Collision Between Two Washington Metropolitan Area Transit Authority Trains at the Woodley Park-Zoo/Adams Morgan Station in Washington, D.C. November 3, 2004

Railroad Accident Report

NTSB/RAR-06/01

PB2006-916301
Notation 7680D

National Transportation Safety Board
Washington, D.C.

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Adopted March 23, 2006

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

National Transportation Safety Board. 2006. ***Collision Between Two Washington Metropolitan Area Transit Authority Trains at the Woodley Park-Zoo/Adams Morgan Station in Washington, D.C., November 3, 2004.*** **Railroad Accident Report NTSB/RAR-06/01. Washington, DC.**

Abstract: On Wednesday, November 3, 2004, about 12:49 p.m., eastern standard time, Washington Metropolitan Area Transit Authority Metrorail train 703 collided with train 105 at the Woodley Park-Zoo/Adams Morgan station in Washington, D.C. Train 703 was traveling outbound on the Red-Line segment of the Metrorail system and ascending the grade between the Woodley Park-Zoo/Adams Morgan and the Cleveland Park underground stations, when it rolled backwards about 2,246 feet and struck train 105 at a speed of about 36 mph. Train 703 was operating as a nonrevenue train; that is, it was not carrying passengers. Train 105, a revenue train, was in the process of discharging and loading passengers at the Woodley Park-Zoo/Adams Morgan station. There were about 70 passengers on board train 105. Some passengers had exited the train just before or during the collision. The District of Columbia Fire and Emergency Medical Service transported about 20 persons to local hospitals. Estimated property damages were $3,463,183.

The safety issues discussed in this report are the lack of a rollback protection feature when trains are operated in the manual mode, operator performance, the lack of passenger emergency exit standards in the transit industry, and the crashworthiness of Metrorail 1000-series railcars.

As a result of its investigation, the National Transportation Safety Board makes safety recommendations to the Washington Metropolitan Area Transit Authority and the Federal Transit Administration. On November 22, 2004, the Safety Board issued Urgent Safety Recommendation R-04-9 to the Washington Metropolitan Area Transit Authority.

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Acronyms and Abbreviations

AGM	Assistant General Manager
APTA	American Public Transportation Association
ATC	automatic train control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
B1/B5	braking positions
CAF	Construcciones Y Auxiliar de Ferrocarriles
CEO	Chief Executive Officer
CFO	Chief Financial Officer
CFR	*Code of Federal Regulations*
DCFEMS	District of Columbia Fire and Emergency Medical Service
DGM	Deputy General Manager
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GERD	Gastroesophageal Reflux Disease
GM	General Manager
GMGR	General Manager
IOECCD	Institute for Occupational Ergonomics and CCD Design and Ergonomics Ltd
MSRPH	*Metrorail Safety Rules and Procedures Handbook*
MTPD	Metro Transit Police Department
OCC	Operations Control Center
P1/P5	propulsion positions
TOC	Tri-State Oversight Committee
VDC	Volts Direct Current
VMS	Vehicle Monitoring System
WMATA	Washington Metropolitan Area Transit Authority
WSAD	warning strobe and alarm device

Executive Summary

On Wednesday, November 3, 2004, about 12:49 p.m., eastern standard time, Washington Metropolitan Area Transit Authority Metrorail train 703 collided with train 105 at the Woodley Park-Zoo/Adams Morgan station in Washington, D.C. Train 703 was traveling outbound on the Red-Line segment of the Metrorail system and ascending the grade between the Woodley Park-Zoo/Adams Morgan and the Cleveland Park underground stations, when it rolled backwards about 2,246 feet and struck train 105 at a speed of about 36 mph. Train 703 was operating as a nonrevenue train; that is, it was not carrying passengers. Train 105, a revenue train, was in the process of discharging and loading passengers at the Woodley Park-Zoo/Adams Morgan station. There were about 70 passengers on board train 105. Some passengers had exited the train just before or during the collision. The District of Columbia Fire and Emergency Medical Service transported about 20 persons to local hospitals. Estimated property damages were $3,463,183.

The National Transportation Safety Board determines that the probable cause of the November 3, 2004, collision between two Washington Metropolitan Area Transit Authority trains at the Woodley Park-Zoo/Adams Morgan station was the failure of the operator of train 703 to apply the brakes to stop the train, likely due to his reduced alertness. Contributing to the accident was the lack of a rollback protection feature to stop the train when operated in the manual mode.

In its investigation of this accident, the Safety Board examined the following safety issues:

- The lack of a rollback protection feature when trains are operated in the manual mode,
- Operator performance,
- The lack of passenger emergency exit standards in the transit industry, and
- The crashworthiness of Metrorail 1000-series railcars.

As a result of its investigation of this accident, the Safety Board makes recommendations to the Washington Metropolitan Area Transit Authority and the Federal Transit Administration. On November 22, 2004, the Board issued Urgent Safety Recommendation R-04-9 to the Washington Metropolitan Area Transit Authority.

Factual Information

Accident Synopsis

On Wednesday, November 3, 2004, about 12:49 p.m.,[1] Washington Metropolitan Area Transit Authority (WMATA)[2] Metrorail train 703 collided with train 105 at the Woodley Park-Zoo/Adams Morgan (Woodley Park) station in Washington, D.C. Train 703 was traveling outbound on the Red-Line segment of the Metrorail system and ascending the grade between the Woodley Park and the Cleveland Park underground stations, when it rolled backwards about 2,246 feet[3] and struck train 105 at a speed of about 36 mph. Train 703 was operating as a nonrevenue train; that is, it was not carrying passengers. Train 105, a revenue train, was in the process of discharging and loading passengers at the Woodley Park station. There were about 70 passengers on board train 105. Some passengers had exited the train just before or during the collision. The District of Columbia Fire and Emergency Medical Service (DCFEMS) transported about 20 persons to local hospitals. Estimated property damages were $3,463,183.

Accident Narrative

Preaccident Events

On the day of the accident, the operator of train 703 started work about 8:00 a.m. at Shady Grove station. He stated that this was an overtime shift during which he was to work as assigned until about 1:00 p.m. and then start his regular work shift later that afternoon.[4] His first assignment was train 156, a revenue train traveling from Shady Grove to Glenmont, which are stations located on opposite ends of the Red Line. The train was operated in the automatic mode for the morning trip. At the Dupont Circle station, a WMATA supervisor for the Red Line boarded the train and performed a quality check[5] of the operator's performance from Dupont Circle to the Gallery Place-Chinatown station. Upon completion of the quality check, the supervisor departed the train without comment.

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[1] All times in this report are eastern standard time.

[2] WMATA is responsible for the Metrorail and Metrobus systems that serve Washington, D.C., and the surrounding suburbs in Maryland and Virginia. Although WMATA is responsible for rail and bus services, this report focuses exclusively on the Metrorail system.

[3] This estimate is based on calculations provided by WMATA.

[4] The operator normally worked the 2:00 p.m. to 11:00 p.m. shift, but on this day he had signed up for overtime to work the 8:00 a.m. to 1:00 p.m. shift prior to working his regular shift.

[5] A *quality check* is an unannounced inspection by a line supervisor monitoring the performance of the train operator.

Train 156 arrived at the Glenmont station, and the operator was informed that he would make a return trip with the same equipment to Shady Grove as train 103. When he arrived at the Friendship Heights station, a supervisor boarded his train and performed another quality check for the ride to the Shady Grove station.

When he arrived at Shady Grove, the operator said that a supervisor told him to take a 6-car nonrevenue train to the maintenance facility at Brentwood. Specifically, he was told to leave four cars on track five and retrieve four cars from track three. He was expected to return to Shady Grove with train 703, a 6-car nonrevenue service train.

After completing his work at Brentwood, the operator of train 703 received instructions from the Operations Control Center (OCC)[6] to enter the mainline at Brentwood Yard and follow train 203, a revenue service train, back to Shady Grove. Train 105, another revenue service train, was to follow him. The operator of train 703 stated that he operated the train in manual mode,[7] as required for a nonrevenue train move, on the trip back to Shady Grove. (See figure 1.) He stated that he was getting ringers[8] frequently during the trip. Every time he received a ringer, he said that he had to brake his train by placing the master controller[9] in either the B4 or B5 position. This slowed the train to the proper speed code (allowable track speed) and silenced the ringer.

The Collision

The operator of train 703 told investigators that he passed through the Woodley Park station at the required speed of 25 mph. In accordance with the operating rules, he sounded the horn but did not stop the train. He stated that he could see a train ahead at the Cleveland Park station platform, and he received an alarm as he ascended the grade approaching the station. He stated that he placed the master controller in the B4 position to slow his train and quiet the ringer. (See the report section entitled "Equipment Propulsion and Braking" for a description of braking designations.) About 12:49 p.m., train 703 rolled backwards about 2,246 feet downhill for about 78 seconds and collided with train 105, which was stopped at platform number 2[10] of the Woodley Park station, where passengers were boarding and deboarding the train. (See figure 2.) The operator was the only employee on board train 703 when the collision occurred.

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[6] The *OCC* controls and provides supervision for all train movements on the entire transit system.

[7] In manual mode, the train is controlled by the train operator, which differs from the train being in the automatic mode under the computerized general control system.

[8] *Ringer* is a slang term for the overspeed alarm, which is automatically activated when a train is following too close or going faster than speed codes allow. It is an element of the Automatic Train Protection (ATP) system.

[9] The *master controller* is a lever with a spring-loaded handle that applies power (P1/P5) in the forward position and braking (B1/B5) when moved in the opposite position. The handle is spring loaded to function as a "deadman" control that applies the train brakes in an emergency if the operator releases the handle.

[10] *Platform number 2* is an outbound platform that services trains transporting passengers away from the metropolitan D.C. area.

Figure 1. WMATA Metrorail system map.

Figure 2. Train 703 resting on top of train 105.

When questioned about the accident, the operator told investigators that after the train started to roll back:

> I would go to B-4, B-5, then back to a power load to pull the train up the hill, because it was going to drift between B-4 and B-5, so you have to come back to coast, in order to go to power load. So, I would come back to coast and usually it would catch but this time I drifted and once I drifted I went to power but the train didn't catch it. So, then I went back, I said to myself, I will give it a second, you know, that is all I could do. I went to B-4, B-5 brake, and the train still did not catch. I tried once more, and I jerked it back as far as I could to B-5, to get the most brake possible but the train is not doing anything. So, at this point I hit the mushroom.[11] A short time later I felt it jerk and I thought the brakes had kicked in. If the mushroom did not work I was going to apply the handbrake that was my last option. When I felt it move I thought okay, the brakes kicked in. But when I looked at my console it was black, keyed down.

He further stated that he was taught in the operator training class to troubleshoot the train by checking the circuit breakers to see why the console had gone dark. As he walked through the train, he stated that he saw smoke and that it looked like the train was buckled. He exited through the side emergency door and saw that his train had collided with another train.

When the accident occurred, all revenue service trains were to be operated in manual Mode 2 Level 1[12] per protocol[13] to enhance operator performance of manual train operations. (See the section entitled "Operational Information" for a description of train operating modes.)

[11] *Mushroom* is a slang term for the activation button that applies the train's emergency brakes on all cars.

[12] *Mode 2 level 1,* as defined in the *Metro Safety Rules and Procedures Handbook,* is when the train is under operator control but protected by the ATP system.

[13] WMATA *protocol* required all trains to operate in manual mode between 10:00 a.m. and 3:00 p.m.

The operator of the struck train, train 105, stated that after he stopped at the station platform, he set his train brakes and the doors opened. As he got up from his console to close the doors, he looked up the tracks and saw train lights that appeared to be coming toward him. At first he was not sure whether the lights were coming toward his train because they were moving so slowly. He said that when he finally realized the other train was moving toward his train, he yelled to the passengers in the first car “get off the train, get off the train now,” and “everyone began screaming and running off the train.” The operator exited train 105 before the collision, and he went to the station manager’s booth on the mezzanine level to call the OCC and report the collision. He then returned to the train to help anyone needing assistance. After assisting one of the passengers retrieve papers left on the train, he applied the hand brakes in the last two cars of the train. He again contacted the OCC and described the actions he had taken. About 1:00 p.m., the Metro Transit Police Department (MTPD) and DCFEMS personnel began arriving at the Woodley Park station.

Damages

WMATA provided the following damage estimates: $3,102,000 for the replacement of rail transit vehicles; $337,031 for the repair of rail transit vehicles; and $24,152 for clean-up costs and related expenses. Total estimated damages were $3,463,183.

Injuries

See table 1 for a summary of injuries sustained in the accident.

Table 1. Injuries[14] sustained in accident.

Type	Train 105[a]	Train 703	Total
Fatal	0	0	0
Serious	1	0	1
Minor	19	0	19
None	52	1	53
Total	72	1	73

a. The total in this column is an estimate based on witness statements.

[14] Title 49 *Code of Federal Regulations* 830.2 defines *fatal injury* as “any injury which results in death within 30 days of the accident” and *serious injury* as “an injury which: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burn affecting more than 5 percent of the body surface.”

Train Operator Information

Operator of Train 703

The operator of train 703 was a 32-year-old male hired by WMATA as a bus driver on December 4, 1997. After formal and on-the-job training, he was transferred and qualified as a train operator in April 2004. The train operator told investigators that he mostly had worked in the yard, performing such tasks as preparing trains for revenue service and moving them to and from the shop. In the yard, trains were operated only manually. He stated he had operated revenue service trains about once every 2 to 3 weeks.

In the 1-month period preceding the accident, the train operator had 19 assigned workdays.[15] On 10 of those days, he was assigned to a single shift, typically working from 2:00 p.m. to 11:00 p.m. On the 9 other days that he worked, he worked a double shift by adding a morning (overtime) shift to his regular shift. These overtime shifts, which began as early as 6:23 a.m., typically lasted 4 to 5 hours, and usually ended between 11:00 a.m. and 12:00 p.m. He was often off duty for 2 to 3 hours between shifts. The days on which his tour of duty included both an overtime shift and a regular shift generally lasted between 15 to 16 1/2 hours from start to finish. At the time of the accident, he was working an overtime shift (from about 8:00 a.m. to 1:00 p.m.), and he was also scheduled to work his regular shift. The train operator periodically worked consecutive days of overtime. On three occasions during the month before the accident, he had less than 8 hours (that is, 7 hours 45 minutes, 7 hours 33 minutes, and 7 hours 23 minutes) off duty between the end of his last (regular) assignment and the start of his next (overtime) shift.

The train operator did not work on Sunday, October 31, or Monday, November 1, 2004. Both days were his regular days off. He spent Monday at home doing chores. He went to bed about 10:00 p.m., fell asleep at 10:30 p.m., and awoke at 6:30 a.m. on Tuesday, November 2. He went on duty about 8:00 a.m. and began working an extra shift, which concluded at 1:00 p.m. About 2:00 p.m., he began working his regular shift, which he completed at 11:00 p.m. After leaving work, he stated that he arrived at his house about 11:30 p.m. and went to sleep about 11:45 p.m. on the night of November 2.

The train operator told investigators that he needs 8 hours of sleep to feel rested the next day. He indicated that he falls asleep "pretty quickly, maybe within 15, 20 minutes." A review of the train operator's cellular phone records for the night before and the morning of the accident showed he received three incoming calls and made one outgoing call. He received the first call, which lasted nearly 10 minutes, about 11:54 p.m. on November 2. The second call lasted about 1 minute and was received about 12:24 a.m. on November 3. The third call lasted 13 seconds and was received about 5:30 a.m. The operator then made a call at 5:31 a.m. That call lasted about 3 minutes. He reported that he awoke at 6:30 a.m. and arrived for work at Shady Grove station about 7:45 a.m. Cellular phone records indicate that the train operator did not use his personal cellular phone while operating train 703.

[15] Sunday and Monday were his regularly assigned days off.

The train operator stated that he was in good health. He had passed his last company physical examination prior to the accident on November 6, 2002. At that time, he had indicated that he did not have any medical problems on the health history portion of the medical examination report. He also indicated that he was not taking any prescription or non-prescription medications. The train operator's medical records from his private physician indicated that since June 2001, he had visited a medical clinic eight times suffering from Gastroesophageal Reflux Disease (GERD) and once for stomach pain (diagnosed as gastritis). On two of those occasions (once for GERD and once for gastritis-related stomach pains), he had missed 2 days of work. About 4:30 a.m. on October 31, 2004, 3 days before the accident, the operator visited a medical clinic for stomach pain, which was determined to be related to epigastric pain and GERD.[16] The clinic records for the operator's October 31 visit indicated that the pain he was experiencing increased at night and had been a reoccurring problem during the previous month.[17]

Operator of Train 105

The operator of train 105 was a 58-year-old male hired by WMATA as a bus driver on October 24, 1978. After formal and on-the-job training, he was transferred and qualified as a train operator in June of 1996. He had spent his entire train career as an operator on the Red Line. On the day of the accident, he had made four trips on the Red Line and was completing his fifth trip when the collision occurred.

The operator of train 105 reported for work about 7:45 a.m. on the Red Line at the Brentwood Yard. He traveled by train from Brentwood Yard to the Silver Spring station to pick up his first train. His initial assignment was from the Silver Spring station to the Grosvenor-Strathmore station and back to Silver Spring. He stated in interviews that the trip was uneventful, and he reported no anomalies. His next trip took him from Silver Spring to the Shady Grove station at the west end of the Red Line, where he arrived about 10:20 a.m. While at Shady Grove, he took a lunch break until 11:00 a.m. Then he began his third trip of the day, departing Shady Grove for the Glenmont station, located at the opposite end of the Red Line. After completing another normal trip, he departed Glenmont at 12:17 p.m. for his return trip to Shady Grove. This was to be his final trip of the day.

[16] Investigators observed the train operator taking an over-the-counter antacid (that purports to relieve heartburn, acid indigestion, gas, and acid reflux) during interviews the day after the accident. It is unclear if any of his previous symptoms had persisted throughout the weekend, or if they reemerged following the accident.

[17] During followup interviews conducted on March 16–17, 2005, the train operator told investigators that since the accident, he had visited another physician who did not believe he was suffering from acid reflux. The operator stated that his condition was more related to irritable bowl syndrome and he was told that he needed to change his diet.

Train Information

Metrorail utilizes a self-propelled, single-level, 175-passenger capacity,[18] electrically powered,[19] common-design passenger railroad car in its passenger transportation operations, as supplied by four manufacturers (Rohr,[20] Breda,[21] CAF,[22] and ALSTOM[23]). (See appendix B.)

Generally described, the cars measure 75 feet in length, 10.16 feet in width, and 10.83 feet in height. They have dual powered truck-assemblies, are constructed principally of aluminum alloy,[24] and operate on 56.25-inch gauge track.[25] A train operator's compartment occupies one end of the car, which is referred to as the front end when the operator is operating the train. The passenger compartment occupies the balance of the carbody.

A car-set consists of two railcars semi-permanently coupled together as a pair, commonly referred to as a married pair, with an operator compartment at each end. The two cars cannot operate separately because the married pair shares certain electronic control components, and the respective components are specific to each individual car. Passenger compartment seating is provided by a series of transverse mounted, paired seat-set assemblies, which are configured on both sides of a longitudinal oriented center aisle passageway. (See figure 3.) Numerous hand-hold stanchion posts and handrails are fitted throughout the car. Three passenger service doors are present on both sides of the car. That is, there are six passenger service doors available per car. There is also a body-end door at each end of the car.[26] Passenger loading and unloading is performed only at Metrorail stations, all of which utilize a high-level passenger-loading platform.[27] The cars involved in the accident were not fitted with event recorders.[28]

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[18] This passenger capacity is published by Metrorail Operations Department.

[19] The cars are electrically powered by 700 Volts Direct Current/rail propulsion.

[20] Built by Rohr Industries, which is no longer in business.

[21] Breda Construzioni Ferroviarie S.p.A of Italy.

[22] Construcciones Y Auxiliar de Ferrocarriles, Madrid, Spain, fabricates the carbody shell, and AAI Transportation Systems, in Hunt Valley, Maryland, provides the technical support (that is, the final carbody assembly).

[23] ALSTOM Transport's, Saint Ouen Cedex, France, fabricates the carbody shell, and ALSTOM Transportation, Inc., in Hornell, New York, provides the technical support (that is, the final carbody assembly). None of the ALSTOM-built railcars were involved in the accident. They were scheduled for delivery commencing in 2005 through 2007.

[24] Welded steel subassembly components are also used for certain structural load-bearing elements of the car.

[25] Whereas, U.S. railroad standard gauge track is 56.5 inches.

[26] Except for the extreme ends of the train, *body-end doors* remain unlocked during revenue operations. Body-end doors are provided for emergency use only, in order to access an adjacent car.

[27] A *high-level passenger-loading platform* is located about 39 inches above the top-of-rail, the height of which matches the passenger service doors.

[28] Metrorail indicated that the 5000-series and only the rehabilitated 2000/3000-series cars are fitted with event recorder equipment, and the 6000-series cars will have event recorder equipment. The accident cars were 1000 (train 703) and 4000 (train 105) series.

Figure 3. Postaccident photo of car 1076 (mate to car 1077), showing typical interior view of an undamaged car.

Trains generally operate as 4- to 6-car trains, about 300 to 450 feet in length. Because the trains consist of car-sets, or married pairs, the shortest train that can be operated is a 2-car train.

Train 703

Train 703 was a 6-car train consisting of 3 car-sets manufactured by Rohr. The operator was located in the first car, car 1128, followed by cars 1129, 1064, 1065, 1076, and 1077. The total train length was 450 feet.

Train 105

Train 105 was a 6-car train consisting of 3 car-sets manufactured by Breda. The operator was located in the first car, car 4018, followed by cars 4019, 4017, 4016, 4093, and 4092. The total train length was 450 feet.

Wreckage

The rear end of the last car (1077) of northbound nonrevenue train 703 collided with the forward end of the first car (4018) of revenue train 105, which had stopped to service the Woodley Park station. The front end of car 4018 came to rest beneath, and substantially inside of, the breached rear carbody shell of 1077. Although almost all of the cars in both trains sustained damage, car 1077 bore the majority of the collision damage.

The collision wreckage was confined to about 100 feet of track immediately adjacent to the station platform. Small elements of collision debris were also found resting on the platform near the wreckage, having apparently separated from the wreckage during the collision.[29] The two entangled carbodies came to rest upright and remained substantially aligned with the track, although elements of the two carbodies were wedged against the track-side of the platform and also on the opposite side, against the wall. There was no evidence of fire.

The point of collision was determined to be about 75 feet south of the north end of the passenger platform. The impact shoved train 105 rearward about 16 feet, relative to where it had initially stopped. Car 1077, at the rear end of train 703, longitudinally overrode the leading end of the first car (4018) of the revenue train by about 20 feet. Car 1077 also sustained a loss of about 34 linear feet of the passenger occupant volume (survival space), which is almost half the length of the passenger compartment. The 34-foot loss of space (the collision intrusion) consisted of a tightly compressed mass of dislodged and displaced crushed seats, floor, ceiling, other interior elements, and the rear bulkhead panel structure. (See figure 4.) The rear end of car 1077 was lifted, and its roof came to rest about 18.8 feet above the top of rail with about a 10° upward incline and about a 4° cross level lean to the left toward the platform. (See figure 5.)

Figure 4. Collision end of car 1077 showing debris field.

[29] Emergency responders could have placed some of these items there during their search and rescue.

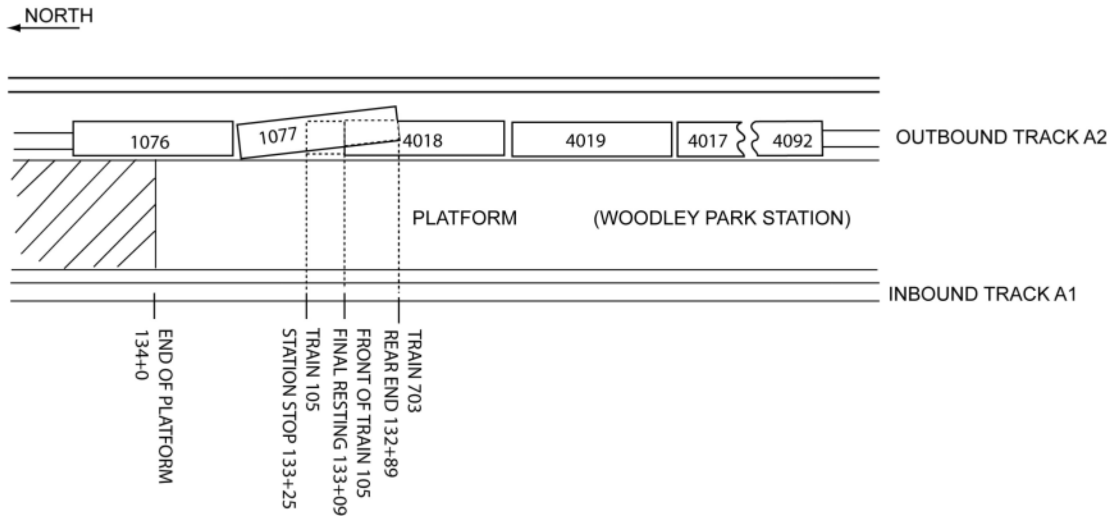

Figure 5. Accident site plan.

The first five cars of train 703 did not derail, and the fifth car (1076) sustained damage at the end adjacent to the sixth car (1077). The body-end doors between these cars were functional; however, the body-end doors between the fifth and sixth cars were wedged against each other and inoperable. The sixth car sustained the most damage when it telescoped and separated from its supporting wheel-set. A visual examination of the anti-climber element showed distinct indications of impact markings and striations on the upper face of the anti-climber flanges (teeth).

The six cars of train 105 did not derail. The second through sixth cars had either a minimal amount of damage or no damage at all. The lead car (4018), although the forward carbody was intact and uncompromised, sustained damage to the front-end cab compartment. The left side window was pushed inward about 27 inches, and the forward body-end door was pushed inward about 20 inches at the top and about 6 inches at the bottom. The operator's compartment, including the ceiling panels, was intact and undamaged.

General Description of Metrorail System, Tunnel/Station, and Track

Metrorail System

WMATA's Metrorail system comprises 106.3 miles with 86 stations. About one-half of the Metrorail system is below ground, and the other half is above ground. Five operating lines, designated by WMATA as Blue, Green, Orange, Yellow, and Red, make up the system that connects the Maryland and Virginia suburbs with the District of Columbia.

The 30.38-mile Red Line serves passengers between the Glenmont station in Glenmont, Maryland, and the Shady Grove station near Gaithersburg, Maryland, by way of downtown Washington, D.C. There are 27 stations along the Red Line, 14 of which are above ground. Generally, it requires about 58 minutes for a train to completely traverse the Red Line and service all 27 stations. Rush hour headways[30] are set for 3 minutes on all WMATA lines except for the Red Line, which allows a 2.5-minute rush hour headway. Headways during off-peak hours are about 12 minutes on all lines.

Tunnel/Station

The accident train was traveling on the Red Line in the single-track tunnel in the direction of Cleveland Park from the Woodley Park station. The tunnel is under Connecticut Avenue, and it is about 150 feet below ground at the Woodley Park station. The accident train collided with the standing train within the Woodley Park station. The station has two tracks (A-1 and A-2) at 37-foot centers separated by a 27-foot platform. Parallel to each track, along the tunnel wall, is a third rail electrified with approximately 750 volts, which supplies traction power to the trains. The interior cross-section of the station is symmetrical and approximates a semicircle with precast concrete sections that are about 52 feet wide by 29 feet high (its maximum height at its center) and about 24 feet above the top of rail of each track. WMATA designates the position and location of the track/tunnel within the system using engineering survey station numbering. For example, the Woodley Park station platform begins at station 128+0 and ends at station 134+0 (or is 600 feet in length), and the track/tunnel continues toward Cleveland Park, where the platform begins at station 165+40 and ends at station 171+40 (or is 600 feet in length). Trains travel through a 3,140-foot twin rock-lined, cast-in-place concrete tunnel between the two stations. Each tunnel approximates a semicircle that is 13 feet 6 inches above the top of rail and 16 feet 9 inches wide.

Track

The collision occurred on the A-2 outbound track at the north end of the Woodley Park station. A review and inspection of the A-2 single main track by investigators determined that the track met WMATA's standards, which allow a maximum authorized speed of 59 mph on the Red Line. A visual examination by investigators did not show any evidence of wheel sliding on the top of the rail in the area of the accident.

WMATA's design criteria specify that the optimal maximum grade for attaining desired station elevation and for mainline running tracks is 4 percent. In exceptional circumstances, such as split level junctions and other isolated cases, the maximum grade may be increased to 5-percent downhill grades only (for normal direction of travel). The steepest grade on WMATA's system is a 4.8-percent grade used to maintain the underground depth through parklands in an isolated area of the Green Line. A number of 3- and 4-percent grades are used to enter and exit underground tunnel portals and to ascend and descend aerial structures.

[30] *Headway* is the time separation between two trains that are both traveling in the same direction on the same track. It is measured from the time the head end of the leading train passes a given reference point to the time the head end of the train immediately following passes the same reference point.

Grade and Alignment. The A-2 track runs in a north-south direction, which is designated as outbound because trains operate away from the downtown area toward Shady Grove. Conversely, the A-1 track is designated as the inbound track. The track geometry approaching the Woodley Park station consists of a 9° 43' 30" left-hand curve into the station. It then continues straight through the station on a 0.35 percent ascending grade. As it exits the Woodley Park station, the track remains straight and ascends on a 3.72 percent grade to the Cleveland Park station.

Speed restrictions are determined by the conformance of the track to WMATA's track standards. The maximum designed speed on WMATA's system is 79 mph, and the maximum regulated speed is set at 59 mph. Maximum speed on WMATA's system is determined by existing track geometry that includes track curvature, super elevation, length of spiral for curves, and other track conditions. During the most recent inspection prior to this accident, WMATA determined that the track was safe for normal speed.

Operational Information

Train Operations

The *Metrorail Safety Rules and Procedures Handbook* (MSRPH), dated January 2004, governs the operation of trains on WMATA's rail system. WMATA officials cited several rule violations applicable to this accident: MSRPH operating rules 3.1, 3.18, 3.57, 3.57.1, 3.69, 3.91, and 3.91.1; in addition to MSRPH general rule 1.1.1. The two most relevant operating rules are 3.57 and 3.91.1, which state in part:

> Rule 3.57 All propulsion problems regardless of severity are to be immediately reported to OCC, the Terminal Supervisor, or Interlocking Operator as appropriate.
>
> Rule 3.91.1 Train operators shall activate the emergency stop pushbutton (mushroom) any time a train must be stopped to prevent a collision with any object or, when the train fails to respond to a call for normal braking from the Master controller.

Operations Control Center

All train control and supervision for the entire transit system is conducted through the OCC, which is located in Washington, D.C. The OCC is equipped with monitoring, control, and communication facilities required to operate the transit system and to handle emergency situations. The OCC is staffed 24 hours a day, 7 days a week.

OCC supervisors are responsible for all mainline train operations and the safe operation of revenue trains in accordance with approved timetables or modifications of them when necessary. When notified of an emergency, the OCC supervisor coordinates all activities to alleviate the situation. Ensuring the safety of passengers and employees and the protection of property and equipment are the OCC supervisor's primary concerns.

When this accident occurred, two supervisors were staffing the OCC desk for the Red Line. One of the supervisors was in charge of all communications with the trains. The other supervisor was in charge of routing the trains and expediting their movement across the system. Both supervisors stated that they would have expected the operator of train 703 to call the OCC for assistance the moment his train did not respond to the commands that he said he had applied.

Method of Operations

"Maximum authorized speed" is defined in the MSRPH as the most restrictive speed that includes the following: limiting speed, operating speeds specified in operating rules, safety rules, standard operating procedures and/or operating and restrictions notices; and speeds issued by verbal instructions of supervisory and OCC personnel. According to the MSRPH, this shall not preclude Mode 2 Level 2 operation of trains. Train operation is carried out via either automatic train control (ATC) or manual control by a train operator.

The ATC system consists of three control subsystems and a computerized general control facility. The three control subsystems are Automatic Train Operation (ATO), Automatic Train Supervision (ATS), and Automatic Train Protection (ATP). Each subsystem performs its own particular functions independently of the other two (to a certain extent). The operation of the three subsystems is coordinated through the computer at the OCC to achieve an integrated control system:

- ATO – The subsystem performing functions normally tasked to an operator. Those functions are acceleration, deceleration, speed regulation, programmed stopping, and door control (in conjunction with ATP and the Train-to-Wayside Communication System).
- ATS – The subsystem that monitors the system status and provides the appropriate controls to direct the operation of trains in order to maintain traffic patterns and minimize the effect of train delays by controlling arrival and departure times, and by using OCC computer programs to accomplish minor schedule adjustments.
- ATP – The subsystem that enforces safety operation. Speed limits are imposed both to maintain safe train separation and to operate trains in accordance with civil speed restrictions. At an interlocking it ensures that train movement is permitted only when a route is available through the interlocking, and the switches are safely locked in position. In all cases where two or more trains request the use of a single segment of track or interlocking, the ATP prevents occupancy by more than one train.

The MSRPH defines various modes and levels of manual train operations with a train operator as follows:

- Mode 2 Level 2 (Manual Operation with zero speed commands) – Train operation with train under train operator control with operation partially monitored and protected by the ATP system. The train is to be operated at restricted speed (15 mph or as directed by OCC) and an Absolute Block[31] or Permissive Block[32] must be established when operating on mainline. This is the normal operating mode in yards.
- Mode 2 Level 1 (Manual Operation with Speed Commands) – Train operation with train under train operator control with operation monitored and protected by ATP. Train speed is not to exceed the more restrictive speed displayed on the console or as designated by OCC, whichever is less.
- Mode 3 (Manual Operation with ATP cut out) – Train operation under train operator control without ATP monitoring and protection. This mode is not allowed unless passengers are off-loaded at the first available station and an Absolute Block or Permissive Block is established to allow train movement.

Signal and Train Control Information

Train operations on the Red Line are governed by a traffic control system that controls train movements in both directions on two main tracks. The system employs General Railway Signal light signals, located at interlocking locations only, and General Railway Signal Model 55E electric switch machines. Audio frequency track circuits control train speeds. All interlocking locations are operated remotely from a control panel in the OCC located in Washington, D.C.

Each mainline route is divided into track blocks[33] from one end of the terminal station to the other. Each block is checked for train occupancy by means of audio frequency track circuits. Tuned impedance devices provide block separation. These devices inject coded signals into the track that detect the presence of a train in the block and automatically transmit limiting and regulated speeds to passing trains. There is generally one track circuit per block with impedance bonds located at both ends of each track circuit.

Computerized Train Movement Report

At the OCC, WMATA has a computer system that uses track-bed detectors to record all train movement operations throughout the system. The system report shows the clock time that a track is occupied and when it is vacated by a train, as well as the minimum, maximum, and average speeds of the head end and rear end of the train. The report also lists the circuit number (block name), outbound and inbound locations, length

[31] *Absolute Block* is a section of track between two specific locations into which no train is permitted to enter while it is occupied by another train.

[32] *Permissive Block* is a section of clear track ahead of a train, in the established direction of traffic, up to a specific point into which no other train, track vehicle, or obstruction is permitted.

[33] *Track blocks* through the accident section are designated with the prefix "A2" and the even station number of the inbound chainage mark. For example, A2-162 represents track number 2 starting at the inbound chainage location 162+27.

of the track circuit, estimated pre- and post-shunt distance, clock time the train occupied and vacated the track circuit, maximum, minimum, and average speeds of the head end and rear end of the train at each track circuit, and the expected speed command. Each report is accompanied with a legend for interlocking and station platforms. (See the report section entitled "Tests and Research.")

Mechanical Information

Car Construction

The cars involved in the accident were from the 1000 and 4000 series built by Rohr and Breda, respectively. The carbody is composed principally of aluminum alloy extrusions and formed shapes with welded steel subassembly components for certain load-bearing structural elements. The front-end cowl assembly is fabricated of molded fiberglass incorporating a pair of collision and corner post elements. Aluminum sheeting makes up the exterior skin of the roof, sidewalls, and rear-end panels.

The front end of each car contains a train operator's compartment[34] (fitted with operating controls). The rest of each car contains the passenger compartment. Although Federal Railroad Administration (FRA) regulations require anti-telescoping features on self-propelled multiple unit cars, the FRA does not have regulatory authority over WMATA's equipment. However, WMATA specified to its car builders that collision post elements must be fitted to the cars and that they must consist of a pair of vertically mounted structural beams installed on both sides of the body-end doors at the front end of the railcar. WMATA further specified that they must be securely attached to both the end underframe assemblies and the carbody roof framing structure.

The main underframe of the 1000- and 4000-series cars consists of transverse aluminum beams attached by blind-fastener bolts to the aluminum lower sidewall (U-channel shaped) extrusions. These beams extend the full length of the carbody and function as side-sill components. The cars do not have a conventional center-sill element (as found in some intercity passenger car designs), but incorporate longitudinally oriented intercostal elements fitted between some of the transverse beams. The end underframe assemblies (one fitted to each end of the car with the truck-assemblies attached to them) are fabricated of low-alloy/high-tensile steel and consist of a body bolster, a draft sill, and an angular end-sill fitted with a conventional anti-climber element, all welded together to form a single-unit assembly. (See figure 6.)

[34] When a train is in service, only one *operator compartment* is occupied and all the others are locked.

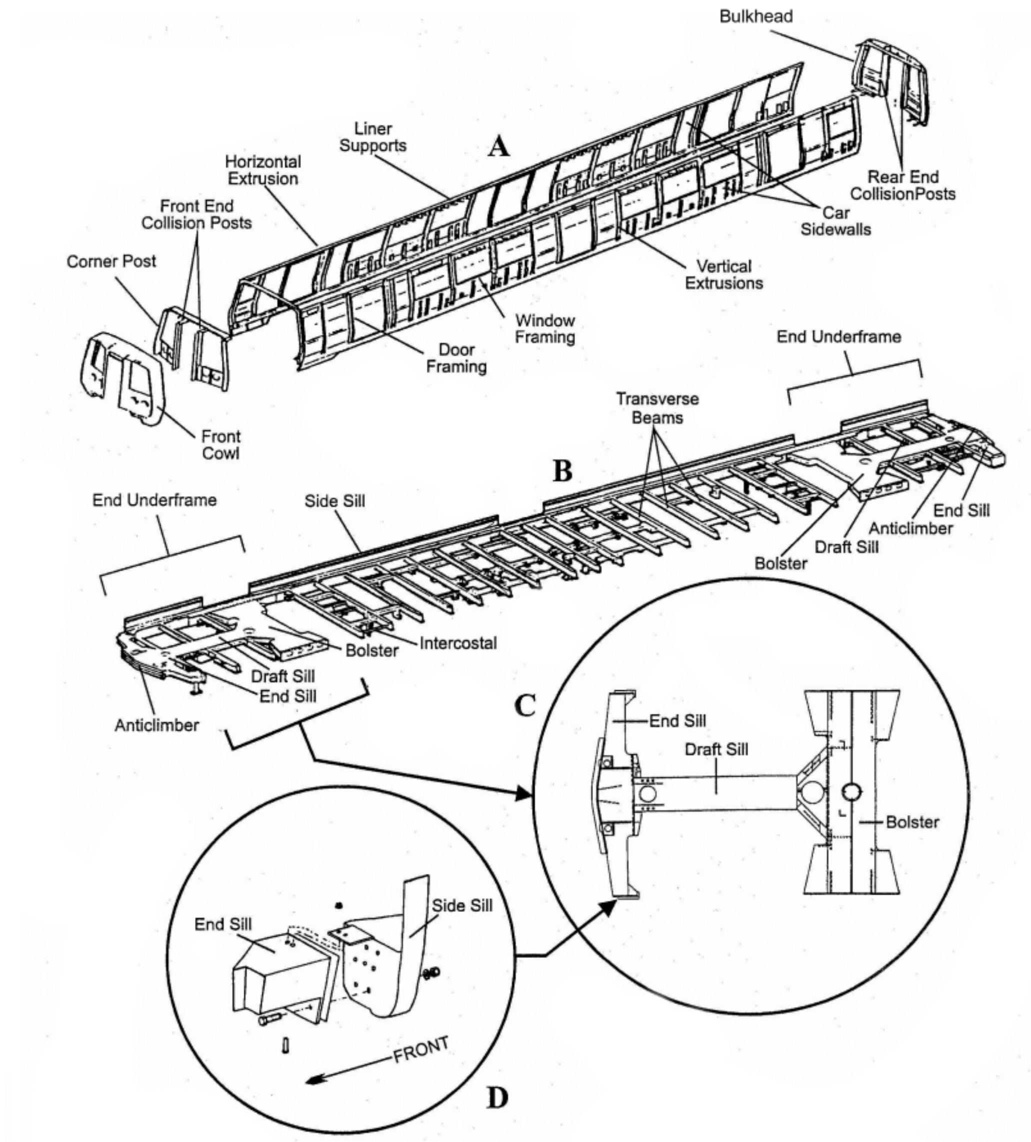

Figure 6. [a](A) Typical WMATA Metrorail carbody structure. (B) Underframe of Rohr Metrorail car. (C) End underframe assembly. (D) Attachment of side sill to end of underframe.

a.This figure first appeared in the following report: National Transportation Safety Board, *Collision of Washington Metropolitan Area Transit Authority Train T-111 With Standing Train At Shady Grove Passenger Station, Gaithersburg, Maryland,* Railroad Accident Report NTSB/RAR-96/04 (Washington, DC: NTSB, 1996) 13. In that report, the figure was used to illustrate the underframe of a Breda Metrorail car. Here it represents the underframe of a typical Rohr Metrorail car in that the structural configuration is very similar.

The exterior carbody shell and the internal floor plan layout are virtually identical for the entire car fleet. However, many of the internal mechanical elements of each successive car delivery group[35] are unique to that specific car group. That is, the Rohr-built cars differ from the Breda-built cars, which differ from the CAF-built cars. Also, cars built by a given manufacturer are required to be operationally compatible with cars built by any of the other manufacturers. WMATA prescribes the design and performance specifications of the cars to be built by the manufacturers, with each successive car delivery group having a separate specification from the previous car delivery group.

Equipment Propulsion and Braking

The operator of train 703 was operating the train from the lead car (1128) using the master controller handle. The master controller handle is equipped with a deadman function.[36] When a master controller is in the "on" position, only that master controller will operate the train.

The master controller handle has five propulsion positions (P1-P5), a coast position, and five braking positions (B1-B5). The positions P5 and B5 designate the maximum propulsion and braking efforts, respectively.

The cars are equipped with both electric (dynamic[37]) and friction brakes. Both brake systems incorporate automatic slip/slide wheel protection designed to prevent wheel slips during acceleration and wheel slides when the train slows or stops.[38] The car braking system is part of the overall ATC system.

The design of the emergency brake causes direct electrical activation in three ways: release of the master controller handle, depressing the emergency stop button,[39] or by an interruption of electrical power anywhere in the brake control circuit.[40] Direct electrical activation engages a magnetic valve resulting in the application of brake cylinder pressure at the emergency rate and value.

An emergency brake application also can be activated pneumatically. A pneumatically pressurized brake pipe is maintained through a train. In the event pneumatic pressure falls below a predetermined value, the magnetic valve deenergizes, initiating an emergency application of the friction brakes.

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[35] Because the cars were delivered in consecutive groups from different manufacturers, they are identified by an assigned number (for example, the 1000-, 2000-, etc. series cars), and they are referred to as successive delivery groups.

[36] The *deadman function* applies the train brakes when the master controller handle is released.

[37] Under propulsion, electric traction motors that receive electricity from an adjacent third rail drive WMATA trains. Under *dynamic* braking, the traction motors are converted to electric generators that supply electricity back to the third rail. This electrical load on the traction motor/generator acts to slow the motor shaft rotation, which results in a braking action being applied to the train wheels.

[38] *Slip/slide* protection is not available when the emergency brake application is initiated.

[39] The *emergency stop button* is also referred to as the mushroom.

[40] Disengaging the friction brake switch has the same effect as a broken wire or other electrical malfunction and will serve to activate an emergency brake application.

Inspections

Investigators inspected the braking systems on trains 105 and 703, to the extent possible (as further described below), before the equipment was moved from the accident site. The friction brakes on train 105 were observed to be fully applied. Each brake pad was tightly pressed against its respective brake disk and did not rattle or move when struck. The working surface of each brake rotor was smooth and appeared polished.

The friction brakes on five cars (1128, 1129, 1064, 1065, and 1076) from train 703 were in a condition similar to those on train 105. The sixth car, 1077, of train 703 had sustained major damage in the collision. The rear truck had derailed and lost hydraulic fluid from the braking system. Hydraulic fluid was evident on the truck components and track structure in the immediate area. The friction brakes on that truck were loose and not applying pressure to the rotors; however, the working surface of the rotors was smooth and polished. The friction brakes on the leading truck of 1077 were applied, and they did not rattle or move when struck.

A second test, performed 24 hours after the first test on train 703, found that friction brakes on the trailing truck of cars 1128, 1129, and 1077 and on the lead truck of car 1076 rattled when struck.

The electronic brake control units from each car of train 703 were removed and the data were downloaded before the cars were moved from the accident site. No faults were recorded on any of the electronic brake control units prior to the collision. After the cars were moved to the Brentwood Shops and the control units were reinstalled in cars 1128, 1129, 1064, and 1065, recordings of brake pressure readings indicated that the pressure levels were within tolerance for every brake application.

Rollback Protection

At the time of the accident, all WMATA passenger railcars were equipped with rollback protection when being operated in automatic mode. Some of the 2000- and 3000-series cars that had been recently rehabilitated were configured with rollback protection when operated in manual mode. However, none of the equipment on train 703 was equipped with the rollback protection feature in the manual mode. There was no documentation on board the WMATA equipment or issued to train operators that explained which cars had rollback protection in the manual mode and which cars did not.

The operator of train 703 told investigators that after the train began to roll back, he applied power in an attempt to stop the rollback and resume forward movement. The Safety Board tested a similar set of six 1000-series cars operated in the manual mode. The Board found that in a rollback event on the grade exiting the Woodley Park station, the rollback could be stopped by applying forward power only if the rollback speed was 2 mph or less. If the rollback speed exceeded 2 mph, a brake application was required to stop the rollback or slow the train to 2 mph or less, at which time any application of power resulted in forward movement. In all cases, applying the train brakes stopped the train.

Meteorological Information

The collision occurred in a well-lit underground tunnel station. The temperature inside the underground tunnel station was about 65° F. The outside weather was clear, and the temperature was about 60° F.

Medical and Pathological Information

The DCFEMS transported 20 patients to five area hospitals. Medical records for these patients indicated that one passenger sustained a serious hip injury and was hospitalized for more than 48 hours. The other passengers were treated for various minor contusions, muscle pains, strains, and sprains and released. The operator of the struck train was treated for shortness of breath and released.

Toxicological Information

The Federal Transit Administration (FTA) regulations, 49 *Code of Federal Regulations* (CFR) 655.44, require transit owners to ensure that covered employees who have been directly involved in or who may have contributed to an accident provide specimens for toxicological testing. The accident train operator indicated that he was not taking any prescription or non-prescription medications. Both train operators provided postaccident toxicological urine specimens that were tested for the presence of drugs. Both operators also took a Breathalyzer test to detect any alcohol in their system. The test results for both operators were negative for drugs and alcohol.

Survival Aspects and Emergency Response

Station Access

The Woodley Park station is located at 2622 Connecticut Avenue, NW, Washington, D.C. One entrance to the station is located at the intersection of Connecticut Avenue, NW, and 24th Street, NW. This entrance has escalators to an intermediate level, from the intermediate level to a mezzanine level, and from the mezzanine level to the platform level. The platform level is about 150 feet underground. The station manager is located in a station kiosk on the mezzanine level.

A second station entrance is located at the intersection of Connecticut Avenue, NW, and Garfield Avenue, NW. This entrance has an elevator to the mezzanine level. There is also a second elevator between the mezzanine level and the platform level.

Passengers

After the accident, the MTPD obtained the names of 70 passengers. Investigators also reviewed WMATA's security videos, recorded by cameras mounted inside of the station, in an attempt to determine the number of people exiting the train and the station. Due to the quality of the videos, an exact count was not possible. One video showed people on the escalators going from the platform level of the station to the mezzanine level. About 75 people were observed on the escalator. The second video showed people on the mezzanine level of the station moving toward the escalators that exit the station. About 150 people were observed exiting the station. These counts could include passengers on the train, other people in the station at the time of the accident, or people who entered and then exited the station after the accident.

Following the collision, four trains traversed through the station on the adjacent track before all train traffic was stopped, about 1:14 p.m.,[41] by WMATA officials at the request of emergency responders. The disembarking and embarking passengers from three trains (two inbound and one outbound) that stopped at the station[42] complicated attempts to acquire an accurate count of passengers involved in the accident.

From the MTPD's statements, hospital records, and witnesses that came forward after the accident, it was estimated that 73 people, including the 2 train operators, were involved in the accident.

Emergency Response

About 12:49 p.m., the DC 911 communications center was notified of a train wreck at the Woodley Park station. Over the next several minutes, other notification calls were received. About 12:51 p.m., the DC 911 dispatcher contacted the MTPD and the DCFEMS.

About 12:54 p.m., the DCFEMS began dispatching emergency units to the Woodley Park station. The first unit arrived on scene about 12:58 p.m. DCFEMS personnel entered the standing train about 1:01 p.m. and determined that everyone had exited the train. DCFEMS personnel began locating, assisting, and triaging the injured. Several of the injured passengers were located at the street level after they had left the station, and some had gathered in a hotel lobby above ground.

About 1:14 p.m., the DCFEMS WMATA liaison officer reported that power to track A-2, where the accident trains were located, had been shut off and that other trains would be moving on track A-1, on the opposite platform side. The incident commander reported that at that time, two trains were waiting outside the station limits on track A-1 and they were going to travel through the station before all train traffic would be stopped.

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[41] About 1:14 p.m., the OCC removed power from track A-1 and began turning back trains on both sides of the Woodley Park station.

[42] About 12:52 p.m., the first inbound train (110) serviced Woodley Park station a minute after the collision. About 12:59 p.m., the second train that serviced Woodley Park (204) was single tracked (outbound) with a supervisor on board to investigate the report of a collision. About 1:11 p.m., an inbound train (201) serviced Woodley Park. About 1:13 p.m., an inbound train (101) arrived in the station but did not service it.

The DCFEMS was unsure if anyone was in the section of the last car of the striking train, train 703, which came to rest on top of the first car of the struck train, train 105. They used photo-imaging equipment to check for body heat readings, and they had difficulty removing car windows to enter the car for a visual search. About 1:24 p.m., both train operators were located at the kiosk on the mezzanine level within the station. About 2:10 p.m., DCFEMS personnel advised that there was no one in the last car of train 703, and they recommended concluding the rescue operation. DCFEMS personnel transported the last of the injured passengers to the hospital about 2:22 p.m. About 3:05 p.m., the incident commander discontinued the operations.

Operations Control Center Communications

About 12:50 p.m., the operator of standing train 105 called the OCC and said:

> I saw another train coming down the track backwards. I opened up my door to get the passengers off. I told everybody to get off. I ran off the train. The other train ran into my train…. The other train ran into my train. It is on top of my train now.

About 12:53 p.m., the operator of the striking train, train 703, called the OCC and said: “I was on the train. It got away. It rolled backwards. I couldn't stop it.”

Metro Transit Police Department

The MTPD is the law enforcement agency for the metro system. The first responding officers arrived on scene about 1:01 p.m. Another MTPD responder advised the MTPD dispatcher that he had a warning strobe and alarm device (WSAD[43]) and would go to the scene. Two additional units responded with WSADs, and a device was placed on the track at each end of the train. Additional units responded to provide security at Woodley Park and the surrounding stations (Van Ness, Cleveland Park, and DuPont Circle).

A MTPD officer coordinated operations with the DC Fire Department incident commander at the command post outside the station, and another officer coordinated with the fire department forward commander inside the station. A liaison was assigned to coordinate with the OCC.

Disaster Preparedness

Emergency Services Manual. WMATA and the Metropolitan Council of Governments Passenger Rail Safety Subcommittee developed the *Emergency Services Manual*. The purpose of the manual is to “serve as a training manual and a reference source for information the Fire and Rescue service will need to handle emergencies in and around the Metrorail system.” The manual was first published in November 2000 and last revised in June 2001.[44] The manual includes information about WMATA’s Metrorail

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[43] A *WSAD* is a warning unit that can be attached to the third rail when power is down. The WSAD provides a visual and audible alert if third rail power is restored.

[44] The precursor to the *Emergency Services Manual* was the *Emergency Services Training Manual,* which was first published in 1987.

system, stations, elevators, escalators, the right-of-way, railcars, electrical systems, communications, ventilations systems, fire detection and alarm systems, fire suppression systems, and rescue equipment. The manual also contains the "Metrorail and Fire/Rescue Services Emergency Procedures Policy Agreement," dated May 13, 1997. WMATA and the region's fire chiefs developed the agreement. The agreement includes specific standard operating procedures for emergency operations.[45]

Emergency Responder Training. WMATA provides training for emergency responders at its training facility in Landover, Maryland. The training facility has a mock tunnel designed to replicate the features found in tunnels on the rail system. The mock tunnel has track with a simulated third rail, an emergency access catwalk, standpipes, an emergency trip station phone, an emergency tunnel evacuation cart, and two railcars that were damaged in a previous accident.[46]

The training includes classroom instruction and a disaster exercise. The classroom instruction provides general information about the Metrorail system and specific information about responding to a rail emergency. Disaster drills simulate an emergency situation that could occur on the system, such as smoke in a tunnel. These drills are specifically designed to incorporate use of the response maps, the standpipes, the ventilation system, the emergency trip station phone, and WSAD.

According to WMATA's records for the class, about 575 DCFEMS firefighters and recruits were listed on sign-in sheets for the training in 2004.[47] Prior to the accident, the most recent disaster response and readiness exercise in which DCFEMS personnel participated was conducted on October 16, 2004, at the Largo Town Center station.

Passenger Car Side Windows

The center door (the emergency exit door) of car 1077 of train 703 was damaged, and debris in the car end did not permit access to search that area. Emergency responders stated that when they tried to place imaging equipment in car 1077, they had difficulty removing a window in the damaged portion of the car. Responders stated that the rubber zip strip[48] surrounding the outside of the window was brittle and kept tearing. The window was stuck in its frame, and only after significant effort was it removed.

According to WMATA, the windows on the 1000-series railcars are an assembly consisting of a safety glass exterior and a polycarbonate interior. The windows on the 2000-, 3000-, and 5000-series cars are single-sheet safety glass. The windows on the

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[45] These procedures are also published in WMATA's *Metrorail Safety Rules and Procedures Handbook*.

[46] National Transportation Safety Board, *Collision of Washington Metropolitan Area Transit Authority Train T-111 with Standing Train at Shady Grove Passenger Station, Gaithersburg, Maryland, January 6, 1996,* Railroad Accident Report NTSB/RAR-96/04 (Washington, DC: NTSB, 1996).

[47] Some persons attended the class more than once during that time.

[48] Although emergency responders referred to the window sealant as a *zip strip,* it was actually a rubber grommet that was not intended for manual removal.

4000-series cars are single-sheet polycarbonate, which is being replaced with single-sheet safety glass.

WMATA's *Emergency Services Manual* provides emergency responders with general window specifications, stating in part:

> Rail car side windows are a combination of safety glass on the exterior and polycarbonate on the interior. These windows are designed not to open. Each window is held in place with a rubber zip strip that can be removed from the inside of the passenger compartment.

For the 1000-series car side windows, the *Emergency Services Manual* further explains that:

> The side windows in the Rohr cars are set in a metal frame. If it is necessary to remove a side window you will remove the zip strip gasket that holds the metal frame in the opening. Then push the window and frame outward from the inside to remove it. It will require considerable force to remove the window and frame; the design of the opening causes an extremely tight fit of the window and frame in the opening.

Tests and Research

Simulation Tests

Investigators reviewed security videotapes from WMATA of the Woodley Park station to determine the time it took for train 703 to depart Woodley Park and then reenter the station and strike train 105. Investigators determined that train 703 struck train 105 about 2 minutes 30 seconds after train 703 had departed from Woodley Park. Based on this information, investigators calculated the time it would have taken a train to roll back from the farthest point train 703 reached after leaving Woodley Park. This point was calculated using the total time (30 seconds) train 703 occupied the last signal block.

Simulation tests were conducted at the accident site on the section of track that train 703 traversed before the collision. Testing began on the evening of November 6, 2004, and continued into the morning of November 7. More tests were conducted on November 15. During these tests, investigators attempted to replicate the train operator's reported actions prior to the collision. Two series of tests were performed using 6-car trains. The first series of tests used an exemplar train consisting of six Rohr train cars operated in the manual and automatic mode. None of these cars were involved in the accident. The second series of tests used four of the six cars that had made up the train consist of striking train 703, plus two other exemplar cars.

In the first series of tests, the train was allowed to drift backwards, and its speed was allowed to increase to 3 mph or greater before the master controller was placed in a power position, at which point the train continued in a backward direction and gained speed as it moved down the grade. After it was determined that a power application would not stop the train, a B3 brake application was used to bring the train to a smooth stop. The first series of tests showed that in manual operation, the train took 1 minute 18 seconds to roll back to the point of the collision (reaching a speed of 34 mph). In ATO tests, the train drifted back and then moved forward, demonstrating the designed rollback protection feature in the automatic mode.

WMATA reported that some train operators had experienced a situation prior to the accident where a power application to a car that was drifting backwards had increased the speed of the backward motion, rather than stopping the car and moving it forward as intended. Following a complete diagnostic evaluation prior to the accident, WMATA had discovered a flaw in the software associated with the braking system on the 2000-series cars. Investigators conducted additional testing to determine whether a similar situation could occur on the 1000-series cars. The test train was allowed to drift backwards toward Woodley Park, and in a series of test speeds of 3 mph, 5 mph, and 8 mph, the master controller was placed in the P4 and P5 positions. Train speed did not increase above the gravitational acceleration that had been observed in the first series of tests to replicate the train operator's actions.

The second series of tests used four cars from train 703 (cars 1128, 1129, 1064, and 1065) and two exemplar Rohr cars. Accident damage to cars 1077 and 1076 precluded meaningful testing with them. Minor repairs were made to the four cars from train 703 in order to make them safe to operate during the tests, but nothing was done to the braking system. The tests were performed at the accident site using the same procedures as in the first series of tests. Again, as in the first series of tests, the train speed was allowed to increase to 3 mph or greater before the master controller was placed in a power position as the train continued in a backward direction and gained speed as it moved down the grade. After it was determined that a power application would not stop the train, a B3 brake application was used to bring the train to a smooth stop. The second series of tests showed that in manual operation, the train took 1 minute 17 seconds to roll back to the point of the collision (reaching a speed of 36 mph).

Test of Rehabilitated Equipment With Rollback Protection

Safety Board investigators conducted several tests of the recently rehabilitated 2000- and 3000-series cars' rollback protection system, using a 6-car train operated in the manual mode. The tests were performed on the same track segment where the accident occurred. In each test, the train was allowed to roll back freely in the manual mode. The rollback protection system stopped the train within 6 to 8 seconds.

WMATA's Train Data Analysis Report

WMATA provided a report generated by its computerized train monitoring system that listed the train movements between the Woodley Park and Cleveland Park stations as time-stamped events. (See appendix C.) The data included information on the striking train (703), the train immediately ahead of 703 (train 203), and the struck train (105) at Woodley Park station.

The data indicated that train 203 had entered track circuit A2-165 at Cleveland Park station about 12:45:28 p.m. (See figure 7 for block layout between Woodley Park and Cleveland Park stations.) At the same time, train 703 was entering track circuit A2-124 (moving at 34.1 mph), which was about 3,827 feet from the beginning of track circuit A2-165. About 12:46:38 p.m., train 203 left track circuit A2-165. At that time, train 703 was transiting circuit A2-146, about 1,097 feet from the beginning of track circuit A2-165. The data then indicated that about 12:46:41 p.m., train 703 would have received a 50 mph ATP regulated speed authority when it entered track circuit A2-154. About 12:46:47 p.m., train 703 was in track circuit A2-157. At this time, train 203 was still occupying track circuit A2-171. According to interpretations by WMATA officials, train 703 received a "reduced 28 mph ATP speed with Train 203 occupying A2-171 circuit," and "train 703 would have received an over speed alarm." In addition, about 12:46:51 p.m., as train 203 left track circuit A2-171, train 703 would have received a 55 mph ATP regulated speed authority. Train 703 traveled into track circuit A2-162 about 12:47:03 p.m. This was the farthest point train 703 traveled on November 3. Because train 203 had left track circuit A2-181, train 703 would have received a 50 mph ATP regulated speed authority.

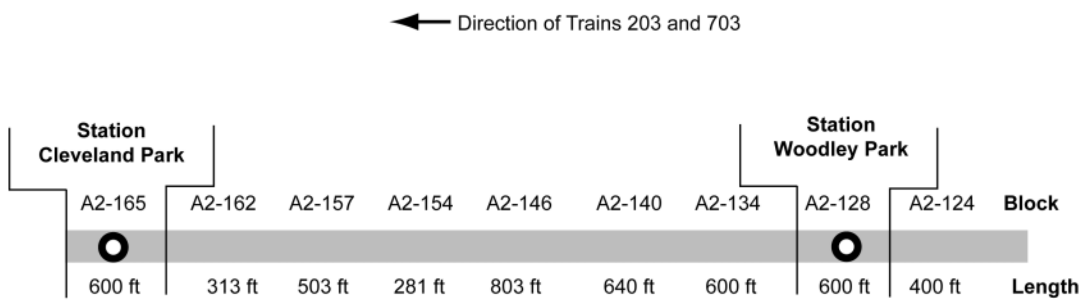

Figure 7. Block identification and length for A2 track outbound on Red Line.

The data then indicated that at least part of train 703 had occupied track circuit A2-162 for about 30 seconds. About 12:47:33 p.m., train 703 was recorded as leaving track circuit A2-162 moving in the reverse direction (negative speed recorded). Train 703 was recorded as exiting track circuit A2-140 with a train speed of 36 mph. This is the last recorded data before train 703 collided with train 105. The estimated total distance train 703 traveled backwards to the collision with train 105 at Woodley Park station was about 2,246 feet.

Postaccident Information

Initially, WMATA officials told Safety Board investigators that all of their cars were equipped with an automatic rollback protection feature, which would automatically apply train brakes, if necessary, to prevent a rollback. WMATA officials later told investigators that at the time of the accident, the only cars in the fleet that had rollback protection in the manual mode were the 70 rehabilitated cars in the 2000 and 3000 series, which had undergone a software upgrade as part of an ongoing rehabilitation program. The remaining 324 cars in the 2000 and 3000 series, as well as the cars in the 1000, 4000, and 5000 series, did not have rollback protection when operated in the manual mode.

During the investigation, it was determined that because of the presence of the rollback protection feature on the cars, WMATA officials did not anticipate a situation in which an uncontrolled rollback could occur. Investigators interviewed several train operators, the training instructor for train operators, and the OCC supervisors. All of the interviewees said they believed that the rollback protection feature would automatically prevent excessive rollback. All were apparently unaware that this feature was not available for all trains being operated manually. Consequently, no specific information had been provided to train operators regarding the proper management of a rollback.

On November 7, 2004, WMATA issued a memorandum to all train operators and Metrorail supervisors concerning the lack of a rollback protection feature on the 1000-series cars. The memorandum advised operators and supervisors that:

> there is [sic] no roll back features on the Rohr series 1000 cars when operating in a manual mode . . . . Therefore, each operator is advised to be aware of any and all operating conditions, related to grade positive or negative, that will affect train handling.
>
> Any changes in operating conditions of the train shall be reported to the Operations Control Center (OCC) immediately.

On November 9, 2004, WMATA issued a supplement to the November 7 memorandum. The November 9 supplement, also directed to all train operators and rail supervisors, stated:

> This reminder covers the balance of the fleet [cars other than the Rohr cars addressed in the previous memorandum] for your clarity and for your governance.
>
> Operators are reminded that 'roll-back' protection exists in Automatic Mode, but not in Manual. However, in Manual, your brake systems (B1 through Emergency/Mushroom) are available and are to be used in accordance with operating conditions and consistent with your training and the provisions of the MSRPH.

The Safety Board was concerned that the guidance provided in the two memorandums may have been too broad to properly prepare train operators for this type of emergency. WMATA officials and train operators acknowledged that small rollbacks (1 or 2 feet) were normal. A train stopped on a grade routinely experiences a rollback during the brief interval between the release of the brake and the reapplication of power. In automatic mode, these small rollbacks are stopped by the automatic application of power and, if the rollback continues beyond certain limits, by the rollback protection system. In the manual mode, applying power to the train is an appropriate response to a small rollback. However, the results of the Board's tests revealed that once a train's rollback speed exceeded about 2 mph, the rollback could not be stopped by a power application alone. In this situation, either the service or emergency brakes must be used.

On November 22, 2004, the Safety Board made the following urgent safety recommendation to WMATA:

R-04-9

Immediately revise the directions to train operators contained in your memorandums of November 7 and 9, 2004, to include specific written instructions for identifying and responding to an emergency rollback situation, and provide training to operators on the procedures to follow if such a rollback event occurs. (Urgent)

On November 23, 2004, WMATA responded to the Board's urgent safety recommendation, advising that new bulletins were issued on November 22 and 23, 2004,[49] which revised the November 7 and 9, 2004, memorandums concerning rollback protection on Rohr 1000-series cars. The revised bulletins of November 22 and 23 again reminded operators that in manual mode there is no rollback protection except in the rehabilitated Breda cars.

WMATA also advised the Safety Board that according to the most recent guidance issued by WMATA, operators were to take the following actions in the event of a rollback:

- In manual mode, a rollback is to be stopped by application of the train brakes.
- Should a rollback of greater than 5 seconds occur, the operator shall apply maximum service brakes by pulling the brake handle to the B4 position.
- Should the train not stop within another 4 seconds, the operator shall apply the emergency brakes by releasing the safety handle or by depressing the emergency stop button.
- Operations Control Center shall be notified immediately.

Because the train's speed—and not the elapsed time of the rollback, as included in the revised bulletins—was the relevant variable in stopping the train, the Safety Board asked WMATA to include a discussion of speed in its written instructions for identifying and responding to a rollback situation. The Board also asked that these instructions be incorporated in WMATA's Initial Train Operator's Course and in its operator recertification training procedures. Pending these additions, the safety recommendation was classified "Open—Acceptable Response" on May 31, 2005.

In a letter dated February 15, 2006, WMATA stated that it did not agree with the Safety Board's position. WMATA stated that "basing a decision to stop a train on the constant, time, is more effective because speed is a variable and is a function of time and distance." WMATA provided information about how time and distance are used to control rollback during automatic train operation, explaining that if a rollback continues for 10 seconds, the operator is to push the "ATO stop." Similarly, WMATA explained that the

[49] WMATA issued a bulletin on November 22, 2004, outlining the procedures for responding to emergency rollback situations. The WMATA Safety Department provided the Safety Board a revised bulletin dated November 23, 2004, that was issued because the braking rate between automatic and manual modes was transposed on the November 22 bulletin.

rollback detection feature in the manual mode is adjustable from 7 to 15 seconds before automatic braking is applied in the cars equipped with this feature. Overall, WMATA believes that the time-based criterion is better because it is simple and easily explained to and understood by the operators.

Other Information

WMATA was formed in 1967. Responsibility was assigned to Maryland, Virginia, and the District of Columbia to plan, finance, construct, and operate a comprehensive mass transit system for the Washington, D.C., metropolitan area. A board of directors comprised of two members from each of the three jurisdictions governs the transit authority. The board of directors does not play a direct role in day-to-day operations of the Metrorail or Metrobus systems, although it may promulgate safety requirements.

Transit Oversight

The Safety Board's interest in the oversight of rail rapid transit safety dates back more than 30 years, beginning with the Board's special study[50] that explored the role of the Urban Mass Transportation Administration, now the FTA, in developing safe transit systems. The Board also investigated a number of rapid rail accidents during the 1970s and 1980s and issued several relevant safety recommendations over the years. Further, the Board conducted a safety study in 1991 that addressed oversight of rail rapid transit safety.[51] On December 18, 1991, considering the Board's safety recommendations and studies, Congress enacted the Intermodal Surface Transportation Efficiency Act of 1991 (P.L. 102-240), which added Section 289 to the Federal Transit Act. This section directed the FTA to require those States that have a rail fixed-guideway system (such as WMATA's Metrorail), which is not regulated by the FRA, to designate a State agency to oversee the safety of the guideway system. It also authorized the FTA to withhold some transit funding should a State fail to implement a safety program.

Safety Oversight

There are no Federal or State regulations specific to train operations; the maintenance, inspection, and the testing of the equipment; the structures; or the track on WMATA's rail transit system. Rather, the FTA in 49 CFR 659 requires each State with a rail transit system to designate an oversight agency to conduct safety and security oversight. The State agency in turn requires the transit system to write a system safety program that includes elements identified by the FTA. In addition, the State agency is responsible for reviewing the transit system's compliance with the system safety program and implementing corrective action when needed.

[50] National Transportation Safety Board, *Special Study of Rail Rapid Transit Safety,* Railroad Special Study NTSB/RSS-71/01 (Washington, DC: NTSB, 1971).

[51] National Transportation Safety Board, *Oversight of Rail Rapid Transit Safety*, Railroad Safety Study NTSB/SS-91/02 (Washington, DC: NTSB, 1991).

According to 49 CFR 659.21(b), if a transit agency operates a system in more than one State, then those States may designate a single entity, other than the transit agency, to implement the requirements of the regulations. The District of Columbia, Virginia, and Maryland formed the Tri-State Oversight Committee (TOC) to carry out the oversight responsibilities for the WMATA system. The TOC then hired a consultant to develop a system safety program standard, conduct safety reviews, establish procedures and conduct investigations, review corrective action plans, and prepare required audit reports. The most recent audit of WMATA was conducted in January 2004. The audit did not identify any anomalies within WMATA's organization that involved issues related to the November 3, 2004, accident.

WMATA is also a member of the American Public Transportation Association (APTA), and it requests periodic APTA safety audits. These audits, which are provided as a service to APTA members, cover all elements of the safety program. Prior to the November 3, 2004, accident, the most recent APTA audit of WMATA was conducted from May 23 through June 4, 2002. The audit did not reveal any issues directly related to the 2004 accident at the Woodley Park station. However, APTA did recommend that WMATA review its hours-of-service guidelines for operating personnel, evaluate industry practices, and initiate appropriate changes as required.

Internal Oversight

WMATA's safety department performs annual internal audits of WMATA's operations. Each audit is reviewed by the TOC, and recommendations are made based upon the findings. The results of the most recent audit, which occurred on August 18, 2004, indicated that WMATA's safety department's system safety program plan complied with the requirements set forth in APTA's guidelines.

Management and Organizational Factors

Title 49 CFR 659.19(c) states that a system safety plan shall include an overview of the management structure of the rail transit agency, including the following:

> (1) An organization chart;
>
> (2) A description of how the safety function is integrated into the rest of the rail transit organization; and
>
> (3) Clear identification of the lines of authority used by the rail transit agency to manage safety issues.

The Safety Board investigated the January 6, 1996, collision between two WMATA trains at the Shady Grove station in Gaithersburg, Maryland.[52] During the course of the Board's investigation, several WMATA employees reported that there was a lack of communication within the organization. The employees further noted that information isolation was a common issue stemming from that lack of communication. As an example, they explained that the general manager (GM), the director of the safety department, and

[52] NTSB/RAR-96/04.

the instructor responsible for operator training were not aware, before the fact, of the policy change regarding full-time automatic train operation.

After the 1996 accident and while the Safety Board's investigation was ongoing, a WMATA safety review committee submitted a report to WMATA's board of directors recommending that the safety department report directly to the GM. This recommendation was subsequently adopted and implemented, and the safety department began reporting directly to the GM.

An organization chart provided by WMATA in 2004 showed that the safety department was still reporting directly to the GM when the November 3, 2004, accident occurred. (See figure 8.) However, after the accident, WMATA instituted a reorganization effective March 17, 2005, that rescinded the direct reporting link between the safety department and the GM. (See figure 9.)

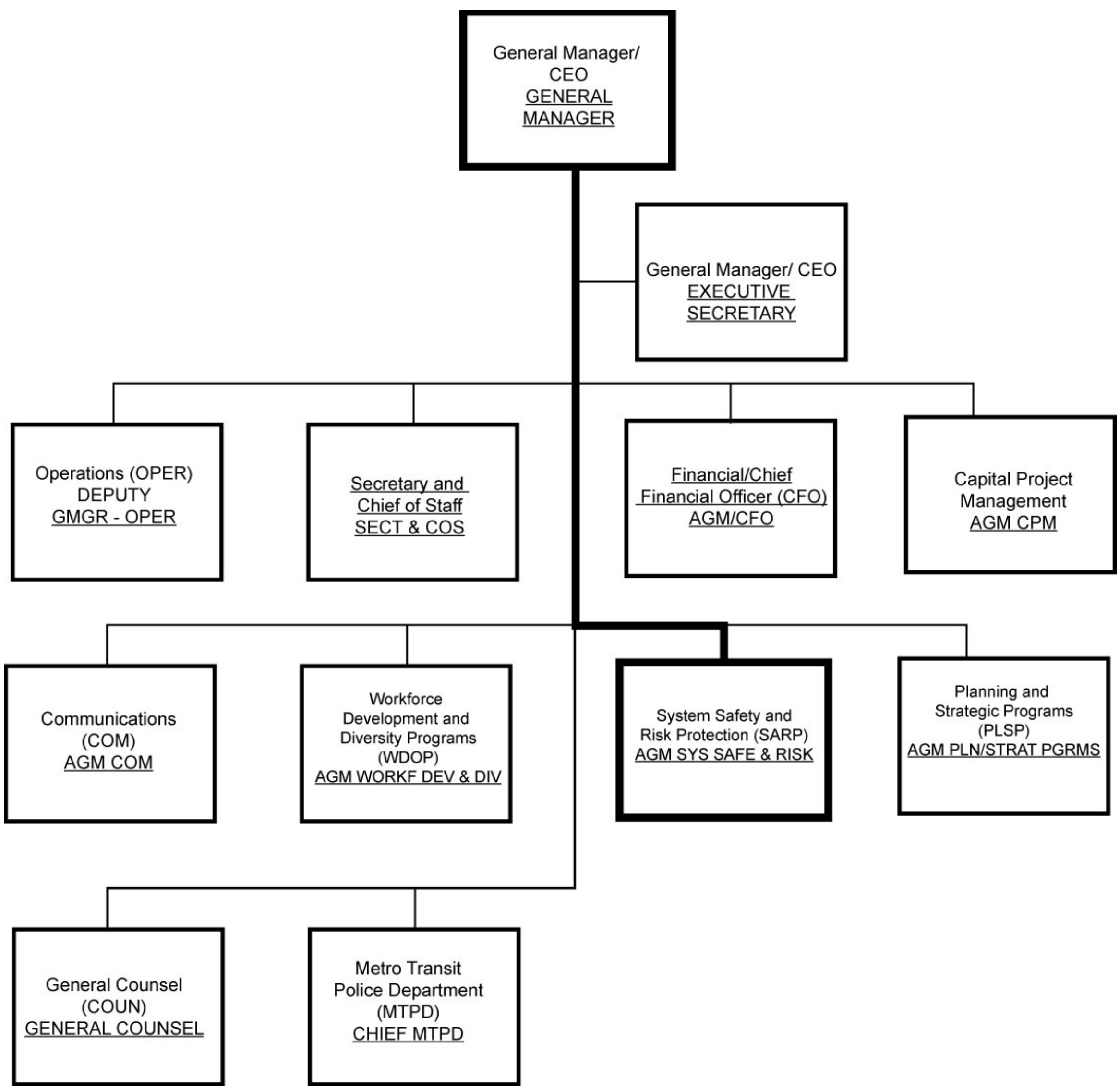

Figure 8. WMATA's organizational chart in effect on November 3, 2004.

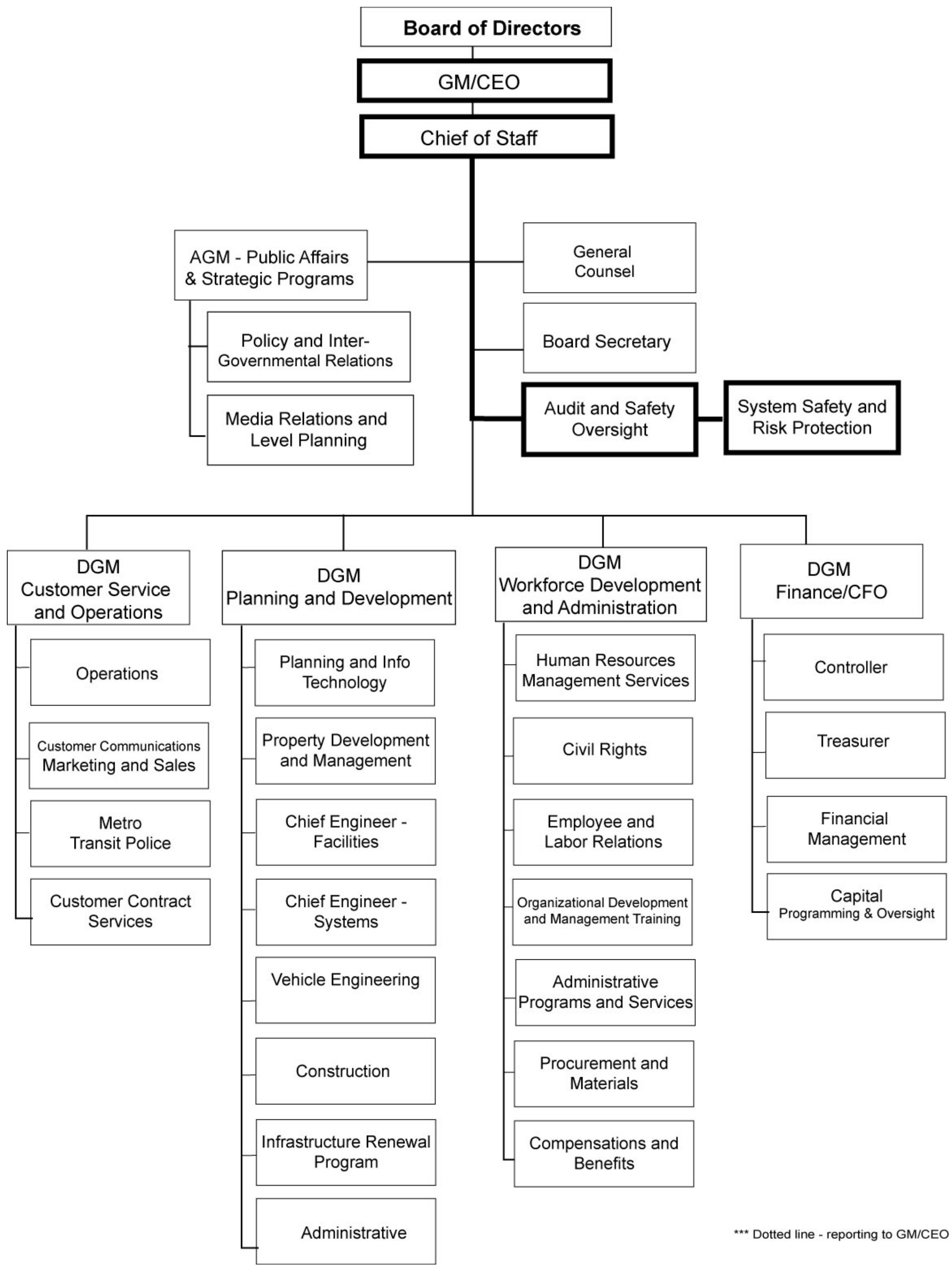

Figure 9. WMATA's organizational chart reflecting the reorganization of its management structure after the November 3, 2004, accident.

In a letter to WMATA, dated March 31, 2005, the TOC expressed concern about the transit authority's reorganization, which eliminated the safety department's direct access to the GM. The GM responded to the TOC and explained that the postaccident change to WMATA's reporting structure would provide for:

> swift resolution of issues and recommendations identified by WMATA Safety and Audit organizations and provide them with a mandate to ensure compliance in the event that necessary corrective actions are not being taken by other parts of the WMATA organization in a prompt fashion.

Crashworthiness of Passenger Equipment

The Safety Board investigated two accidents on WMATA's Metrorail system prior to this accident: the January 13, 1982, accident at the Smithsonian interlocking[53] and the January 6, 1996, collision at the Shady Grove station in Gaithersburg, Maryland.[54]

In the 1982 accident, one car of a 6-car train derailed as it negotiated a track-crossover (interlocking). The center section of the derailed car crashed into a concrete barrier wall, resulting in a breach of the carbody sidewall structure and a loss of survival space in the middle of the passenger compartment. Of the approximately 220 passengers in the car, 25 passengers were injured, and 3 sustained fatal injuries. There were no relevant crashworthiness-related safety recommendations issued by the Safety Board.

In the 1996 accident, a 4-car train failed to stop at a station platform and continued moving for about 470 feet. Moving at an estimated 22 to 29 mph, the train struck a standing, unoccupied 6-car train. The operator of the 4-car train was fatally injured; the train's two passengers, who were riding in the last car, were not injured. The front end of the lead car of the striking train overrode the front end of the standing train. The lead car of the striking train experienced a catastrophic failure of the forward end bulkhead structure, resulting in an inward displacement of that structure and a telescoping of the carbody, effectively causing a loss of about 21 feet of survival space. The front end of the lead car of the standing train sustained a uniform crush of approximately 10 inches across the front of the car at frame level, and it telescoped approximately 21 feet into the striking train. The Safety Board issued the following safety recommendation to WMATA on November 14, 1996:

> <u>R-96-37</u>
>
> Undertake, with the assistance of qualified engineering support, a comprehensive evaluation of the design and design specifications of all series of Metrorail cars with respect to resisting carbody telescoping and providing better passenger protection, and make the necessary modifications, such as incorporating underframe bracing or similar features, to improve the crashworthiness of cars in the current and/or future Metrorail fleet.

[53] National Transportation Safety Board, *Derailment of Washington Metropolitan Area Transit Authority Train No. 410 at Smithsonian Interlocking, January 13, 1982*, Railroad Accident Report NTSB/RAR-82/06 (Washington, DC: NTSB, 1982).

[54] NTSB/RAR-96/04.

In a March 22, 2002, letter to the Safety Board, WMATA stated that its consultant had determined that adding underframe reinforcement was neither desirable nor practical and that such modification could result in higher longitudinal accelerations and possibly more injuries. In addition, WMATA stated that the mid-life overhaul of the Rohr (1000-series) cars had been completed and that it would be impractical to modify the cars before they were scrapped. WMATA also contended that the cost and downtime that would be involved in modifying the balance of the fleet when the Breda cars are refurbished was prohibitive. Considering WMATA's position on its existing fleet to be reasonable, the Board responded to WMATA on May 28, 2002, stating that the intent of Safety Recommendation R-96-37 had been met. The recommendation was then classified "Closed—Acceptable Action."

The original contract specifications for the 2000-, 3000-, and 4000-series cars show that the car collision posts have the same section modulus and yield stress material as the 1000-series cars, but the ultimate shear value was increased by 50 percent. No crashworthiness improvements were required in the recent rehabilitation of the 2000- and 3000-series cars.

The Safety Board's investigation of the November 3, 2004, WMATA accident shows that the 1000-series, Rohr-built, passenger railcars experienced telescoping damage and complete loss of occupant survival space in a longitudinal end-structure collision. In reviewing the crashworthiness collision protection of the Metrorail passenger railcar fleet, the Board found that the fleet will be comprised of four successive delivery series generations of carbody structural designs. Investigative data further revealed that each of WMATA's successive delivery series railcars (Rohr, Breda, CAF, and ALSTOM) will have a higher degree of carbody end-structure resiliency (that is, resistance to catastrophic carbody telescoping) than its immediate predecessor. Therefore, WMATA's successive introduction of progressively more robust carbody designs is consistent with an ensuing increase in carbody end-structure crashworthiness protection.

Transit passenger railroad systems, such as WMATA's Metrorail, operate railcars that are comparable to those used in commuter train operations in many regards: physical size, passenger capacity, and frequency of stops. However, unlike commuter train operations, transit passenger railroad systems are not subject to FRA crashworthiness requirements as described under 49 CFR 238, Passenger Equipment Safety Standards. That is, there is no Federal regulatory requirement that addresses structural crashworthiness provisions for passenger cars operating in transit service. The FTA addresses only flammability resistance for the elements of passenger cars operating in transit service in a 1986 publication, "Recommended Fire Safety Practices for Rail Transit Materials Selection."

Operator Training

WMATA requires that all prospective train operators have 65 days of formal training prior to becoming certified on WMATA's system. The training schedule includes about 3 weeks of classroom instruction, and the remaining time is divided between classroom and on-the-job training in the yard. The on-the-job training familiarizes the trainee with equipment, yards, tracks, tower operations, terminals, communications, and operating rules. A trainee is required to score 75 percent or higher on the exam to pass the class. If a trainee scores less, the trainee is given one-on-one instruction and another opportunity to take the exam. However, if the trainee scores less than 80 percent on the second attempt, the trainee will be dropped from consideration for a train operator position.

A review of WMATA's training instructions showed that during their on-the-job training, students were taught on a daily basis how to use the emergency brake. However, rollback protection was not part of the curriculum for operator training.

The operator of train 703 stated that he had never experienced having a train "drift" (rollback) as it did during the moments before the collision. He stated he had experienced minor drifting while operating in the automatic mode, but when the train drifted back, the brakes would "kick in" relatively quickly. He said that he had never received formal training in managing a rollback; although he understood that hitting the emergency brakes (by depressing the mushroom) was an acceptable option if braking and propulsion were not adequate to stop the train.

A WMATA rail instructor told investigators that train operators are instructed to use the emergency brake (mushroom) immediately if normal braking fails to stop the train. He indicated that operator trainees practice applying emergency brakes during their formal training. Specifically, they practice hitting the mushroom in the yard, and they also simulate hitting the mushroom while operating on the mainline. The instructor indicated that during a rollback situation, if train operators could not stop the train through "initial (normal) braking," they should not make more than one attempt to apply the brakes. Although the instructor indicated that an operator should press the mushroom during any problematic situation, which would include a rollback, this was not part of WMATA's formal training.

Event Recorders

Neither train 703 nor train 105, consisting of 1000-series Rohr equipment and 4000-series Breda equipment, respectively, were equipped with event recorders to record specific train operation events. Therefore, no information was available for investigators to confirm the statements made by the operator of train 703 regarding his application of the train brakes.

Following its investigation of the accident at the Shady Grove station on January 6, 1996, the Safety Board issued the following recommendation to WMATA[55] regarding event recorders:

[55] NTSB/RAR-96/04.

R-96-39

> Finalize the specifications for a new advanced-technology carborne monitoring system and, once that is complete, retrofit existing Metrorail cars with monitors/recorders during rehabilitation and require that all new Metrorail cars be equipped with the devices.

On March 22, 2002, WMATA responded that the new 5000-series cars would be equipped with monitors on each car. In its response, WMATA further stated that the 2000- and 3000-series cars would be retrofitted during mid-life rehabilitation, with a completion date of 2005. Starting in 2012, the 4000-series cars would begin their mid-life rehabilitation and would also be retrofitted with monitors on each car. After the 4000-series rehabilitation, WMATA stated that it would reevaluate the 1000-series to determine whether the monitors on each car could be made compatible. WMATA noted that the 1000-series cars are scheduled for retirement between 2012 and 2015. On May 28, 2002, the Board classified Safety Recommendation R-96-39 "Closed—Acceptable Action."

During the investigation of this accident, Safety Board investigators examined the installation and status of event recorders on WMATA's operating fleet. According to WMATA, about 292 1000-series cars are currently available for service. These cars are nearing their 35-year life expectancy, at which time WMATA plans to retire or rehabilitate them. The 2000- and 3000-series cars are currently going through a mid-life rehabilitation. During the rehabilitation, the cars will be retrofitted with an on-board event recorder system. About 100 4000-series cars are currently available for service, but they have not reached their mid-life rehabilitation schedule checkpoint. The 5000-series cars that have been delivered are equipped with an on-board event recorder system. The 6000-series cars, which are currently being manufactured, will also be equipped with an on-board event recorder system. (See appendix B.)

Analysis

General Factors

Safety Board investigators inspected the Washington Metropolitan Area Transit Authority (WMATA) track and reviewed its recorded train movement records. No anomalies were found in the track, signal, or communications systems, including the wayside communications devices and the electronic command systems related to Automatic Train Control (ATC). Therefore, the Safety Board concludes that the track, signal, and communications systems were not factors in this accident.

WMATA's postaccident toxicological test results showed no drug or alcohol use by the operator of train 703. Therefore, the Safety Board concludes that the use of drugs or alcohol was not a factor in this accident.

The DC 911 communications center received its first call at 12:49 p.m. Emergency response units began arriving on scene within 8 minutes. A battalion chief assumed incident command and established a command post outside the station for transportation, treatment, and staging groups to manage the medical operations. A second battalion chief managed the search and rescue operations on the platform inside the station. Therefore, the Safety Board concludes that the emergency response to the accident was well coordinated and effectively managed.

The Accident

Train 703 departed Brentwood Yard traveling in the direction of the Shady Grove station, closely following revenue train 203. The train 703 operator received overspeed alarms, alerting him that his train was getting too close to train 203. The train operator applied braking to slow the train, thereby silencing the alarm and creating more distance between the two trains. Overall, the trip to Woodley Park station was uneventful. The accident sequence began after train 703 left the Woodley Park station, ascending upgrade toward the Cleveland Park station.

Because there was no train movement event recorder on train 703, the Safety Board considered several other sources of information to reconstruct the events leading up to the accident, including interviews with the train operators, training instructors, and managers; physical evidence at the scene (security video); data collected and analyzed from the track circuits pertaining to the movement of the trains; and accepted transit standard operating practices and procedures.

WMATA's computerized train movement record showed that train 703 left the Woodley Park track circuit about 12:46 p.m., traveling about 24.1 mph[56] as it ascended the grade toward the Cleveland Park station. About 17 seconds later, train 703 received an Automatic Train Protection (ATP) regulated speed authority of 45 mph. (The record showed an actual average train speed of about 30 mph.) Eighteen seconds after that, the train received an ATP regulated speed authority of 50 mph. (The record showed an actual average train speed of about 32 mph.) About 6 seconds later, train 703 received an ATP regulated speed authority of 28 mph because it was getting closer to train 203. As a result, the operator of train 703 received an overspeed alarm. Knowing that train 203 was servicing the next station,[57] the operator of train 703 likely made a brake application to silence the alarm and likely placed the master controller in the coast setting, slowing the train speed from about 31 mph to 19 mph in 15 seconds. However, about 1 second after train 703 received the ATP regulated speed authority of 28 mph, it received an ATP regulated speed authority of 50 mph. During this interval, train 703 reached its farthest point from the Woodley Park station and began to roll back. About 78 seconds passed before train 703 collided with train 105, which was servicing the Woodley Park station.

The operator of train 703 stated that he tried to brake the train and apply power in succession during the rollback. However, he said he did not receive power to the train before applying the emergency brakes.[58] Postaccident testing of the train equipment did not support the train operator's claim that he applied normal braking. Had train 703 been equipped with an event recorder, the operator's statements could have been verified. Examination and testing of the accident train's four undamaged cars showed no evidence of mechanical or brake failure. Consequently, any brake application should have at least slowed or stopped the train. There is no indication, however, that the train slowed as it rolled backwards toward the Woodley Park station. On the contrary, data retrieved and analyzed indicate that the train's speed progressively increased during the rollback, from 7 mph to about 36 mph, up to or near the point of collision.[59] Moreover, the speed and acceleration of the accident train closely correlated with that of two similar test trains that were rolled back from the same location with no brake application. Also, investigators could not find any evidence of flat spots on the wheels or markings on the track, which would have suggested that emergency brakes had been applied before the collision. The emergency brake mushroom, which apparently had been pushed, may have been applied

[56] See appendix C.

[57] After departing Woodley Park station, train 703 ascended the grade, and the train operator was eventually able to see train 203 servicing Cleveland Park.

[58] The train operator had several options to slow or stop the train, including releasing the master controller, which would have automatically resulted in a brake application; moving the master controller to a brake setting; or applying the emergency brake mushroom. WMATA's operating rules require train operators to radio the OCC for assistance when they experience a braking problem. The operator of train 703 did not contact the OCC.

[59] The available data from the track circuits were collected and calculated for the accident train until it entered the circuit, where the accident occurred. No speed calculations are possible for a train that has entered, but not exited, a track circuit. Consequently, it could not be determined if any braking occurred in the track circuit occupied by the struck train. (It was estimated that train 703 entered the last track circuit 3 to 5 seconds before the collision.) Therefore, if any normal braking did occur, it would have likely occurred only seconds before impact.

at the time of the impact or shortly afterwards. Therefore, the Safety Board concludes that the braking systems of train 703 were operable on the day of the accident and, if applied, could have stopped the train.

Analysis Overview

The accident investigation identified several areas that needed to be examined to determine the probable cause and contributing factors of the accident: (1) the lack of rollback protection when trains are operated in the manual mode, (2) the failure of the operator of train 703 to take appropriate action to stop the train from rolling backwards, (3) the adequacy of the safety oversight of WMATA's operations, (4) the adequacy of the accessibility to passengers in WMATA's train cars during an emergency response, and (5) the crashworthiness of WMATA's equipment.

Rollback Protection

WMATA officials had initially informed Safety Board investigators that they believed that all of their cars were equipped with a rollback protection feature. Later, it was determined that the rollback protection feature was available in the automatic mode for all equipment but only for the rehabilitated 2000- and 3000-series cars in the manual mode. Therefore, the Board issued an urgent safety recommendation to WMATA on November 22, 2004, because rollback protection was not available in the manual mode for all equipment:

> R-04-9
>
> Immediately revise the directions to train operators contained in your memorandums of November 7 and 9, 2004, to include specific written instructions for identifying and responding to an emergency rollback situation, and provide training to operators on the procedures to follow if such a rollback event occurs. (Urgent)

WMATA has sent the Safety Board two letters, dated November 23, 2004, and February 15, 2006, explaining the actions it has taken to address the rollback protection safety issues and the Board's related concerns raised by the November 3, 2004, accident. WMATA's guidance prescribes that a rollback is to be stopped by application of the train brake, but also allows for a rollback of 5 seconds before the operator must make a maximum brake application. If the train does not stop in another 4 seconds, the emergency brake is to be applied. The Board finds WMATA's 2004 and 2006 responses to be lacking in that WMATA has not addressed train speed during a rollback event. Also, WMATA has not provided a discussion in its written instructions and training that explains that once rollback speed exceeds 2 mph, the train cannot be stopped by applying forward power, and brakes must be applied.

The Safety Board's simulation testing found that trains that did not have the rollback protection feature could be controlled only by applying the train brakes when the train speed exceeded 2 mph in a rollback situation. The Board is disappointed that WMATA's response noted that it will not address train speed factors in its written instructions for identifying and responding to a rollback situation. Therefore, Urgent Safety Recommendation R-04-9, previously classified "Open—Acceptable Response," is reclassified "Open—Unacceptable Response."

Rollback protection is an engineered safety redundancy. The train operator is primarily responsible for safety in accordance with all established procedures. In the event a train operator fails to take appropriate action to prevent a train from rolling backwards within predetermined limits, the rollback protection feature is designed to safely stop the train. WMATA obviously saw value in this feature because its entire fleet was equipped with it in the automatic mode. WMATA also assumed its fleet was equipped with the rollback protection feature in the manual mode, but was unaware of the fact that it was not. Therefore, the Safety Board concludes that WMATA was unaware, at the time of the accident, that the rollback protection feature was generally not available when a train was operated in the manual mode, and consequently no specific training was provided to operators about the lack of this feature on all cars. The Board could not determine why WMATA neglected to equip its fleet with the rollback protection feature in the manual mode or why WMATA was unaware of the lack of this safety redundancy feature within its entire fleet.

The rollback protection feature was readily available in the transit industry for the type of cars WMATA operated. One of WMATA's primary car building and refurbishing contractors had been installing and maintaining the rollback protection feature in manual mode on similar equipment for another transit agency for many years. Therefore, the Safety Board concludes that if the equipment on train 703 had been equipped with a rollback protection feature in the manual mode, the train could have been safely stopped, regardless of the train operator's action or inaction, and the accident could have been prevented. The Safety Board believes that WMATA should equip, as soon as possible, all existing and future train equipment with rollback protection for trains operated in the manual mode.

Train 703 Operator's Performance

The Safety Board examined the performance of the operator of train 703, specifically his failure to stop the train while it rolled back, ultimately striking train 105 as it was servicing Woodley Park station. Although he had been operating trains for only 6 months, the operator of train 703 was adequately trained and experienced in both automatic and manual train operating modes.[60] He was experienced in slowing and

[60] The train operator never received formal training about how to manage a rollback. Nevertheless, he understood that applying the emergency brakes (by depressing the mushroom) was an acceptable option if braking and propulsion were not adequate to stop the train. A WMATA rail instructor also told investigators that train operators are instructed to use the emergency brakes (the mushroom) immediately if normal braking fails to stop the train.

stopping trains through normal braking, and he understood that using the emergency brake (mushroom) was a reasonable and expected response if normal braking was inadequate. During the accident trip, train operations were routine.

The Safety Board explored other explanations for the train operator's failure to respond to the train's 78-second rollback and prevent the collision. Specifically, the Board examined three other factors that may have reduced his alertness and impaired his performance: his medical fitness, the low operating demands on the accident trip, and the adequacy of his sleep.

Medical Fitness

On October 31, 2004, at 4:30 a.m., the train operator's Gastroesophageal Reflux Disease (GERD)[61] and epigastric pain,[62] which had persisted for a month and increased at night, forced him to seek treatment at a medical clinic. Although this episode occurred 3 days before the collision, the train operator's symptoms may have affected his fitness for duty on the day of the accident. Beyond general discomfort, GERD has been shown to affect sleep. Moreover, the majority of those suffering from heartburn experience it at night, and nighttime GERD is a significant contributor to sleep problems.[63] In addition, because the pain increased at night during the month preceding the accident, the operator's nighttime sleep may have been further disrupted during this period. Thus, as a result of his condition, he may have experienced a cumulative sleep debt.[64]

Further, since the operator received little or no sleep between late Saturday night and Sunday morning (when he normally would have been asleep), he also would have experienced an acute sleep debt.[65] Even if his treatment relieved his pain and discomfort, his sleep routine was disrupted by his visit to the clinic, making it even more difficult for him to get the necessary sleep to recover from his sleep debt before the start of his next work assignment.

Although it is not clear if the train operator's performance on the day of the accident might have been impaired by his medical condition, his condition could have

[61] *Gastroesophageal reflux* is a physical condition in which acid from the stomach flows backward up into the esophagus. Some will experience heartburn symptoms when excessive amounts of acid flow back up into the esophagus. Others describe heartburn as a feeling of burning discomfort, localized behind the breastbone, which moves up toward the neck and throat. (Source: American College of Gastroenterology.)

[62] Pain in the upper middle region of the abdomen.

[63] Source: National Sleep Foundation.

[64] *Cumulative sleep debt* refers to the chronic build up of sleep deprivation, which occurs when successive periods of inadequate sleep are experienced. This can produce a cumulative increase in lapses, even during the daytime. Recovery from a sleep debt typically involves more deep sleep and not an hour-for-hour payback of lost sleep that requires extended sleep. Generally, 2 nights of usual sleep, at a person's regular bedtime, can reduce the cumulative sleep debt. See National Transportation Safety Board, *Uncontrolled Collision with Terrain American International Airways Flight 808, Douglas DC-8-61, N814CK U.S. Naval Air Station Guantanamo Bay, Cuba August 18, 1993*, Aviation Accident Report NTSB/AAR-94/04 (Washington, DC: NTSB, 1994) 136.

[65] An *acute sleep debt* is the difference between the amount of sleep needed and the amount one slept in a 24-hour period.

affected the quantity and quality of sleep he received on the days leading up to the accident. Therefore, the train operator's medical condition might have affected his sleep, alertness, and ultimately, his performance on the day of the accident.

Low Task Demands and Unremarkable Operating Environment

During the accident trip, the train operator's task demands were relatively low. He was operating during off-peak hours, a time when WMATA's system moves fewer trains and time between revenue trains is greater. Further, he was operating a nonrevenue train, that is, a train that was not carrying passengers. Therefore, the operator did not have the usual responsibilities associated with attending to passengers, such as making public address announcements, stopping at stations, and opening and closing doors.[66] In the absence of station stops, his primary requirements were operating his train in accordance with track speed, slowing to 25 mph, and sounding his horn at each station. When he operated too close to the train ahead of him, the overspeed alarm was activated, and subsequently silenced by the operator making a regular brake application. The train operator also believed that his train was equipped with rollback protection that would prevent it from rolling backwards. Thus, in contrast to operating a revenue train during peak hours, the workload on the accident trip was comparatively low.[67]

During test rides in the control cab of an exemplar train, investigators noted that the operating compartment of the train, even while the train was moving, was generally comfortable and quiet, particularly when the master controller was in the coast setting. As previously discussed, train 703, after the train operator received the overspeed alarms and eventually placed the train into coast, slowed to a stop and then began to roll back. Safety Board investigators further noted during their test rides that a train rolling back remains relatively quiet and free of unusual sounds, creating minimal rocking or vibration, and only a subtle physical sensation of movement. Under these conditions, there were no obvious external cues that would have been a deterrent to an operator's reduced alertness. Investigators found that focusing on the position of the tunnel lights relative to the position of the train was the most salient cue to determining the movement of the train. However, an operator experiencing reduced alertness, or one who is particularly inattentive to train operations or activity inside and outside the operating compartment, could remain unaware of conspicuous external cues for the duration of the rollback. Therefore, the Safety Board concludes that the low task demands and unremarkable operating environment during the accident trip were conducive to the train operator becoming disengaged from some critical train operations.

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[66] At Woodley Park station, a train operator in revenue service making a station stop would have to leave his seat, move to the other side of the operating compartment, open the window, and stick his head out to visually confirm that the doors had fully closed. The operator then would have to close the window and return to his seat before departing the station.

[67] The Safety Board is mindful that prolonged periods of low activity may be fatiguing and may inhibit immediate attention to operations. See "Train Driver Mental Workload: The Train Driver Workload Principles Guidance Note," produced by the Institute for Occupational Ergonomics and CCD Design and Ergonomics Ltd as part of the project 20-T147-IOECCD *Investigation into Train Driver Mental Workload* on behalf of the Rail Safety and Standards Board (2005).

Work Schedule and Sleep

From Monday night to the time of the accident on Wednesday, about 38 hours, the train operator had very limited opportunity to recover any needed sleep, and he did not get much sleep. Because of his late arrival home Tuesday night (following his 13-hour workday) and his interrupted sleep that night due to calls to and from his cellular phone, his opportunity for uninterrupted sleep was limited to about 5 hours.

The train operator reported a usual sleep requirement of 8 hours. Therefore, his 3-hour acute sleep loss the night before the accident might have affected his ability to remain alert and to safely operate his train. Research has shown that acute sleep loss may affect subsequent alertness and performance.[68] Generally, obtaining 2 hours less sleep than a person needs results in a significant alertness and performance decrement, and more acute sleep loss results in a greater corresponding deficit in alertness.[69] Moreover, laboratory research has clearly established the relationship between sleep loss, both acute and cumulative, and decreased performance and alertness.[70]

The train operator's lack of any measured action to stop the train's rollback for about 78 seconds before the collision, when several options were available to him, suggests that he was unaware of the movement of the train or of any impending danger. Therefore, the Safety Board concludes that the train operator's alertness was likely reduced due to inadequate sleep.

Opportunity for Adequate Sleep During Off-Duty Hours

The FTA does not have hours-of-service regulations for train operations. By contrast, the Federal Aviation Administration, the Federal Railroad Administration (FRA), and the Federal Motor Carrier Safety Administration all have hours-of-service regulations. Consequently, rail transit companies are under no constraint regarding the number of hours an employee may work or the number of hours an employee is required to have off duty. WMATA told the Safety Board that its practice (established with the union representing train operators and bus drivers) limits train operators' on-duty time to 16 hours. WMATA's practice also requires train operators to have at least 8 hours of continuous off-duty time between the completion of their last shift and the start of their next shift within a 24-hour period.

[68] M.A. Carskadon and T. Roth, "Sleep restriction," ed. T.H. Monk, *Sleep, Sleepiness and Performance* (Chichester, U.K.: John Wiley, 1991) 155-167.

[69] M.R. Rosekind, "Managing Safety, Alertness and Performance through Federal Hours of Service Regulations: Opportunities and Challenges." Document created and produced independently by Alertness Solutions, 2005.

[70] Varying amounts of acute sleep loss (2, 4, 6, and 8 hours) were found to increase sleepiness more than ethanol and had comparable effects to ethanol on degrading psychomotor performance. In this study, 2 hours of sleep loss equated to a breath-alcohol concentration (BrEC percent) of .045 percent or the equivalent of ingesting 2 to 3 12-ounce beers. Four hours of sleep loss equated to a .095 percent BrEC percent or the equivalent of ingesting 5 to 6 12-ounce beers. T. Roehrs, E. Burduvali, A. Bonahoom, and others, "Ethanol and Sleep Loss: A 'Dose' Comparison of Impairing Effects," *Sleep* 26 (2003) 981-985.

The night before the accident, the train operator went off duty about 11:00 p.m., and 9 hours later (about 8:00 a.m.) began his next shift. It took him about 30 minutes to commute each way to work and home; the 60-minute round trip provided him with 8 hours at home. The train operator informed investigators that he needs 8 hours of sleep to wake up feeling rested. However, realistically, there was inadequate opportunity for him to receive 8 hours of sleep after his last shift and before the start of his first shift on the day of the accident. Specifically, during his 9 hours off-duty time, he stated that he took about 30 minutes commuting from work to home, about 15 minutes to fall asleep after he arrived home, and a combined 75 minutes in the morning to get ready and commute to work in order to arrive 15 minutes before the start of his shift. Therefore, since the train operator arrived home at 11:30 p.m. on Tuesday night and woke up Wednesday at 6:30 a.m., he had no more than 7 hours available for him to sleep. This assumes that he fell asleep immediately after arriving home and spent little or no time eating meals and tending to family matters. The Safety Board is thus concerned that because a person, on average, needs 8 hours of sleep, allowing an operator as little as 8 hours off duty between shifts does not provide a realistic opportunity for adequate sleep.

The available time train operators have for sleep is limited by various necessities, including commuting, as well as the usual time it takes to prepare for bed, fall asleep, shower, and prepare for work the next day. Other typical needs, such as eating meals or tending to family or personal matters, further impinge on their available rest (sleep) time. In actuality, in order to have an opportunity to sleep for 8 hours, a train operator's off-duty time must be appreciably greater than 8 hours. Further, the Safety Board notes that WMATA's practice of allowing train operators to start a shift after having only 8 hours off duty conflicts with its own scientifically-based fatigue-educational material,[71] which indicates that, on average, adults physiologically require 8 hours of sleep for optimal waking performance and alertness.

The Safety Board concludes that WMATA's practice of allowing train operators to return to work after having as few as 8 hours off between shifts following prolonged tours of duty does not give train operators the opportunity to receive adequate sleep to be fully alert and to operate safely.

The Safety Board is also concerned that train operators working an extended tour of duty may not be able to obtain adequate rest before the start of their next assignment. While working an extended day may in itself be demanding,[72] it also reduces the available time off before the start of their next shift. For instance, the operator of the accident train worked an additional (overtime) shift on 9 of the 19 days in the month preceding the

[71] WMATA provides fatigue awareness training, which is presented to train operator trainees during formal train operator training classes. The fatigue program, developed by the FTA, encompasses a wide range of fatigue-related issues, such as fatigue signs and symptoms (that is, lack of alertness, nodding off, slow reaction time, and micro sleeps). The material also discusses the need for train operators to achieve adequate sleep and to report to work rested before the start of their shift. Specifically, the information (accurately) details that people, on average, require about 8 hours of sleep (per day).

[72] Continuous hours of wakefulness is another factor that can affect performance and alertness. Data suggest that 16 or 17 hours of continuous wakefulness can be associated with significantly reduced performance and alertness. See NTSB/AAR-94/04.

accident. Often, his overtime assignments occurred on several consecutive days. These extended days, typically lasting between 15 and 16 1/2 hours, began with an overtime shift starting as early as 6:23 a.m., followed by his regular shift ending at 11:00 p.m. As a result, the time off between the end of one day's tour and the start of the next day's shift was as little as 7 hours 23 minutes. So, rather than having 14 hours off between regular assignments, the extra assignment reduced the time off to 8 hours or less. Thus, prolonged tours of work on successive days reduce the opportunity for train operators to get adequate sleep.

The Safety Board recognizes that assigning overtime shifts is not necessarily an unsafe practice. That is, the operator on the accident train could have worked the same number of assignments over the last month without jeopardizing his sleep. For instance, working an extra assignment on alternate days would provide ample opportunity for adequate rest before returning to work. Thus, train operators can safely work extra assignments if their work time is not exceedingly long and if their time off is adequate for them to receive sufficient rest before the start of their next shift.

Other transit agencies contacted by the Safety Board have a maximum time on duty and minimum time off practice that is similar to WMATA's.[73] Therefore, the Safety Board believes that the FTA should require transit agencies, through the system safety program and hazard management process if necessary, to ensure that the time off between daily tours of duty, including regular and overtime assignments, allows train operators to obtain at least 8 hours of uninterrupted sleep.

Oversight

During the investigation of the January 6, 1996, accident at the Shady Grove station, the Safety Board identified employee concerns about WMATA's organizational structure, specifically, a perceived lack of communication and a sense of information isolation. These concerns were addressed by a WMATA safety review committee, which recommended that WMATA change its organizational structure to have the safety department report directly to the GM. This recommendation was subsequently adopted and implemented, and WMATA's safety department began reporting directly to the GM.

WMATA's organizational structure was not an issue in the November 3, 2004, accident at the Woodley Park station. However, following the 2004 accident, WMATA restructured its organization again, reverting back to the safety department having a disconnected responsibility and accountability reporting chain. In effect, this restructuring maneuver rescinded the direct reporting link between the safety department and the GM that had been established as result of the Shady Grove accident. This postaccident reorganization could recreate the systemic information isolation that existed within

[73] For instance, New York City Transit, Metro Transit (Minneapolis, Minnesota), and Metropolitan Atlanta Rapid Transit Authority allow as little as 8 hours off between shifts. The Southeastern Pennsylvania Transportation Authority permits scheduling operators for as many as 18 hours in 1 day.

WMATA prior to the Shady Grove accident, which in turn could inhibit serious safety problems from being identified or adequately addressed.

The FTA apparently believes that an effective management structure is important, and it has established that a transit system must include an organizational chart in its system safety plan along with a description of how the safety function is integrated into the rest of the transit organization. Still, the Safety Board is concerned that the more distant reporting relationship between WMATA's safety department and the GM could inhibit serious safety problems from being identified or adequately addressed. Therefore, the Safety Board believes that the FTA should assess the adequacy of WMATA's current organizational structure and ensure that it effectively identifies and addresses safety issues.

Passenger Safety

In a life-threatening situation, emergency responders must be able to enter the passenger cars quickly. Passengers must also be able to evacuate the cars rapidly and safely. The Safety Board is concerned about the limited number of emergency access/egress points on Metrorail passenger cars.

The windows on Metrorail cars are not designed to open easily. WMATA's *Emergency Services Manual* provides emergency responders with general window specifications, stating that the windows are not designed to be removed, but can be removed from the inside by taking off the inside zip strip. However, according to the General Superintendent of Rail Car Maintenance, the rubber grommet surrounding the window inside the car must be pried off with a tool, and it is not easily removed by hand.

As reported during the emergency response activities, the emergency responders had extreme difficulty removing the Metrorail car windows because the rubber grommet surrounding the outside of the window was brittle and kept tearing; and the window was stuck in its frame and could not be removed easily. They had to remove a window in the damaged portion of a car to insert imaging equipment because they did not know whether the car was still occupied by any incapacitated passengers. Fortunately, the visual and thermal imaging searches confirmed that no one was trapped in the car.

The conditions surrounding the search and rescue operations after this accident were optimal. The collision occurred within a lighted rail station while the passenger load was light. One train had no passengers, the occupied train was disembarking passengers, and the last car of the striking train was next to the platform. In addition, both the incident commander and the forward commander reported that they had attended WMATA's training for emergency responders. Despite these conditions, the limited access into the cars delayed the search of the last car. As previously stated, the center door (the emergency exit door) of car 1077 of train 703 was damaged, and debris in the car end did not permit access to search that area. Further, two other door panels that can be opened from the outside the car were in a section that was severely damaged by the collision.

The Safety Board investigated WMATA's January 13, 1982, accident at the Smithsonian interlocking in which a Metrorail train car derailed, struck the end of a reinforced concrete wall, and was severed, resulting in three fatalities. Following the investigation, the Board issued Safety Recommendation R-82-70 to WMATA.[74]

R-82-70

> Require the installation of an adequate number of marked emergency escape windows on all new Metrorail cars and implement a program to similarly retrofit existing cars.

In a letter dated October 18, 1984, WMATA expressed concern that emergency windows would create new hazards, such as an uncontrolled evacuation in tunnels or vandals opening the windows. Instead of emergency windows, WMATA installed passenger-initiated evacuation devices that allow passengers to open center doors of cars. On January 14, 1986, the Safety Board classified Safety Recommendation R-82-70 "Closed—Acceptable Alternate Action."

Although there is an emergency exit on each side of a car, passengers are instructed to exit the train from only one side during an emergency evacuation. The emergency exits are located at the center doors on each side of the car. These center doors have two panels. However, only one panel can be opened using a mechanical emergency pull located next to the door. Passengers can slide the door open only if it is undamaged, and there is no debris or obstruction in the doorway path. However, passengers can also use the end bulkhead doors to exit from one car into another if the side doors are inoperative and the end doors are not damaged. In this accident, the side door panels and the end doors in the last car of train 703 could not have been used.

Emergency responders' access to the Metrorail cars is substantially limited to doors. Electrical power and a special key are required to open the door panels. In the event that third-rail power is down, an on-board battery can be used to furnish power to open the doors.

The Safety Board is concerned that the only means for emergency responders to quickly enter the cars relies on electrical power and key-controlled access. In an accident, third-rail power may be turned off and the back-up battery in the passenger car could be damaged, which would prevent the doors from operating properly. Further, although WMATA distributes access keys to fire departments in WMATA's territory, bystanders who may be on scene and willing to help cannot open doors. Therefore, the Safety Board concludes that emergency access/egress points for WMATA's equipment do not provide adequate means for emergency responder entry or passenger evacuation.

Passenger railroads regulated by the FRA, per 49 *Code of Federal Regulations* (CFR) 238.113, are required to have a minimum of four emergency window exits on their passenger cars. However, there is no requirement for rail transit equipment to have

[74] NTSB/RAR-82/06.

emergency window exits. The Safety Board believes the FTA should develop transit railcar design standards to provide adequate means for safe and rapid emergency responder entry and passenger evacuation.

Equipment Crashworthiness

The last car of train 703 sustained damage that was vastly disproportionate to that sustained by the lead car of train 105. The carbody structure of car 1077 inboard of the collision posts failed, which demonstrates a fundamental flaw in the crashworthiness structural design of the 1000-series carbody. Even though the anti-climber showed indications of engagement,[75] the last railcar of train 703 telescoped and overrode the leading end of the first railcar of train 105, sustaining a catastrophic loss of approximately 34 feet of survival space in the passenger compartment. However, the collision post elements of the lead car of train 105 remained intact, and the operator's cab was not compromised.

The Woodley Park station collision scenario was not much different from that of the January 1996 collision at the Shady Grove station.[76] In that accident, the collision speed was calculated between 22 and 29 mph occurring on a 0.35-percent descending grade of straight track with the moving train telescoping 21 feet over the stopped equipment, severely compromising the occupant volume of the striking car. In the November 3, 2004, accident, the calculated speed of train 703 was 36 mph as it rolled backwards down a 3.72-percent descending grade of straight track and collided with stopped train 105 and telescoped 20 feet over it. Almost half of the passenger occupant volume of the striking car of train 703 was also severely compromised.

In WMATA's March 2002 response to the Safety Board's recommendation (R-96-37) to conduct a comprehensive evaluation of Metrorail cars and make modifications to improve their crashworthiness, WMATA stated that its consultant determined that it was neither practical nor desirable to add underframe reinforcement and that such modification possibly could result in more injuries. WMATA also stated that it would have been impractical to modify the 1000-series Metrorail cars before they are scrapped and it would be prohibitive to modify the 2000, 3000, and 4000 series when they are refurbished. As a result of this response, the Board classified Safety Recommendation R-96-37 "Closed—Acceptable Action" based on the information that WMATA's position on the existing fleet was reasonable and that the intent of the recommendation had been met.

The Safety Board concludes that the failure of the carbody (underframe) end structure of the 1000-series Metrorail cars may make them susceptible to telescoping and potentially subject to a catastrophic compromise of the occupant survival space. WMATA's evaluation, which determined that it was impractical to modify the 1000-series

[75] *Engagement* was indicated by the shear damage to the anti-climber flanges (teeth), which suggested that there was positive engagement with the anti-climber of the adjacent railcar (4018).

[76] NTSB/RAR-96/04.

cars and their crashworthiness performance in collisions, in effect validates the scheduled retirement of the cars.[77] Any replacement car should be designed with crashworthiness components for absorbing maximum energy in a collision and to transmit minimum acceleration to passengers without override or telescoping, as found in the current 5000-series railcars and specified for the 6000-series cars.

Railroad and commuter passenger railcars are subject to FRA regulations and are required to have carbody structural provisions to reduce the propensity of carbody telescoping during severe end-structure collisions.[78] Conversely, the FTA has not established requirements to address structural crashworthiness provisions for passenger cars operating in transit service. Because transit passenger railroad systems operate railcars of a similar size and passenger capacity to that used by commuter train operations, which are subject to FRA crashworthiness requirements as described under 49 CFR 238, the Safety Board concludes that the failure to have minimum crashworthiness standards for preventing telescoping of rail transit cars in collisions places an unnecessary risk on passengers and crew. The Safety Board believes that the FTA should develop minimum crashworthiness standards to prevent the telescoping of transit railcars in collisions and establish a timetable for removing equipment that cannot be modified to meet the new standards.

Because the 1000-series, Rohr-built, passenger railcars, which will comprise 26 percent of the Metrorail passenger railcar fleet when all the cars are delivered, are vulnerable to catastrophic telescoping damage and complete loss of occupant survival space in a longitudinal end-structure collision (as occurred at the Woodley Park station), the Safety Board believes that WMATA should either accelerate retirement of Rohr-built railcars, or if those railcars are not retired but instead rehabilitated, then the Rohr-built passenger railcars should incorporate a retrofit of crashworthiness collision protection that is comparable to the 6000-series railcars.

[77] The 1000-series cars (292 cars) are currently scheduled for retirement between 2012 and 2015. The 4000-series cars (100 cars) will begin their mid-life rehabilitation in 2012.WMATA plans to have in service during 2006 its 5000- (192 cars) and 6000- (184 cars) series Metrorail cars and have completed the rehabilitation of the 2000- (76 cars) and 3000- (288 cars) series cars.

[78] A feature as described in 49 CFR 238.211.

Conclusions

Findings

1. The track, signal, and communications systems were not factors in this accident.

2. The use of drugs or alcohol was not a factor in this accident.

3. The emergency response to the accident was well coordinated and effectively managed.

4. The braking systems of train 703 were operable on the day of the accident and, if applied, could have stopped the train.

5. If the equipment on train 703 had been equipped with a rollback protection feature in the manual mode, the train could have been safely stopped, regardless of the train operator's action or inaction, and the accident could have been prevented.

6. The Washington Metropolitan Area Transit Authority was unaware, at the time of the accident, that the rollback protection feature was generally not available when a train was operated in the manual mode, and consequently no specific training was provided to operators about the lack of this feature on all cars.

7. The low task demands and unremarkable operating environment during the accident trip were conducive to the train operator becoming disengaged from some critical train operations.

8. The train operator's alertness was likely reduced due to inadequate sleep.

9. The Washington Metropolitan Area Transit Authority's practice of allowing train operators to return to work after having as few as 8 hours off between shifts following prolonged tours of duty does not give train operators the opportunity to receive adequate sleep to be fully alert and to operate safely.

10. Emergency access/egress points for the Washington Metropolitan Area Transit Authority's equipment do not provide adequate means for emergency responder entry or passenger evacuation.

11. The failure of the carbody (underframe) end structure of the 1000-series Metrorail cars may make them susceptible to telescoping and potentially subject to a catastrophic compromise of the occupant survival space.

12. The failure to have minimum crashworthiness standards for preventing telescoping of rail transit cars in collisions places an unnecessary risk on passengers and crew.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the November 3, 2004, collision between two Washington Metropolitan Area Transit Authority trains at the Woodley Park-Zoo/Adams Morgan station was the failure of the operator of train 703 to apply the brakes to stop the train, likely due to his reduced alertness. Contributing to the accident was the lack of a rollback protection feature to stop the train when operated in the manual mode.

Recommendations

As a result of its investigation of the November 3, 2004, collision between two Washington Metropolitan Area Transit Authority trains at the Woodley Park-Zoo/Adams Morgan station, the National Transportation Safety Board makes the following safety recommendations:

New Recommendations

To the Washington Metropolitan Area Transit Authority:

Equip, as soon as possible, all existing and future train equipment with rollback protection for trains operated in the manual mode. (R-06-1)

Either accelerate retirement of Rohr-built railcars, or if those railcars are not retired but instead rehabilitated, then the Rohr-built passenger railcars should incorporate a retrofit of crashworthiness collision protection that is comparable to the 6000-series railcars. (R-06-2)

To the Federal Transit Administration:

Require transit agencies, through the system safety program and hazard management process if necessary, to ensure that the time off between daily tours of duty, including regular and overtime assignments, allows train operators to obtain at least 8 hours of uninterrupted sleep. (R-06-3)

Assess the adequacy of the Washington Metropolitan Area Transit Authority's current organizational structure and ensure that it effectively identifies and addresses safety issues. (R-06-4)

Develop transit railcar design standards to provide adequate means for safe and rapid emergency responder entry and passenger evacuation.
(R-06-5)

Develop minimum crashworthiness standards to prevent the telescoping of transit railcars in collisions and establish a timetable for removing equipment that cannot be modified to meet the new standards. (R-06-6)

Recommendation Reclassified in This Report

To the Washington Metropolitan Area Transit Authority:

R-04-9

Immediately revise the directions to train operators contained in your memorandums of November 7 and 9, 2004, to include specific written instructions for identifying and responding to an emergency rollback situation, and provide training to operators on the procedures to follow if such a rollback event occurs. (Urgent)

Urgent Safety Recommendation R-04-9, previously classified "Open—Acceptable Response," is reclassified "Open—Unacceptable Response" in the "Rollback Protection" section of this report.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

MARK V. ROSENKER
Acting Chairman

DEBORAH A. P. HERSMAN
Member

ELLEN ENGLEMAN CONNERS
Member

KATHRYN O'LEARY HIGGINS
Member

Adopted: March 23, 2006

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Appendix A

Investigation

The National Transportation Safety Board was notified of the collision between two Washington Area Metropolitan Transit Authority trains about 2:18 p.m., eastern standard time, on November 3, 2004. An investigative team was dispatched with members from the Safety Board's Washington, D.C., headquarters and its Los Angeles, California, regional office. The team included Member Deborah A. P. Hersman and investigative groups for transit operations, track, and oversight; mechanical; human performance; survival factors and emergency response; event recorders; and crashworthiness. The Office of Public Affairs assisted with the on-scene public/media relations.

Parties to the on-scene investigation included the Washington Area Metropolitan Transit Authority, the District of Columbia Fire Department, and the Tri-State Oversight Committee.

Appendix B

Composition of Metrorail Passenger Railcar Fleet

The composition of the Metrorail passenger railcar fleet is provided below. This information was received from the Washington Metropolitan Area Transportation Authority's Office of Rail Systems Engineering on December 7, 2004.

Railcar Manufacturer	Assigned Car Numbers	Production Dates	Event Recorder Equipped	Car Count		Notes
				Original	Current	
Rohr	1000-1299 8000-8003	1974 - 1978	NO	300	292 4	4 damaged (retired from service): 1028/29, 1076/77. Mid-life rehabilitation completed on all cars mid-1990s. Revenue collection cars: (formerly 1010/11, 1044/45).
Breda	2000-2075	1983	YES*	76	76	Mid-life rehabilitation completed December 2004.
Breda	3000-3291	1984 - 1988	YES*	290	288	2 damaged (retired from service): 3191, 3252. Cars 3190 and 3253 married as: 3290/91. Mid-life rehabilitation of this Series in process; scheduled completion October 2005.
Breda	4000-4099	1992 - 1994	NO	100	100	
CAF	5000-5191	2001 - 2004	YES	192	192	
ALSTOM	6000-6183	2005 - 2007	YES	0	0	This series (184 railcars) currently in production; anticipated delivery (to commence) August 2005.
Total				958	952	Current count includes 4 revenue collection cars

* The 2000- and 3000-series cars will be equipped with the Vehicle Monitoring System (VMS) during rehabilitation and they will have the same type recorder as the 5000- and 6000-series cars. Each married pair unit will be equipped with a VMS. Power supply and sensor components will be distributed between the married pair, with the central unit located in the A car of each pair.

Appendix C

Summary of Events

The following is a summary of events derived from the Washington Metropolitan Area Transit Authority Train Data Analysis Report.

Time	Train Number	Event
12:45:22	#203	Entered track circuit A2-162 approaching the Cleveland Park station track circuit, A2-165.
12:45:28	#203	Entered track circuit A2-165.
	#703	Entered track circuit A2-124 (moving at 34.1 mph), A2-124 was about 3,827 feet from the beginning of track circuit A2-165.
12:46:06	#703	Maintained a speed of 24.1 mph as it traveled through the underground Woodley Park station, leaving the track circuit A2-128 moving in the direction of the Cleveland Park station.
12:46:23	#703	Would have received a 45 mph ATP regulated speed authority when it entered track circuit A2-146.
12:46:38	#203	Left track circuit A2-165
	#703	Transiting circuit A2-146, about 1,097 feet from the beginning of track circuit A2-165.
12:46:41	#703	Would have received a 50 mph ATP regulated speed authority when it entered track circuit A2-154.
12:46:47	#703	Is in track circuit A2-157. According to WMATA, "…receive(d) reduced 28 mph ATP speed with Train 203 occupying A2-171 circuit."
	#203	Still occupying track circuit A2-171.
12:46:51	#203	Left track circuit A2-271.
	#703	Would have received a 55 mph ATP regulated speed authority.
12:47:02	#703	Exiting track circuit A2-154 at a speed of 31.9 mph (head end) and at a speed of 19.2 mph (rear end).
12:47:03	#703	Entered track circuit A2-162 and would have received a 50 mph ATP regulated speed authority.
12:47:33	#105	Entered A2-128 at Woodley Park station.
	#703	Recorded as leaving track circuit A2-162 moving in the reverse direction (negative speed recorded).
12:46:47	#703	Rear of train entered track circuit A2-157 at a speed of 7 mph.
12:47:35	#703	Speed had increased to 16 mph entering track circuit A2-154.
12:47:47	#703	Speed had increased to 26 mph entering track circuit A2-146.
12:48:08	#703	Speed had increased to 29 mph entering track circuit A2- 140;
12:48:23	#703	Speed had increased to 32 mph entering track circuit A2-134.
	#105	Train stopped at Woodley Park station.
12:48:32	#703	The data recorded the trailing end of train as it exited track circuit A2-140 as 36 mph.
12:48:38		Electrical DC Feeder Tie Breakers tripped at time of collision.