapses related to risk identification and mitigation, its proposed additional processes and resources for expanding the role of trend analysis in identifying safety risks would, if implemented, increase the likelihood of WMATA successfully identifying and mitigating safety risks before accidents occur.

6. Washington Metrorail Safety Commission oversight of the Washington Metropolitan Area Transit Authority's (WMATA) planned implementation of trend analysis is necessary to ensure that the WMATA's operations remain compliant with the safety management system documented in its public transportation agency safety plan, and that the as-implemented changes to trend analysis support continuing improvements in identifying and mitigating risks.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the derailment of Washington Metropolitan Area Transit Authority train 407 south of Rosslyn Station was an out-of-specification wheelset that caused a wheel to depart the rail at a turnout; the wheelset was out of specification because the wheelset's design allowed the wheels to migrate outward and eventually exceed the maximum permitted back-to-back measurement.

4 Recommendations

New Recommendations

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

Washington Metropolitan Area Transit Authority

Implement processes and resources to expand the role of trend analysis in identifying and mitigating safety risks. (R-23-28)

Washington Metrorail Safety Commission

Develop and implement a program to support and monitor the Washington Metropolitan Area Transit Authority's use of trend analysis within its safety management system. (R-23-29)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Chair

BRUCE LANDSBERG

Member

MICHAEL GRAHAM

Member

THOMAS CHAPMAN

Member

Report Date: December 12, 2023

Appendixes

Appendix A: Investigation

The National Transportation Safety Board (NTSB) was notified on October 12, 2021, of the derailment, in which Washington Metropolitan Area Transit Authority (WMATA) train 407 derailed while traveling from Rosslyn Station toward Arlington Cemetery Station in Arlington, Virginia. Train 407 had 187 passengers and 1 operator on board. All passengers and the operator were evacuated to Arlington Cemetery Station. No injuries were reported. One passenger was transported to the hospital and treated and released. WMATA estimated the damage to track and equipment to be about $690,000.

The NTSB launched Chair Jennifer Homendy, an investigator-in-charge, and a team to investigate the cause of the derailment and WMATA's emergency response.

Parties to the investigation included the Federal Transit Administration, the Washington Metrorail Safety Commission, WMATA, Kawasaki Rail Car, Inc. (the railcar manufacturer), ORX (the wheelset manufacturer), and the Amalgamated Transit Union.

Appendix B: Consolidated Recommendation Information

Title 49 *United States Code* 1117(b) requires the following information on the recommendations in this report.

For each recommendation—

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the Washington Metropolitan Area Transit Authority

R-23-28
Implement processes and resources to expand the role of trend analysis in identifying and mitigating safety risks.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4, Trend Analysis. Information supporting (b)(1) can be found on pages 37-41; (b)(2) on pages 40-41; and (b)(3) is not applicable.

To the Washington Metrorail Safety Commission

R-23-29
Develop and implement a program to support and monitor the Washington Metropolitan Area Transit Authority's use of trend analysis within its safety management system.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4, Trend Analysis. Information supporting (b)(1) can be found on pages 37-41; (b)(2) and (b)(3) are not applicable.

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The NTSB is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant events in the other modes of transportation—railroad, transit, highway, marine, pipeline, and commercial space. We determine the probable causes of the accidents and events we investigate and issue safety recommendations aimed at preventing future occurrences. In addition, we conduct transportation safety research studies and offer information and other assistance to family members and survivors for each accident or event we investigate. We also serve as the appellate authority for enforcement actions involving aviation and mariner certificates issued by the Federal Aviation Administration (FAA) and US Coast Guard, and we adjudicate appeals of civil penalty actions taken by the FAA.

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