Traction Power Electrification System Investigation

Washington Metropolitan Area Transit Authority (WMATA)

FINAL REPORT

Federal Transit Administration
U.S. Department of Transportation
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Acronyms

AC	Alternating Current
APTA	American Public Transportation Association
ATC	Automatic Train Control
CAP	Corrective Action Plan
CENI	Chief Engineer, Infrastructure
CENV	Rail Car Engineering
CM	Corrective Maintenance
CPDO	Capital Program Department Office
DC	Direct Current
DOT	Department of Transportation
EMI	Engineering Modification Instruction
ETS	Emergency Trip Station
IRCM	Infrastructure Renewal Construction Management
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FWSO	FTA WMATA Safety Oversight
HVAC	Heating, Ventilation and Air Conditioning
LSNH	Low Smoke No Halogen (cable specification)
MCM	Cable gauge measurement; an abbreviation for thousands of circular mils, where a mil is 1/1000 inch
MOC	Maintenance Operations Center
MNR	Metro North Railroad
MSRPH	Metrorail Safety Rules and Procedures Handbook
MW	Megawatt
NTSB	National Transportation Safety Board
OAP	Operations Administrative Procedure
OEM	Office of Emergency Management
QAAW	Office of Quality Assurance and Warranty
PM	Preventive Maintenance
PMI	Preventive Maintenance Inspection
PWRS	Power Engineering Services, Office of the Chief Engineer, Infrastructure
QICO	Department of Quality and Internal Compliance Operations
ROCC	Rail Operations Control Center
RWIC	Roadway Worker In-Charge
RWP	Roadway Worker Protection
SAFE	Department of Safety and Environmental Management
SCADA	Supervisory Control and Data Acquisition
SMI	Safety Management Inspection
SOP	Standard Operating Procedure
SSOA	State Safety Oversight Agency
TBS	Tie Breaker Station
TGV	Track Geometry Vehicle
TOC	Tri- State Oversight Committee
TPE	Traction Power Electrification

TRPM	Traction Power Maintenance
TRST	Office of Track and Structures
TSFA	Track, Structures and Facilities, Office of Chief Engineer, Infrastructure
WMATA	Washington Metropolitan Area Transit Authority

1.0 Executive Summary

This report documents 22 findings and 47 required actions resulting from an investigation conducted by the Federal Transit Administration (FTA) into the condition and safety performance of the traction power electrification (TPE) system utilized by the Washington Metropolitan Area Transit Authority (WMATA) Metrorail system. These requirements will be formally issued to WMATA through FTA Special Directive 17-1.

Over the last year, WMATA has experienced a sharp increase in the number of TPE system-related failures and incidents. Since the FTA assumed temporary safety oversight of the Metrorail system on October 26, 2015, WMATA has reported 70 safety events resulting from electrical arcing in the TPE system at insulators, cables, connector assemblies, and track fastening components. Each of these 70 events required emergency response, and some of these events resulted in the partial or full shutdown of a station or the evacuation or off-loading of a passenger train. The FTA WMATA Safety Oversight (FWSO) Office initiated this investigation to ensure sufficient corrective action for these events, and also to address concerns raised during prior FWSO inspections, which highlighted the deteriorated condition of WMATA's traction power infrastructure.

This FWSO investigation focused on four categories of safety critical concerns:

- Category 1: TPE System Roles, Responsibilities, and Resources;
- Category 2: TPE Infrastructure;
- Category 3: Testing and Inspection Programs; and
- Category 4: Capital Projects.

FWSO's investigation confirmed that the safety performance of WMATA's TPE system has deteriorated with age, deferred maintenance, and increased exposure to water and moisture with contaminating materials. FWSO's investigation also found that key components designed to provide insulation resistance for both the traction power positive and negative return systems have been compromised and are no longer performing as originally specified.

FWSO also found that while WMATA has taken many positive steps to create a new traction power maintenance department and establish a new cable inspection program, the agency still does not have sufficient personnel resources to complete required preventive and corrective maintenance on the TPE system. Recruitment and training of TPE system electrical mechanics lags behind need, and corrective maintenance work orders are backlogged for both high voltage equipment and cable plant. New demands for managing power outages for SafeTrack and other maintenance activities further strain WMATA's TPE system resources.

A recurrent factor/element in many of the arcing/fire events experienced by WMATA over the last year is the presence of mud and standing water, leading to arcing, which is often the result of debris and clogged drains restricting the free flow of water entering the system. In numerous inspections and investigations regarding WMATA's track conditions, FWSO has found that track and tunnel drainage defects have not been adequately identified and prioritized for repair, allowing cables and connectors laying on or near the track bed to become encased in mud, water,

and other contaminants. WMATA is working to address several FTA findings and required actions regarding this situation.

FWSO's investigation also found that the use of temporary cable connectors on the running rails, combined with the poor quality installation of insulators and track fasteners in some locations and the generally poor condition of the insulating materials in some floating slab tunnel sections, introduces the potential for issues with the control of negative return power and stray current corrosion, increasing the likelihood of electrical arcing and flashovers.

Budget limitations and changing maintenance priorities have also influenced the condition and performance of the TPE system. In recent years, in response to changing budgetary and staffing conditions, WMATA eliminated preventive maintenance programs to test traction power feeder cables for cable insulation integrity and to predict failures. Cleaning programs in tunnels were eliminated or cut back to the point that they failed to keep pace with the buildup of metallic dust and particles generated by normal train operation. WMATA's corrosion control testing program was largely limited to interlockings and special requests, with very limited testing of rail and third rail fastening systems and components.

FWSO also confirmed that programs to replace and upgrade critical TPE infrastructure, including tiebreakers and cable plant, have not been sufficient for the age of the system or the demand placed on it. While approximately 80 percent of primary positive feeder cables have been replaced on the Metrorail system in the last 15 years, most secondary cables, which connect the primary cables to the contact rail or traction power substations or bridge engineered gaps in the contact rail system, are original with the Metrorail system. The age and degraded condition of this secondary cabling system now presents a potential point of failure for sustained electrical arcing events and fires.

Further, FWSO found that previous power assessments, conducted by WMATA to support engineering studies to determine power requirements for 100 percent 8-car train operation, do not accurately reflect the deteriorated condition and performance of WMATA's cable plant. Incomplete information regarding the condition and performance of the aging TPE infrastructure used in these assessments indicates that additional upgrades and cable replacement will be required to adequately and safely power 100 percent 8-car train operation.

Since FWSO assumed temporary safety oversight of Metrorail, WMATA has taken a number of critical steps to address deficiencies within its TPE system. In response to NTSB Safety Recommendation R-15-25, WMATA initiated and has almost completed a program to ensure that its power cable connector assemblies are properly constructed and installed, including the weather tight seals that prevent intrusion by contaminants and moisture. WMATA has enhanced its visual and thermal inspection program for its TPE cable plant, including jumper and transition cables. WMATA has also begun eliminating third rail expansion joints in tunnels and has developed new work instructions to ensure that electrical cables are correctly installed, secured off the ground, and appropriately bolted to the contact rail. WMATA recently reinstated its tunnel cleaning program and insulator cleaning program in specific locations. WMATA is also expanding its cable replacement program and re-starting plans to upgrade both its positive and negative electrical return system to manage 100 percent 8-car train operation. WMATA is testing

new insulators that can be removed for cleaning and then re-installed. To better address challenges with TPE system state of repair, WMATA is also reviewing roles and responsibilities for inspecting, testing, and maintaining its TPE system elements and just created a new department with exclusive responsibility for high voltage TPE system maintenance.

Finally, on May 11, 2016, FTA issued an immediate action letter, which directed WMATA to complete repairs to TPE system components on the Red Line between Medical Center and Van Ness and on the Blue/Orange/Silver Line between Potomac Avenue and the D&G junction.[1] As a result of WMATA's maintenance activity in these locations, the number of arcing events has reduced. For example, on the Red Line, WMATA experienced 18 arcing incidents in this area between March 1 and June 14, 2016, including 4 major events at the end of April and early May. Since June 15, 2016, WMATA has only experienced 8 relatively minor events in this area.

In June 2016, as part of its on-going oversight of WMATA's accident investigation program, the FTA accepted a request from WMATA's Department of Safety and Environmental Management (SAFE) to conduct a special investigation of the agency's TPE system failures. WMATA proposed this approach to resolve 58 open accident investigations, all related to electrical arcing in the TPE system, on file with the FTA dating back to the beginning of the year. To complete its investigation, WMATA SAFE used a multi-disciplinary task force comprised of WMATA personnel supplemented by an American Public Transportation Association (APTA) peer review and engineering, organizational, and staffing assessments completed by the HNTB Corporation.

The FTA recognizes WMATA's clear progress in completing this investigation, which reviews systemic issues regarding the inspection, maintenance, and performance of the TPE system and provides greater transparency for the public and WMATA's employees regarding how the agency is evaluating and managing these events. WMATA's investigation also addressed many of the issues and concerns discussed between FTA and WMATA over the last year and jointly investigated in the field. WMATA SAFE delivered its draft report to FWSO on October 19, 2016. The findings and recommendations set forth in the WMATA report generally are consistent with the findings and required actions set forth in FWSO's report, and to the extent feasible, FWSO has incorporated the 32 recommendations from the draft WMATA report into the findings and required actions issued through Special Directive 17-1. FTA will formally review and approve WMATA's draft investigation report in the near future.

As directed by Special Directive 17-1, WMATA must develop corrective action plans to address 22 findings of this report and the 47 required actions. WMATA TPE system staff, engineers, specialists, and contractors have also identified many of these required actions as critical to strengthening the safety performance of the TPE system. FWSO will review, provide feedback on, request changes as appropriate, and approve WMATA's corrective action plans and will monitor and work with WMATA to oversee their completion.

[1] Please see: https://www.transit.dot.gov/regulations-and-guidance/safety/fta-letter-wmata-urgent-repairs-required-prior-start-wmata-safe.

2.0 Introduction

This report documents findings and required actions resulting from an investigation conducted by the Federal Transit Administration (FTA) into the condition and safety performance of the Washington Metropolitan Area Transit Authority (WMATA) traction power electrification (TPE) system. The TPE system, used to power WMATA's electric trains, is a potential source for fire and smoke events, explosions, electrocution, and stray current that can corrode track and wayside equipment.

The FTA considers the inspection, testing, and maintenance of the TPE system a major safety priority for WMATA and for all heavy rail public transportation systems nationwide and appreciates that WMATA is not alone among its peers in managing the safety consequences of aging TPE systems with deferred maintenance. In May 2016, the FTA issued *Safety Advisory 16-2* to request information from State Safety Oversight Agencies (SSOAs) and Rail Fixed Guideway Public Transportation Systems (RFGPTS) nationwide regarding the design, condition, and safety performance of contact rail TPE systems.[2] FTA is currently reviewing these submittals to support potential further action. In this Advisory, the FTA also encourages SSOAs to increase their oversight focus on contact rail TPE systems. In addition, the FTA is working with the SSOAs and the rail transit industry to address NTSB Safety Recommendations to issue regulatory standards for tunnel infrastructure inspection, maintenance, and repair (R-16-01) and to issue regulatory safety standards for emergency egress in tunnel environments (R-16-02).

This report, when taken with others issued by the FTA, continues to highlight the impact on Metrorail of years of deferred maintenance. Deferred maintenance leads to deteriorating infrastructure, and at the time the FTA took over temporary safety oversight of the Metrorail system, this had put Metrorail on a path that could have led to unsafe operations. As part of its temporary oversight responsibilities, FTA has directed WMATA to take the necessary steps to begin reversing this decline, and WMATA is demonstrating considerable effort toward returning the system, eventually, to a state of good repair. It is important to note that FTA's reports do not amount to a finding that the Metrorail system is unsafe. In each investigation and report, and with each step taken, the FTA has assessed the risk associated with the flaws found in the Metrorail system and determined that those risks are not so great that they place passengers and workers at substantial risk of death or injury. FTA, therefore, has allowed Metrorail to continue in operation while WMATA takes the actions required by FTA.

2.1 Purpose

The FTA WMATA Safety Oversight (FWSO) Office initiated this investigation in response to a rising number of smoke and fire events originating from electrical arcing in WMATA's TPE system. Since a major cable fire at McPherson Square Station on March 14, 2016, WMATA has experienced 58 electrical arcing events that resulted in smoke and/or fire and required emergency response, and 70 total events since FTA assumed temporary oversight authority on October 26,

[2] Please see: https://www.transit.dot.gov/regulations-and-guidance/safety/fta-safety-advisory-16-2-third-rail-data-collection

2015. This rate of occurrence is more than double the average number of electrical arcing events experienced at WMATA between 2012 and 2015 (approximately 2 per month).

FWSO's investigation examines underlying causes and contributing factors affecting the safety performance of the TPE system, focusing on four major areas:

- TPE System Roles, Responsibilities, and Resources: The roles and responsibilities assigned across WMATA departments to manage and maintain the TPE system, and the resources available to carry out these activities;
- TPE Infrastructure: Performance issues and potential safety concerns associated with individual components of WMATA's TPE infrastructure;
- Testing and Inspection Programs: The effectiveness of inspection and testing programs to monitor the condition of the TPE system; and
- Capital Projects: The status of capital projects underway to upgrade the TPE system to manage WMATA's procurement of the 8-car, 7000-series trains manufactured by Kawasaki.

2.2 Major Activities

FWSO conducted this TPE system investigation between March 23 and October 24, 2016. This investigation stemmed from FTA's track integrity investigation, which took place between March 21 and July 30, 2016.[3] Given the complexity of WMATA's TPE system, the unique failure modes observed by FWSO's team, and the number of on-going activities at WMATA–including WMATA's own extensive internal investigation and a formal peer review conducted by the American Public Transportation Association (APTA)–FWSO determined in July 2016 that a separate investigation would be completed for TPE issues and concerns.

FWSO's investigation addressed:

- WMATA's staffing for TPE system inspection, testing, and maintenance functions;
- WMATA's procedures and practices for inspecting and maintaining high voltage equipment and TPE system elements;
- The integrity of the contact rail system, including third rail fastening systems (insulators, grout pads, anchor systems), third rail joints, WMATA's new joint elimination program, and third rail gauging;
- The condition of the wayside cable system (mounting/fastening, cable type, termination, testing, and replacement);
- The status of upgrades to meet the enhanced power requirements for operation of WMATA's new 8-car trains (substation upgrades, cable and tie breaker station replacement and upgrade, and negative return systems);
- The effectiveness of the circuit breaker settings used by WMATA to identify and manage low-level faults in direct current traction power circuit breakers;

[3] Please see: https://cms.fta.dot.gov/regulations-and-guidance/safety/fta-final-report-track-integrity-investigation-washington.

- The effectiveness of WMATA's corrosion control and stray current testing program;
- The quality of information provided by WMATA's track geometry vehicle (TGV) and thermal image testing program; and
- The training and effectiveness of the Rail Operations Control Center (ROCC) and Maintenance Operations Center (MOC) in managing TPE requirements and events.

The FWSO team possesses multidisciplinary expertise in electrical engineering, traction power systems for contact rail, rectifier substations, power load simulations and studies, electrical interfaces with rolling stock, maintenance practices, and capital improvement programs for system upgrades. To gather information, FWSO held a series of technical meetings with Metrorail's systems maintenance and capital engineering personnel to review the agency's inspection, testing, maintenance, and capital improvement programs. The FWSO team also participated in a technical conference on April 5, 2016 with WMATA technical leadership to review and discuss the following:

- March 16, 2016 shutdown/inspection report;
- WMATA TPE system design standards;
- WMATA's new cable inspection checklist, procedures and teams;
- Capital management improvement replacement program for cables, traction power; substations, and circuit breaker houses;
- New fleet upgrade and impact to TPE system;
- Corrosion control program;
- Thermal imaging program;
- TPE maintenance programs; and
- TPE testing programs.

This investigation included a review of standards, engineering (field) modification instructions, and a review of draft procedures and training material for WMATA's newly developed inspection and training program for inspecting traction power cables. FWSO also reviewed WMATA's new cable inspection, repair, and training program and observed several locations where cables had been removed from the ground and secured using new work instructions issued by WMATA's Chief Engineer, Infrastructure (CENI).

The FWSO team also reviewed WMATA reports from previous incidents and photos of interim repairs to cable supports. FWSO also followed-up on actions taken since WMATA suspended system operations on March 16, 2016 to conduct an inspection of its visible cable plant and to correct high priority cable defects. FWSO inspected all 27 locations where high priority repairs were made during the March 2016 shutdown and conducted spot observations of approximately 450 locations identified with cables laying in water or mud, damaged cables or connector assemblies, and poor or broken connections. Throughout the inspection period, FWSO continued to respond to arcing events at WMATA and to collect and review technical and operational information related to these incidents.

FWSO's team also conducted a series of inspections on the Metrorail system to assess WMATA's cable inspection and repair program and provide recommendations for

improvements. For example, the FWSO technical team strongly recommended that WMATA consider reviewing the engineering requirements for third rail expansion joints in the tunnel environment, and/or consider alternate methods for installation of expansion joint cables to minimize exposure to physical damage.

FWSO's wayside inspections were accomplished over a several month period that culminated with an observation of WMATA's new traction power cable inspection team on October 12, 2016 between Metro Center and Dupont Stations. In addition to inspecting traction power facilities, the FWSO team also observed and noted other potential contributing factors to cable and insulator failure. These observations included contamination from water, mud, deleterious debris, support structure corrosion, and proximity of electrical facilities to metallic structures. These inspections, along with the contents in this report, provide WMATA with detailed information necessary to implement actions to rehabilitate the traction power infrastructure to mitigate and minimize the power related incidents that have adversely impacted the Metrorail system.

The results of an assessment that WMATA conducted with APTA in July and August 2016, and the WMATA SAFE internal investigation completed this October, reinforce the findings of this report. FTA and WMATA also conducted several meetings to review the factual content of this report and to discuss options available for additional TPE system corrective action within WMATA's existing budget and maintenance programs. Results from additional FTA inspections conducted at various SafeTrack locations since June 4, 2016 and findings from the Tri-State Oversight Committee's (TOC) three-year review on traction power substation maintenance and training have also been incorporated into this investigation.

Finally, as part of its investigation, FWSO evaluated the final report released by the National Transportation Safety Board (NTSB) documenting the results of that agency's investigation into the January 12, 2015 smoke and fire event at L'Enfant Plaza station. The NTSB's investigation identified systemic deficiencies in the inspection, maintenance, and repair of WMATA's TPE system and resulted in several safety recommendations, which are being implemented by WMATA, and monitored by the FTA and the NTSB. The NTSB also issued safety recommendations to the FTA, which are underway. The final investigation report is available online, and the safety recommendations issued to WMATA and FTA are discussed in Chapter 4 of this report.[4]

2.3 Electrical Arcing

Electrical arcing can range from a single spark to a continuous flow of electricity that generates an extreme amount of heat and ignites fires on the track bed and on rail transit vehicles. Intermittent electrical arcing, in the form of sparking, occurs on all TPE systems with contact rail. Trains create an arcing dynamic at certain locations where there may be a gap in connection between the train's current collection assembly and the contact rail.

[4] Please see: http://www.ntsb.gov/investigations/AccidentReports/Reports/RAR1601.pdf.

Extended electrical arcing, however, is less common. Extended electrical arcing occurs when high voltage current leaks from a positive traction power cable and flows along a surface contaminated with carbon dust, rust particles, dirt, and grime, eventually finding a path to ground. This leakage current is no longer isolated from track components, debris, and cables. A continuous electrical arc can then form between the loose current and another conducting surface, igniting surface contamination on cables, insulators, tunnel walls and floors, and in cable connector assemblies.

Electrical arcing can burn cables and track components, cause flashovers and explosions, damage railcar components, and ignite fires to debris located in track beds that can be accelerated by petroleum product contamination or other inflammable debris. The smoke from these events, especially in the tunnel environment, may also expose passengers, employees and emergency responders to potentially toxic fumes. Extended electrical arcing at locations, such as insulators, rail fasteners, and cable joints, which are insulated to protect against short circuits and electrical leakage typically indicates a significant failure of isolation or insulation resistance. These incidents bring increasing safety concerns and a greater risk to passenger safety.

2.4 Electrical Arcing Events at WMATA

Since FTA began this investigation in March 2016, WMATA has experienced 58 electrical arcing events that resulted in smoke and/or fire and required emergency response; 70 total such events have occurred since FTA assumed temporary oversight authority on October 26, 2015.

Figure 1 depicts the location of each of the 70 electrical arcing incidents in the TPE system reported by WMATA between October 26, 2015 through October 21, 2016. Appendix C lists these events by date and location.

The majority of these events occurred on the Red Line, on both tracks, between White Flint and Farragut North Stations, with the highest concentration occurring between Medical Center and Van Ness Stations. Dupont Circle, Rosslyn, Metro Center, and Federal Center SW Stations have also experienced multiple electrical arcing events.

During the course of this investigation, the FTA issued Safety Directive 16-3 to WMATA on May 7, 2016. This Safety Directive outlined specific actions to mitigate smoke and fire events related to the TPE system in the wake of a series of 8 electrical arcing events over the span of 12 days.[5] Figure 2 depicts one of these events, a flashover that occurred at Federal Center SW Station on May 5, 2016.

[5] Please see: https://www.transit.dot.gov/regulations-and-guidance/safety/fta-safety-directive-16-3.

Figure 1: Electrical Arcing Events with Smoke/Fire between October 26, 2015 and October 21, 2016

Figure 2: Electrical Arcing Event at Federal Center SW Station on May 5, 2016

On May 11, 2016, FTA issued a follow-up letter, which directed WMATA to complete repairs to TPE system components on the Red Line between Medical Center and Van Ness and on the Blue/Orange/Silver Line between Potomac Avenue and the D&G junction.[6] In support of this activity, FWSO conducts on-going inspections of this track to assess conditions and progress, and FWSO's reports are available online.[7]

Through the month of May, using partial and full shutdowns, WMATA completed substantial work identified by FTA on Track 2 of the Red Line segment to replace insulators, eliminate third rail joints, secure power cables off of the ground, and improve drainage. WMATA also prioritized its work on the Blue/Orange/Silver Line between Potomac Avenue and the D&G junction as SafeTrack Surge #2.

WMATA was not able to complete work on the Red Line before the initiation of its SafeTrack program on June 4, 2016, but under an agreement with FTA, the agency continues to improve track and traction power conditions in this area through early work outages and weekend shutdowns. WMATA is expected to complete rehabilitation of this area for both tracks by the end of February 2017. WMATA also has deployed a crew of 12 track maintainers to focus on drainage and water issues reported by inspectors along this section of the Red Line. These maintainers predominantly work during early evening service hours and when the system is closed overnight and can also be deployed on an emergency basis as part of a single tracking or shut down on this section of the Red Line.

[6] Please see: https://www.transit.dot.gov/regulations-and-guidance/safety/fta-letter-wmata-urgent-repairs-required-prior-start-wmata-safe.
[7] Please see: https://www.transit.dot.gov/regulations-and-guidance/safety/fta-wmata-metrorail-safety-oversight-monthly-inspection-reports.

As a result of WMATA's increased maintenance activity on the Red Line, the number of arcing events in this area has reduced:

- WMATA experienced 18 arcing incidents in this area between March 1 and June 14, 2016, including four major events at the end of April and early May.
- Since June 15, 2016, WMATA has only experienced 8 relatively minor events in this area as shown in Figure 3 below.

Arcing Event Identification	Date	Location
E16159	6/16/16	Friendship Heights
E16180	6/28/16	Medical Center
E16188	7/8/16	Bethesda
E16216	8/1/16	Van Ness Station
E16220	8/2/16	Medical Center Station
E16259	8/15/16	Medical Center
E16430	10/8/16	Between Tenleytown and Friendship Heights
E16467	10/18/16	Medical Center

Figure 3: Arcing Events on Metro Center and Van Ness Station between June 15, 2016 and October 21, 2016

3.0 TPE System Inspection, Testing, and Maintenance at WMATA

This section of the investigation report provides background regarding TPE system components and the organization, process, and procedures used at WMATA to inspect, test, and maintain the TPE system and to conduct capital projects to upgrade and replace degraded equipment and infrastructure.

3.1 TPE System Components

WMATA's TPE system converts electric power from the Alternating Current (AC) provided by the electrical company for public utility use to the voltage, Direct Current (DC), and frequency required for operating WMATA's trains. To perform this function, WMATA's TPE system uses rectifier substations, tiebreaker stations, contact rail, an extensive cable plant, and a negative power return system managed via impedance bonds and track running rails. By diagramming WMATA's new Silver Line track bed, Figure 4 illustrates the location of some of the most common TPE system and track components, including:

1. Running Rails;
2. Ballast;
3. Crossties;
4. Rail Fasteners;
5. Impedance Bond and Cables;
6. Insulated Joint;
7. Contact Rail Heater Box;
8. Insulators;
9. Contact Rail (also called third rail);
10. Cover Board;
11. Stub-Up Conduit;
12. Cable Connector Assemblies (also called orange boots or hair dryers);
13. Pigtail Cables; and
14. Power Supply Cables.

The contact rail, also known as the third rail, is located outside the running rails and supported by ceramic, composite fiberglass or porcelain insulators installed on plinths (tunnel) and concrete or wood crossties (outside the tunnel). A fiberglass protection cover board is suspended over the top of the third rail to protect workers and others on the right-of-way from accidental contact. Current collection shoes, which are mounted on WMATA's railcars, ride on the top of the contact rail, transferring the DC voltage to the train. Figure 5 depicts a current collection shoe used by WMATA's trains for current collection to the entire train, including the traction power motors. The shoe, circled in red, fits under the cover board and sits on top of the contact rail, applying approximately 17 to 22 pounds of pressure to the contact rail to draw current.

Figure 4: TPE System Components

Figure 5: Current Collector Shoe

WMATA's TPE system is fed from traction power substations (TPSS) located approximately every mile with tiebreaker stations between each substation. The tiebreaker stations located throughout the system provide electrical continuity and load sharing between sections of third rail. The tiebreaker stations also permit third rail power to be isolated in defined areas to allow for maintenance or emergency response activities. Figure 6 shows a typical TPSS.

Figure 6: WMATA TPSS

Throughout the rail system, third rail gaps exist to support interlockings, safe access to enclosures, and means of egress as well as to facilitate wayside equipment placement. Jumper cables maintain electrical continuity across these gaps, ensuring that the third rail remains energized on both sides of the gap. There are approximately 660 locations with jumper cables in the tunnels system-wide. Generally, each jumper location has four cables. Jumper locations typically include crossovers, transitions, and gaps in the contact rail. Figure 7 shows an expansion joint in the third rail, which creates a gap that must be bridged by jumper cables.

Figure 7: Third Rail Expansion Joint and Jumper Cables

WMATA has 207 traction power facilities (substations and tiebreaker stations) with thousands of circuit breakers and hundreds of transformers, rectifiers, and protective relay devices. WMATA also has over 2 million feet of positive traction power feeder cable and almost 1.5 million feet of negative return cable.

Conduit stub-ups also bring positive traction power feeder cables from the substation to locations near the contact rail. Power supply cables, cable connector assemblies, and pigtail cables then bring the power from the stub-up to the contact rail.

Figure 8, from the construction of the Silver Line, shows the cable plant underneath and connected to the track bed.

The design of WMATA's TPE system is fully coordinated with the signal system. WMATA's TPE system uses the running rails as an electrical conductor to "return" the traction power to the substation from which it originated. Since the track circuits in WMATA's signal system must be broken into relatively short blocks, insulated joints are used in the running rails to separate signal blocks from each other. These signal blocks are used to detect trains and control safe train movement.

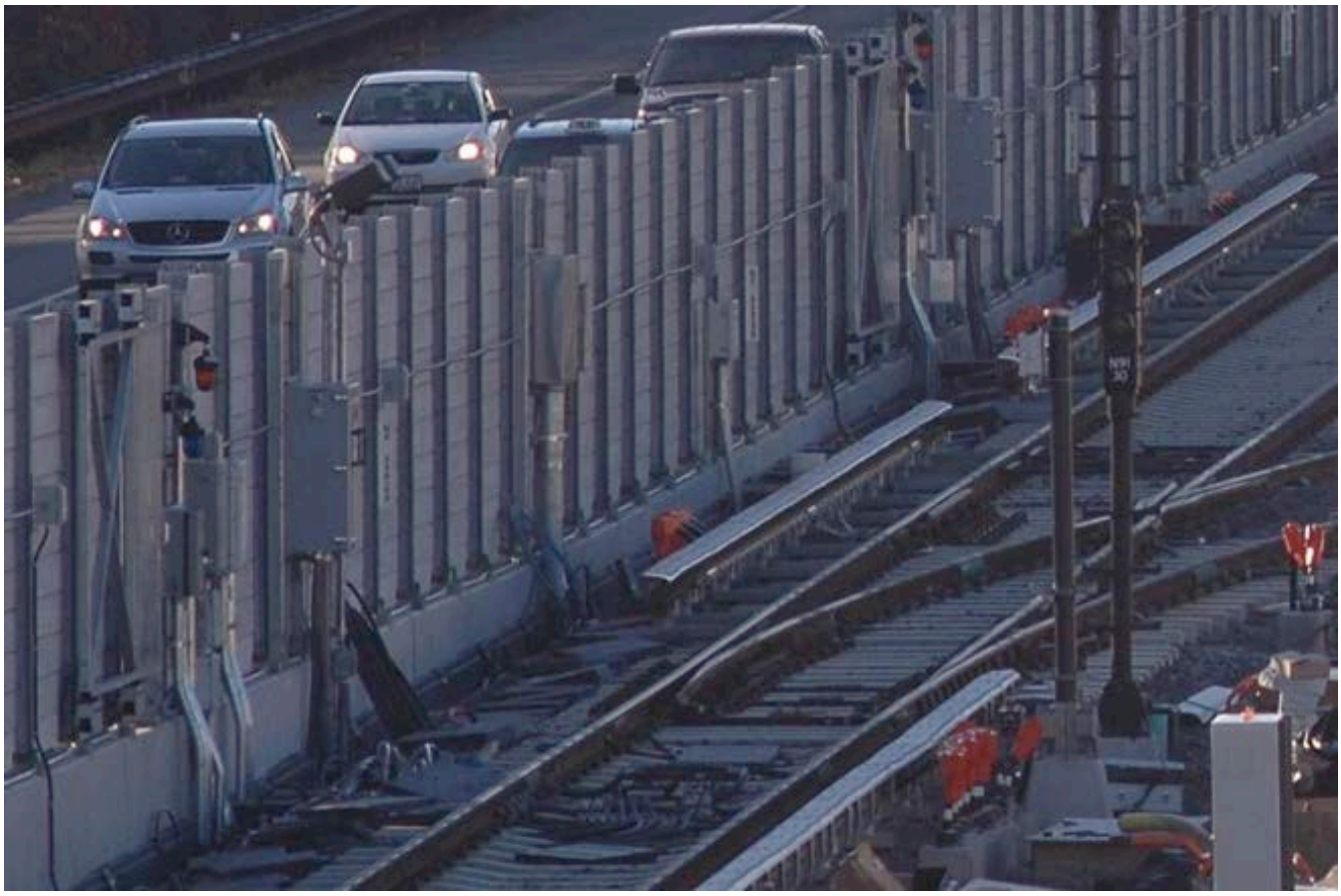

Figure 8: Cable Plant Visible during Silver Line Construction

This design initially creates a conflict because the insulated joints in the running rail block the return current from reaching the substation. To address this situation, WMATA places an impedance bond across the insulated joints of the track to stop the higher frequency signal track circuit from passing through, while allowing the traction return circuit to pass through at a lower impedance on its way back to the substation. Often designed so that it can be connected to a return conductor at substations or cross bonds, the impedance bond also supports the running rails in providing the traction power return circuit.

Traction power supplied to the train enters the train from the third rail through the collector shoe and returns to the substation via the train wheels to the running rail through impedance bonds and cables installed at each substation. Impedance cross bonds in the track bed equalize the traction return currents in the rails providing parallel paths for the return current. At these locations, conduit stub-ups and cables will be installed beneath the tracks connecting the two parallel tracks. Impedance bonds are also required by the signal system at the end of each signal block.

WMATA's Advanced Information Management (AIM) system is a supervisory control and data acquisition system used for its rail operations. The AIM system monitors, sends, and receives data and controls the wayside equipment, such as signals, power, smoke detectors, intrusion, and

other systems, from the ROCC. The data is used to create graphic displays on ROCC controller screens that provide control operators with the information they need to manage traffic flow around the rail system and recognize and respond to one-time events such as power isolation associated with equipment failures.

The design of WMATA's TPE system provides operational flexibility to isolate third rail sections at stations and interlockings for planned and emergency track outages. Emergency Trip Stations (ETS), located every 800 feet, provide emergency de-energization of the related third rail segment and emergency telephone service for contacting the ROCC.

3.2 TPE System Enhancements

WMATA's original TPE system, installed in the mid-1970s for the system's oldest track and expanded through the 1980s, was designed to power approximately 124, 6-car trains moving throughout the system at maximum service. WMATA has ordered 748 of the new 7000-series railcars, enough to replace all 1000-, 4000- and 5000-series cars and expand the size of the Metro fleet by 128 cars. WMATA is now receiving as many as 16 new 7000-series vehicles manufactured by Kawasaki each month, and the full order is expected to be delivered over the next four years. These railcars are designed to run optimally as an 8-car train.

To prepare for the transition to 7000-series trains, WMATA commissioned computer simulated load studies for the traction power system. Beginning in 2004, WMATA initiated infrastructure upgrades to include substation rectifier upgrades and additions, tiebreaker station upgrades, and positive cable replacement at substations and tiebreakers.

WMATA further included relay protection upgrades, third rail upgrades to composite (aluminum clad- 84C rail), and upgrades to automatic train control (ATC) signal impedance bonds and cable terminations to running rail in support of the expansion. WMATA also upgraded cables (both in quantity and size) at substations and tiebreaker stations and initiated impedance bond upgrades to high current substation return bonds for increased return capacity and replacement of associated switchgear.

The planned system improvements did not originally include upgrades or replacement of positive wayside jumper cables, transposition cables, and negative equalizer cables. To date, upgrade work associated with TPE has only been completed to support 50 percent operation of 8-car trains. Additional upgrades and system requirements for 100 percent operation of 8-car trains are still in the planning and engineering stages. Simulated load studies completed for this upgrade were based on approved Design Criteria, but additional assessment of the actual conditions of WMATA's cable plant are needed to take into account its condition and performance.

WMATA's engineering team has made recommendations to prioritize cable replacement, including the removal of all 1000MCM rated cables (MCM is a cable gauge measurement, an abbreviation for thousands of circular mils, where a mil is 1/1000 inch) installed during WMATA's original construction and replacement with larger 1500MCM rated cables that are low-smoke/zero halogen cables. However, based upon interviews with key personnel, and the results of an assessment conducted by a contractor to the traction power maintenance

department, the resources to support the current programs are not adequate to complete this work for the entire system by 2020 or even by 2025.

3.3 TPE Maintenance Roles and Responsibilities

WMATA recently completed a re-organization regarding the responsibility for inspection, testing and maintenance of its TPE system. Until recently, the Electrical Power Branch of the Office of Systems Maintenance (SMNT) within the Department of Transit Infrastructure and Engineering Services (TIES) was responsible for the inspection and maintenance of WMATA's high voltage and low voltage power systems and equipment, as well as all electrical measurement and testing.

3.3.1 Traction Power Maintenance Department

The new Traction Power Maintenance (TRPM) department is focused exclusively on high voltage equipment and cables, including TPSS and tiebreaker station equipment as well as the associated positive and negative high voltage cabling. TRPM also performs quarterly inspections of wayside cable assets through a dedicated inspection program. TRPM has three divisions: Preventive Maintenance Inspections (PMI), Regional Support, and Capital Cable Inspections (CCI). Responsibilities for low voltage power systems and equipment have been transferred to another department.

The recently-created TRPM department currently has 15 managerial positions, including the Acting General Superintendent, 30 shift supervisors, and approximately 224 represented positions staffed from the Local 689 labor pool.

This group of employees is responsible for 24/7, three shift coverage of WMATA's entire TPE system, including the extensive testing and inspection program required for each of the 207 traction power and 192 other facilities (passenger stations, pumping stations, and chilled water plants) with high voltage equipment, and cable inspection. In addition, this group provides support for all capital construction projects that require red tag outages, and emergency response to equipment failures, service outages, accidents and other events.

3.3.2 Coordination with Other WMATA Departments

While this new organization ensures that TRPM is focused on the high voltage electrical system, including testing, inspection, and maintenance of TPSS and associated switch gear, station AC rooms and tie breaker stations, traction power cables and connections, it leaves other WMATA departments with maintenance and inspection responsibilities for additional elements that are essential to the performance and safety of the TPE system, including:

- The Track function within Track and Structures (TRST) has responsibility for inspecting and maintaining third rail. These items include third rail insulators, grout pad mounts, third rail cover board and brackets, alignment/gauging of the third rail, and third rail joints and expansion joints, tunnel leaks, drainage grates and appliances, and general track bed conditions.

- The Structures function within TRST has responsibility for drainage defects and water remediation. Low voltage power systems and equipment have been transferred to SSRV Support Services.

- The Infrastructure Renewal Construction Management (IRCM) group under the Capital Projects Delivery Operation (CPDO) group shares responsibility for testing, inspecting, and replacing third rail cable on a program basis and is supported by personnel from the newly formed TRPM department. They maintain records that reflect the current age and known state of the electrical infrastructure. In addition, CPDO manages a contractor team that performs testing to identify low electrical resistance where stray current may adversely affect the operation of signaling equipment. Until recently, this activity was limited to interlockings and special inspections.

- The negative return system is a shared responsibility among several departments. The ATC group is responsible for the impedance bonds to running rail connections, c-bonds, and huck-bolted cables on the running rail. TRPM is responsible for power cables from impedance bonds to substation return. TRST has ownership of mechanical joint bars, insulated joints, and running rails. These standards are defined in WMATA's TRST 1000 and Electrical Power Branch Maintenance Control Policy.

- The Power Engineering (PWRS) group under the Chief Engineer of Infrastructure Services (CENI) is responsible for the design, monitoring, inspections, and maintenance support for the TPS. This includes the TPS and tiebreaker substations, along with third rail cabling and associated components.

- The Rail Car Engineering (CENV) office maintains a rail car that is equipped with thermal imaging equipment, which they operate during peak hours to identify "hot spots" in the wayside TPS components that may indicate stray current flow and failure conditions.

- The CENI Track, Structures and Facilities (TSFA) group operates the Track Geometry Vehicle (TGV), which measures third rail geometry on a twice yearly basis on the mainline and once per year in the rail yards.

- A Procurement Office trained Contract Officer Technical Representative (COTR) has primary responsibility to review independent test reports and perform incoming inspections on TPS equipment such as insulators. This position resides in TRST for the insulator contract.

- Department of Quality and Internal Compliance Operations (QICO) group performs quality assurance checks on TPS maintenance. In addition, the QICO group audits and performs assessments of procurement of TPS parts, such as insulators. As a result of WMATA's indepedent investigation report, QICO has assumed responsibility for all incoming inspections and evaluation of new insulator shipments.

3.4 Work Process

As a result of the TRPM re-organization, WMATA must update its Electrical Power Branch Maintenance Control Policy (MCP), which describes roles and responsibilities for maintaining all TPE system components. In addition to the MCP, WMATA has also established 58 preventive maintenance inspections (PMI) for high voltage equipment documented in specific procedures with corresponding test sheets or other required documentation. Depending on the electrical component, these PMIs take place bi-weekly, annually, biennially, and/or triennially and require up to a day each to complete.

Mechanics perform work based on their classification; they are not currently designated by a specific function or specialty. Mechanics can only be assigned work according to their classification, but preventive maintenance procedures do not require a mechanic to attain a specific level of advancement. New hires within each classification start as mechanic helpers and may advance based on successful test completion for each level in addition to meeting the following experience requirements:

- Helper – entry level;
- C mechanic – one year of experience;
- B mechanic - two years of experience;
- A mechanic - three years of experience; and
- AA mechanic - four years of experience.

Each shift supervisor work group has a five-day work week with distinct work hours and days off to provide coverage for all days and hours. The work schedule results in the largest number of mechanics available for work Tuesday-Thursday. Mechanics obtain shift assignments for their classification through an annual pick.

All mechanics assigned to a shift supervisor are of the same classification and only perform work for that classification; however, shift supervisors assign work to mechanics based on the employee's technical knowledge and qualifications. All work requires a minimum of two mechanics, only one of whom can be a helper. A breakdown of TRPM budgeted positions shows the following distribution for power mechanics: Helper (21%), C (20%), B (20%), A (4%), AA (35%).

3.4.1 Staffing

Even with its recent re-organization, WMATA's TRPM has extremely limited resources to complete testing, inspection, and preventive maintenance activities for high voltage equipment and cables. Corrective maintenance and production, including cable replacement activities, are also significantly understaffed.

For example, an analysis performed by WMATA's traction power contractor, HNTB Corporation, pointed out that TRPM's Capital Cable Replacement Group has identified over 17,500 positive cables totaling 988,500 feet that need to be replaced on the system:

- 5,300 feeder cables totaling 262,500 feet of cable;
- 476 expansion joints totaling 95,200 feet of cable;
- 1,192 crossover cables totaling 238,400 feet of cable;
- 856 transition cables totaling 171,200 feet of cable;
- 356 jumper cables totaling 71,200 feet of cable; and
- Approximately 9,500 pig tails with around 150,000 ft. of cable that connecting the feeder cable to the third rail.

In addition, there is approximately 1,312,500 feet of negative return cable that need to be replaced. This brings the total cable needing to be replaced to 2,301,000 feet on the system. Historical Cable Replacement program data shows that the Capital Cable Replacement Group replaced an average of 75,000 feet of cable per year with 2 crews, each consisting of 5 WMATA and 9 Contractor personnel. Based on this assumption, it would take over 30 years to replace the remaining 2,301,000 feet of cable on the system. Unfortunately, at this time there is only one crew assigned to cable replacement, corresponding to a 60-year cable replacement cycle.

Initial analyses, based on the time required to perform assigned activities for all three groups within TRPM, including preventive maintenance, corrective maintenance, switch order requests and cable requirements, indicate that 89 additional positions are required to complete all testing and inspections and perform required maintenance and emergency repairs. TPRM uses contractors to support analysis, project planning, and special activities, but to date has not used them to address the maintenance and production backlog.

3.4.2 Training

Training and testing is administered by the Technical Services & Maintenance Training (TSMT) Department within the Operations Management Services (OPMS) Office, and by TRPM contractors and personnel who have developed new training and programs to support cable inspection and replacement.[8] Whether training is developed by TSMT or TRPM, advancement requires both a written test and demonstration of practical knowledge geared to the level of advancement.

The Electrical Power Branch MCP includes a Training Matrix for mechanics and supervisors indicating technical courses to be provided for each personnel category. The technical training covers inspection and maintenance procedures for specific electrical facilities and equipment and was described by WMATA as recommended rather than a minimum requirement. The Training Matrix lists 25 courses and indicates 20 personnel categories to which they apply. Personnel are categorized by supervisory function (shift, area), mechanic classification, and mechanic level (AA, A, B, C, Helper).

[8] While WMATA previously had a meggering program, which was discontinued several years ago, until recently, WMATA did not have a formal program for testing and inspecting traction power cables, including feeder cables, jumper cables, and transition cables. TRPM works with its contractor team to provide this training for its personnel.

The number of courses identified for any one personnel category ranges from 1 to 20, with the largest number of courses applicable to the highest mechanic levels. Records of training completed can be queried by supervisors for individual personnel, but there is no training matrix report or process for monitoring overall training completion and identifying what is lacking for the entire work force. Area Managers were reported to be responsible for reviewing levels of training completion for individual personnel. WMATA has issued a Request for Proposal for a Curriculum Design Engineer to finalize this program.

While training can be queried for individal mechanics, there is no overall process for monitoring the completion of technical training by all power mechanics. It is not evident in any documentation whether completion of the training program is a requirement or recommendation or if there is a specific timeframe for completion. Also, there does not appear to be a process for tracking the progress of individual personnel in completing the courses identified for their classification.

During a recent review with WMATA, FWSO found that the primary, 12-week training course for power mechanics was recently halted because the instructors were no longer available. WMATA is developing new training to advance and qualify power mechanics to complete testing and inspection on TPSS components. This new training, which will replace the standard 12-week course, is being developed, in part to address findings from FTA's SMI. Prior to the halting of this training, there was a two-year wait list for power mechanics. The new training will not be available for piloting in July 2017, at the earliest.

In the interim, WMATA's training consists of new hires working with the preventative maintenance group for on-the-job (OJT) training, working in WMATA's breaker shop for understanding of functionality of breakers as well as safety training, roadway worker protection training, and other required training.

Given this situation, FWSO remains concerned regarding the availability of formal training to address existing demands and to support the additional positions required to tackle WMATA's backlog of preventive and corrective maintenance. Further, in the absence of formal training, OJT is used informally, and is not structured for consistency or quality across TRPM personnel. While TSTM and TRPM are working on a documentation process for this training, also in response to a previous FTA SMI finding, their OJT training package remains several months from development.

3.5 TPE System Preventive Maintenance Program

The Electrical Power Branch MCP includes a general description of the preventive maintenance (PM) inspection process, methodology, and responsibilities including development of PM procedures, scheduling, and performance. Individual procedures and schedules for PM and equipment and systems requiring PM are not identified in the MCP. The general MCP description refers to the entry and availability of such information in in WMATA's enterprise asset management system (Maximo).

The TRPM General Superintendent and Assistant Superintendent are responsible for implementing PM procedures for power equipment and systems approved by the CENI, and they perform a review of all procedures every two years. The Superintendent and Assistant Superintendents are also responsible for ensuring that PM procedures are available and scheduled in Maximo prior to commissioning of any new equipment.

Area Managers are responsible for implementing PM performance in accordance with schedules, documenting PM completion in Maximo, and spot checking closed Maximo work orders to assure proper completion. Shift supervisors are responsible for reviewing and certifying the performance of PM inspections and the accuracy of Maximo documentation. Shift supervisors are also responsible for closing PM work orders. Mechanics are responsible for performing PM according to approved procedures and documenting completion in Maximo.

3.5.1 PM Procedures

TRPM implements 58 individual PM procedures for various systems and equipment. PM is required for equipment voltages of 750V DC, 480V AC, 13.8kV AC, 34.5kV AC. All procedures follow a similar format summarized as follows:

- Title page identifying equipment manufacturer, model, type of equipment, PM schedule, document revision number and date;
- Signature approval page;
- PM procedures are dated;
- Sections containing safety and technical references, safety warnings, and qualifications required to perform the procedure;
- Sections identifying required tools and test equipment;
- Sections identifying and describing the equipment, components, and function;
- Sections identifying and describing required tasks for preparation, inspection, testing, and maintenance including detailed inspection and test requirements; and
- Data sheets required to be completed for each PM inspection or test
    - Each PM has a unique data sheet for inspection
    - Test data sheets may be unique for individual PMs
    - Many PMs use the same data sheet for megger, low voltage, and contact resistance tests.

The 58 PM procedures cover a range of electrical equipment and systems with varying schedule requirements. Maximo, based on the required schedules identified in the PM inspection procedures, automatically generates PM work orders monthly. Shift supervisors assign personnel to perform scheduled PM. Supervisors are also responsible for ensuring that completed PM documentation is entered and approved in Maximo. PM completion is tracked and reported monthly in PM Compliance Summary Reports.

The General Superintendent is responsible for approving all PM procedures, which require signature by the General Superintendent and the CENI Deputy Chief Electrical Power.

The Track Geometry Vehicle (TGV) provides additional inspection and geometry detail for third rail gauging, and WMATA's thermal imaging system uses revenue vehicles that detect hot spot details that exceed a baseline temperature level, typically a fluctuation of four degrees or more. There is no structured cyclical testing program for meggering DC traction power cables.

3.5.2 Completion of PM Inspection Data Sheets

All PM procedures require completion of one or more data sheets. Data sheets identify the procedure being performed and the tasks to be completed, indexed by the task number in the PM procedure document. Space is provided to indicate PM location, date, completion of tasks, entry of values, mechanic identity, and supervisor signature. Completed data sheets are required to be on file at the Area Office where shift supervisors responsible for PM completion are located. PM procedures are to be available to supervisors and mechanics at the Area Office by hard copy or online.

Recent reviews conducted by FWSO and the Tri-State Oversight Committee (TOC) indicate that data sheets are missing or not available for inspections that are shown as complete in Maximo. Combined with the results of the recent assessment regarding insufficient time to perform all PM activities, FWSO found that preventive maintenance is not being conducted as required by WMATA's PM procedures and standards.

The FWSO and TOC also found that neither data sheets nor maintenance procedures define acceptable thresholds for some measurements. For example, the AC TPSS Inspection data sheet requires the recording of information such as voltage leakage, but neither the data sheet nor the PM inspection procedure lists the proper threshold. It is important for proper thresholds to be clearly marked so that action may be taken for measurements that fall outside the acceptable limits.

Currently, there is no requirement to note corrective maintenance work order numbers alongside defects identified during inspections. As a result, managers cannot identify whether defects have been addressed.

3.6 Corrective Maintenance

A Corrective Maintenance (CM) work order is opened when a repair or adjustment is required as a result of PM inspection or an incident report. The ROCC issues an Incident work order if service is impacted. The Maintenance Operations Center (within the ROCC) then issues a corresponding CM work order.

The MCP provides a brief description of the Maximo work order process. Area Managers and Shift Supervisors are responsible for monitoring CM completion. The newly established cable inspection program is not yet tracked in Maximo, but corrective maintenance items do have work orders for scheduling and tracking. However, there is no current requirement to note corrective maintenance work order numbers alongside defects identified during inspections. As a result, it is difficult for PM managers to identify whether defects have been addressed.

During the investigation period, since March 2016, FWSO confirmed that WMATA's TPE maintenance function has been unable to fully utilize the track time allocated to its activities to personnel to complete preventive and corrective maintenance on the TPE system. Responsibilities for taking power down (red tag outages) and re-energizing power to support construction during the nightly maintenance window, responding to emergencies and equipment failures, addressing NTSB recommendations, and conducting the extensive testing and inspection program required for high voltage equipment, have left WMATA's power managers, shift supervisors, and electrical mechanics with the ability to utilize only about 45 and 60 percent of their available track time to support TPE system repairs.

Over the course of a week, WMATA TPE system inspectors often identify more items than they can repair in a single week, contributing to a growing corrective maintenance backlog of approximately 860 work orders plus approximately 300 cable repairs identified through enhanced cable inspections conducted since the March 16, 2016.

4.0 Previous FTA Findings and WMATA Actions

Considerable action is already underway at WMATA to address previous findings, required actions, recommendations and corrective action plans related to the condition and safety performance of the TPE system.

4.1 FWSO Track Integrity Investigation, Safety Directive 16-4

During the track integrity investigation, the FTA assessed systemic deficiencies in the inspection, maintenance, and repair of track that have contributed to or could have resulted in train derailments and other track-related incidents. [9] During the track integrity investigation, FWSO's team also inspected all 27 locations where emergency repairs were made to traction power cables as a result of WMATA's March 16, 2016 emergency shutdown. FTA also conducted over 70 inspections of track conditions throughout the WMATA Metrorail system.

As a result of these inspections and findings, FTA issued a total of 12 findings and associated required actions in its track integrity report. Six of the required actions in Safety Directive 16-4 are directly applicable to WMATA's TPE system:

- FTA-T-16-007: WMATA must develop a formal procedure and protocol to ensure the maintenance managers and track inspectors share information and jointly establish maintenance priorities;

- FTA-T-16-008: WMATA must provide additional training and resources to maintenance managers related to the use of inspection information to establish maintenance priorities;

- FTA-T-16-009: WMATA must ensure that track inspectors and maintenance managers prioritize drainage defects;

- FTA-T-16-010: WMATA must provide additional supervisory staff or contractors to oversee track inspection and track maintenance activities and ensure conformance with WMATA track safety standards;

- FTA-T-16-011: WMATA must develop a special inspection and repair plan to address inappropriate stud bolt installation and missing fasteners, and ensure track maintainers and contractors are trained in stud bolt installation and rail clip installation, and that work is adequately overseen; and

- FTA-T-16-012: CADWELD C-bonds must be identified and replaced with huck bolted cables in the webs of the rail as specified in WMATA's design and construction standards.

[9] The track integrity investigation was one of a three-part series. The other two parts involved investigations of vehicle securement and stop signal overruns. FTA released the Stop Signal Overrun Final Report on August 15, 2016, and the Vehicle Securement Final Report on August 24, 2016.

As required, WMATA recently submitted its 60-day corrective action plans for FTA review and approval. FTA previously reviewed draft versions of these CAPs and provided comments.

4.2 FTA Safety Management Inspection

In response to concerns regarding WMATA's safety performance after the January 12, 2015 smoke and fire incident at L'Enfant Plaza Station, the FTA initiated a comprehensive Safety Management Inspection (SMI) of WMATA in February 2015 to look at WMATA's operations and maintenance programs, safety management capabilities, and organizational structures. During the 2015 SMI, the FWSO evaluated the WMATA Metrorail system's maintenance and inspection programs for critical infrastructure, including track and traction power systems. The FWSO also completed a general assessment of track and third rail conditions at locations throughout the system.

On June 17, 2015, FTA released a report with 54 safety findings and Safety Directive 15-1with 91 required actions, including actions to improve TPE programs and the condition of this infrastructure. Safety Directive 15-1 directed WMATA to ensure that maintenance and inspection crews have sufficient access to the track to complete their work and that the work is adequately supervised, inspector and maintainer training and quality programs are improved, and enhancements are made to WMATA's roadway worker protection (RWP) program.

Appendix D provides a listing of applicable SMI findings for TPE system infrastructure and the status of WMATA corrective actions to address them.

4.3 National Transportation Safety Board

The NTSB launched an investigation into the January 12, 2015 smoke and fire event occurring at L'Enfant Plaza, which resulted in the NTSB issuing a series of recommendations to the FTA and WMATA. Specifically, the NTSB recommended that WMATA:

- R-15-25: Promptly develop and implement a program to ensure that all power cable connector assemblies as properly constructed and installed in accordance with your [WMATA] engineering design specifications, including the weather tight seals that prevent intrusion by contaminants and moisture.

Additional detail on the NTSB recommendations can be found in Appendix E of this report. The FTA is working with both WMATA and the NTSB to address these recommendations. Several findings in this investigation report will also support implementation of NTSB recommendations.

4.4 Recent WMATA Inspections

Following the L'Enfant Plaza incident on January 12, 2015, WMATA took measures to inspect its TPE system, replace degraded jumper cables, and replace electrical boot connector/assemblies including heat shrink terminations and sealing sleeve/protections at the terminal connections to prevent water intrusion and contamination. After experiencing another significant electrical arcing and smoke event at McPherson Square station, on March 16, 2016, WMATA executed a

29-hour shutdown of the entire Metrorail system to re-inspect the traction power cable plant and conduct emergency repairs as necessary. In all, WMATA completed cable replacements and or repairs at 27 locations.

Inspections conducted during WMATA's March 16, 2016 system wide shutdown included a visual assessment of the TPE system cable plant and contact rail system in all tunnels for conformance with its track and traction power safety standards and design criteria, including the following system related elements: cable bonds; contact rail cable feeds; contact rail feeder cable; feeder cable connections to the contact rail; including stub-up conduit with supply power cable, cable connector assemblies, pigtail cable, and all associated splices, welds and terminal connections.

WMATA's visual inspection identified over 450 system defect locations with:

- Cables on the ground, in mud or standing water, or coated with calcite or water deposit leaks;
- Cables that are cracked, frayed, gouged, sliced or damaged, with exposed elements;
- Improper cable installations or bad cad-welds that are now at risk for contamination, exacerbated wear, or exposure;
- The presence of debris on the right-of-way, including collector shoes, track materials, and other hard or sharp items that may have cut, sliced or gouged nearby cable; and
- Drainage conditions near high voltage cables and connector assemblies for clearing or repairing clogged drains, vents, grates, or pipes.

Also, as part of their inspection, WMATA critically assessed the level of contaminants on TPE system surfaces, including cables, insulators, and contact rail cover boards.

Other deficiencies identified by WMATA personnel include: cables that are cut, broken, loose, missing welds, and dangling with only one end connected; cuts in cables with exposed conductors; broken cable connector assemblies with exposed energized lugs, damage to stub ups, missing or damaged connector assembly components or pigtails; and other damaged cable conditions where the insulation is compromised or has gouges exposing the conductor. Finally, WMATA noted whether traction power feeder cable was laying along ballast, tunnel inverts, or other locations, loose with no additional protection, such as rubber matting as a protective barrier or underlayment.

The results of these inspections revealed a deteriorated cable plant in need of more frequent inspection, testing, and repair. The results from this survey also raised additional concerns regarding the existing cable plant's ability to handle the additional electrical stresses associated with the expanded 8-car train operations.

4.5 WMATA Actions

In response to these findings, WMATA has enhanced its visual and thermal inspection program for its TPE cable plant, including jumper and transition cables. To address NTSB safety recommendation R-15-25, WMATA initiated a program to assess the condition of over 9,492 cable connector assemblies systemwide. WMATA recently completed cable connector inspection and repairs, including installation of sealing sleeves where needed, in all underground sections of the system and reports this activity is over 95 percent complete for the entire mainline system.

WMATA began replacing insulators and eliminating third rail expansion joints in tunnels, and issuing new work instructions to ensure that electrical cables are secured off the ground and appropriately bolted to the contact rail. WMATA is also expanding its cable replacement program, and re-instating its plans to upgrade both its positive and negative electrical return system to manage 100 percent 8-car train operation. Figure 9 shows a newly installed insulator and in the background a pile of insulators removed the third rail, contaminated with dirt, mud, dust, and other elements.

Figure 9: Newly Replaced Insulator and Old Insulators

WMATA is also reviewing roles and responsibilities for inspecting, testing, and maintaining its TPE system elements and has created a new department with exclusive responsibility for the high voltage maintenance function. A contractor performed an assessment of staffing requirements necessary to implement and maintain a power cable inspection and maintenance program. This new department also has established cable mitigation action plan to prioritize and eliminate areas where power cables are in contact with the ground or otherwise unsupported.

WMATA released its SafeTrack Program on May 19, 2016 that included target infrastructure maintenance programs via 15 long duration track outages, including weekend and night track outages, to accelerate needed maintenance programs. This includes enhancements in the TPE system, such as the elimination of third rail expansion joints and the replacement of third rail insulators. SafeTrack is part of a larger Track Quality Improvement Program (TQIP) that includes track, drainage, and TPE system enhancements at 18 other prioritized locations on the Metrorail system. Power cable replacement crews are piggybacking in SafeTrack work zones to expedite TPE system repairs.

Over the course of the late spring and early summer, WMATA work crews replaced all porcelain insulators with fiberglass insulators at all underground station platforms. WMATA SAFE led an investigation to identify and resolve a series of issues with insulator quality and handling. WMATA also recognizes the need to expand its corrosion control testing for stray current.

Finally, and perhaps most significantly, as discussed earlier in this report, WMATA SAFE and its technical leadership team conducted an extensive review of recent electrical arcing events and failures in the TPE system. This is a systemic assessment of issues involved with inspecting, maintaining, and upgrading WMATA's aging TPE system infrastructure, and the FTA commends WMATA for conducting this type of analysis, and for opening the results to the public and its employees. The FTA, to the extent feasible, has incorporated the recommendations from WMATA's internal investigation into the findings and required actions issued in Special Directive 17-1.

5.0 New Findings and Required Actions

FWSO's investigation finds that WMATA is taking many steps to strengthen the safety performance of its TPE system and to address existing NTSB and FTA findings related to traction power issues. More work is needed, however, to restore the condition of the TPE system, reduce electrical arcing events, and prepare the TPE system for increased 8-car train operation.

Based on the results of FWSO's investigation and careful review of WMATA's internal traction power study, the assessment completed for WMATA by the HNTB Corporation, and the APTA Peer Review, FWSO issues 22 findings and 47 required actions organized into 4 categories of safety critical concerns:

- Category 1: TPE System Roles, Responsibilities, and Resources;
- Category 2: TPE Infrastructure;
- Category 3: Testing and Inspection Programs; and
- Category 4: Capital Projects.

Within these categories, FWSO makes specific findings based on the results of interviews, document and records reviews, field observations, and independent inspections, testing and measurements. In Special Directive 17-1, FWSO issues required actions that WMATA must take to address the findings described in each category of this report. Safety Directory 17-1 also establishes required response times, a process for FWSO approval of work plans, and the FWSO's approach to the monitoring of the implementation WMATA's work plans.

These findings and required actions are detailed below by category and presented in a matrix format in Appendix A.

5.1 TPE System Roles, Responsibilities, and Resources

FWSO's investigation found that several different WMATA departments have responsibility for the TPE system and that insufficient resources are available to complete preventive and corrective maintenance activities. FWSO's team identified 3 findings and 9 required actions regarding this topic.

5.1.1 Situation

FWSO finds that WMATA's TRPM team faces significant challenges in coordinating with other departments to ensure priority attention is paid to traction power issues and corrective maintenance needs. Several electrical arcing events that occurred during the course of FWSO's investigation happened because TPE cables, connector assemblies, insulators, and negative return system components were not maintained adequately by other departments, were left covered in water and mud, or were not properly inspected or repaired.

The peer review that WMATA conducted with APTA indicated that WMATA would benefit from adding responsibilities for third rail and the negative return system to the new TRPM Department with additional personnel. This assessment also recommended the creation of

positions that clearly assign ownership of specific areas of the power infrastructure (such as Traction Power Substation Maintainer, Electrician, Cable Maintainer, Bondsperson, etc.) instead of the more generic power "mechanic" title. WMATA SAFE, through the course of its investigation, also concluded that a single department focused on TPE issues would provide additional focus, clarity, and an ability to address systemic issues affecting the TPE system. FWSO also agrees with this assessment.

Over the last few months, TRPM has documented the extent of its staffing and work scheduling challenges. Under the current configuration, even if TRPM were given more responsibilities, it could not carry them out with a substantial increase in staff. FWSO findings focus on what would be required to manage this transition and ensure single-point accountability for the condition and safety performance of the TPE system.

Finally, FWSO finds that ROCC personnel would benefit from additional operational awareness regarding the functioning of WMATA's TPE system and a more proactive approach to the removal of power in smoke emergencies and the management of 8-car trains.

- **Finding 1: Multiple WMATA departments have responsibility for critical TPE system inspection, maintenance, and repair activities, preventing clear ownership of the TPE system and identification of systemic issues and priorities.**

FWSO's team finds that critical TPE system engineering, inspection, maintenance, and repair functions at WMATA are currently shared across eight different departments. Communication and coordination among these departments is not sufficient to support the development of joint priorities. There is no formal process in place to ensure that information is available and useful to those who need it, reviewed collectively, or that decision-making is done from a systemic and integrated perspective.

In addition, FWSO is concerned that the current organizational arrangement, with so many departments involved, contributes to a lack of urgency to resolve issues that impact the condition and safety of the traction power system, including water remediation and debris removal in the tunnels, cables laying loose on the ground, quality issues with insulator procurement and installation, and needed cable repair and replacement activities.

FWSO agrees with WMATA SAFE that a centralized, properly resourced department that is responsible for the bulk of TPE system functions would have a better understanding of the overall TPE system, including its problems, requirements, and needs.

- **Finding 2: WMATA ROCC and MOC personnel are not sufficiently proactive in managing TPE concerns during emergencies.**

Based on interviews and incident investigation reports, it appears that employees operating in the ROCC lack traction power operational intelligence, which may be hampering their ability to execute logical and timely decisions when it comes to removal and restoration of third rail power. Decisions to remove power early on in a smoke event would greatly enhance the

effectiveness of response and reinforce implementation of critical procedures to ensure that trains are safely clear of the de-energized sections of track.

WMATA must educate and train these employees on the interaction of train movement and power feeds including circuit breaker operations, gapping and bridging of electrical circuits, and design features including traction power return systems and the effects of train movement with respect to negative return power. WMATA could also be more proactive in implementing *SOP #2: Emergency Removal and Restoration of Third Rail Power Mainline*, to remove power early for situations that may turn into extended arcing events.

Finding 3: Insufficient resources are available to support the testing, inspection, and maintenance of WMATA's TPE system.

FWSO found that while WMATA has taken many positive steps to create a new traction power maintenance department and establish a new cable inspection program, the agency still does not have sufficient personnel resources to complete required preventive or corrective maintenance on the TPE system. Recruitment and training of TPE system electrical mechanics lags behind need, and corrective maintenance work orders are backlogged for both high voltage equipment and cable plant. New demands of managing power outages for SafeTrack and other maintenance activities further strain WMATA's TPE system resources.

A recent assessment completed for WMATA determined that the new Traction Power Maintenance department is understaffed by 89 positions to properly perform its services. FWSO carefully reviewed this assessment, which identified the time required to complete each of TRPM's 58 preventive maintenance procedures and the time required to complete life cycle corrective maintenance for the TPE system, as well as the escort, emergency response, and system repair activities performed by TRPM. The assessment converted that time to person hours, organized by group within the TRPM department.

FWSO generally agrees with this assessment, although FWSO finds that it does not go far enough to evaluate the time required to complete all activities performed by all WMATA departments with responsibility for the TPE system. This not only includes the TPE system inspection, maintenance, and repair performed by TRPM, but also the third rail inspection and maintenance work performed by TRST, the negative return system inspection and maintenance activities performed by ATC, the cable replacement activity performed by IRCM, the engineering services provided by PWRS, and the lock-out/tag-out procedures implemented by the ROCC and MOC.

As was found in FWSO's Track Integrity Investigation, there is concern that preventive maintenance inspections for TPE system elements are not always conducted or conducted in a thorough manner. During the course of this investigation, WMATA acknowledged that the PM group's active repair workload does not leave sufficient time for the recommended preventive maintenance services. Missing data sheets documenting testing and inspections and the general condition of the some of the high voltage infrastructure, from basic housekeeping issues in TPSS units to the number and type of corrective maintenance work orders associated with WMATA's circuit breakers and tiebreaker stations, to the number of emergency repairs, to the details

surrounding the cause of the recent fire at the Stadium Armory TPSS, all seem to indicate a significantly understaffed preventive and corrective maintenance team.
Also, FWSO's team spent considerable time with TRPM's new cable inspection group. This group performs on-going cable inspections and infrared photo review work to monitor the condition of the cable plant and to identify and prioritize repairs. The group has identified over 2.3 million feet of cable that needs to be replaced on the WMATA system, either because of its condition or to support the upgrades needed for 8-car operation. FWSO confirmed that with only one single, active cable replacement crew available, as is the case now, replacement of these cables will take TPRM's Capital Cable group 60 years to complete.

As also noted during FWSO's track integrity investigation, FWSO finds that WMATA could do more to clean its tunnels. In response to Safety Directive 16-4, WMATA is taking action to improve the identification and resolution of drainage defects, including the removal of mud and debris that can clog drains. In addition, as WMATA SAFE noted during its independent investigation into electrical arcing events occurring in 2016, WMATA has additional options available to remove debris and litter from track beds, tunnels and stations, including three vehicles used for vacuuming purposes. However, one of these vehicles has been out-of-service for an extended period.

WMATA has not made a final determination regarding the status of this vehicle, and whether it should be repaired or permanently retired and replaced. To obtain more information from potential vendors regarding available vacuum vehicles and features, WMATA recently issued an expression of interest. FWSO agrees with WMATA that the removal of trash and litter, which can spark and ignite, should be "viewed as part of the overall global strategy to protect the system from smoke and fire events." Additional vacuuming capacity will contribute substantially to this overall strategy.

Finally, to ensure the effectiveness of its thermal imaging vehicle-borne system, which provides infrared pictures and video of the entire TPE system, FWSO finds that additional cameras, and camera calibration, will provide more options for the thermal imaging car to pick up cable hot spots. FWSO noted that in some runs, the thermal imaging system did not view or pick up cable hot spots, and that adjusting the camera field of view would offer a better vantage point for observing cables along the field side of the third rail.

5.1.2 Findings and Required Actions

TPE Investigation Category 1: Roles, Responsibilities, and Resources			
Finding		**Required Action**	
Finding 1	Multiple WMATA departments have responsibility for critical TPE system inspection, maintenance, and repair activities, preventing clear ownership of the TPE system and identification of systemic issues and priorities.	FTA-TPE-17-001-a	WMATA must conduct an assessment to determine if all TPE system program components should be integrated into a single department with sole responsibility for managing, inspecting, maintaining, repairing, and upgrading the TPE system. At a minimum, this assessment must include those elements of TPE system inspection, maintenance, and repair currently performed by TRPM; third rail inspection and maintenance work currently performed by TRST; negative return system inspection and maintenance activities performed by ATC; cable replacement activity performed by IRCM; engineering services provided by PWRS; and lock-out/tag-out procedures implemented by the ROCC and MOC.
		FTA-TPE-17-001-b	WMATA must implement the results of the assessment conducted to address FTA-TPE-17-001-a following a schedule reviewed and approved by FTA.
Finding 2	WMATA ROCC and MOC personnel are not sufficiently proactive in managing TPE concerns during emergencies.	FTA-TPE-17-002-a	WMATA must develop and provide TPE system awareness training for ROCC and MOC personnel.
		FTA-TPE-17-002-b	WMATA must revisit SOP #2: Emergency Removal and Restoration of Third Rail Power Mainline to consider: 1) removal of power during smoke conditions, especially with corresponding third rail power outages caused by unknown conditions, and 2) a requirement to de-energize third rail power at the adjacent power substation or tie breaker, provided the situation does not strand a train that needs to be moved from the smoke condition.
Finding 3	Insufficient resources are available to support the testing, inspection, and maintenance of WMATA's TPE system.	FTA-TPE-17-003-a	WMATA must amend or update the TRPM workload assessment completed by the HNTB Corporation to address the results of FTA-TPE-17-001-a.
		FTA-TPE-17-003-b	WMATA must develop a 5-year plan for staffing to implement results of the revised workload assessment, reflecting the results of FTA-TPE-17-001-a.
		FTA-TPE-17-003-c	WMATA must evaluate options for using contractors to complete its TPE system corrective maintenance backlog and outstanding preventive maintenance requirements in the near-term and implement results.

TPE Investigation Category 1: Roles, Responsibilities, and Resources		
Finding	**Required Action**	
	FTA-TPE-17-003-d	WMATA must perform a cost benefit analysis with regard to repairing or replacing the out-of-service vacuum vehicle and implement the results.
	FTA-TPE-17-003-e	WMATA must improve the functionality of the thermal imaging car to more accurately pick up cable hot spots.

5.2 TPE System Infrastructure

FWSO's investigation found that the safety performance of WMATA's TPE system has deteriorated with age, deferred maintenance, and increased exposure to water and moisture with contaminating materials. FWSO's team identified 8 findings and 21 required actions regarding this topic.

5.2.1 Situation

In numerous inspections and investigations regarding WMATA's track conditions, FWSO has confirmed that track and tunnel drainage defects have not been adequately identified and prioritized for repair, allowing insulators, cables, and connectors on or near the track bed to become encased in mud, water, and other contaminants. Figures 10, 11 and 12 show examples of this condition observed by FWSO's team.

Budget limitations and changing maintenance priorities have also influenced the condition and performance of the TPE system. In recent years, in response to changing budgetary and staffing conditions, WMATA eliminated preventive maintenance programs to test traction power feeder cables for cable insulation integrity and predict failures. Cleaning programs in tunnels were eliminated or cut back to the point that they failed to keep pace with the buildup of metallic dust and particles generated by normal train operation.

Figure 10: Cable and Connector Assembly Coated in Mud and Water

Figure 11: Water and Debris under Third Rail

Figure 12: Power Cables on Tunnel Floor in Damp and Muddy Conditions

FWSO finds that the use of cadweld C-bonds and temporary cable connectors on the running rails, combined with the poor quality installation of insulators and track fasteners in some locations, introduces the potential for issues with the control of negative return power and stray current corrosion and increases the likelihood for electrical arcing and flashovers.

- **Finding 4: Traction power cables are often loose on the ground, subjecting them to contamination, vibration, and damage from movement.**

Following the McPherson Square incident on March 14, 2016, WMATA implemented a 29-hour system shut down and emergency cable inspection program to document and inspect all underground cables. Twenty- seven critical locations were identified for immediate repair, which were completed before the system reopened for service. Approximately 450 other locations were identified where cable repairs were required. Almost 200 of these locations required cable securement to remove cables from the ground.

To date, WMATA has repaired 79 of the approximately 200 locations requiring cable securement repairs identified on March 16, 2016. These repairs require cleaning and inspection of cable, elevating cables off the ground on secured Kindorf with ceramic insulators, and replacing or adding cables as necessary. Figure 13 shows a typical repair. Through the course of their inspections, TRPM cable teams continue to find other locations where cables are loose on the ground and must be secured. Figures 14 and 15 show examples of cables on the ground or touching the tunnel wall that have been identified for repair.

TRPM continues to develop its mitigation strategy to address cables laying on the concrete tunnel surface by establishing defined criteria for the prioritization of repairs. Prioritization of repairs is based upon factors such as the cable's proximity to passenger stations (within 500 feet), insufficient quantity of cables to carry load, and environmental conditions (dry vs. wet). At the current time, this approach focuses only on positive cables.

Figure 13: Typical Repair for Securing Cables Off the Ground

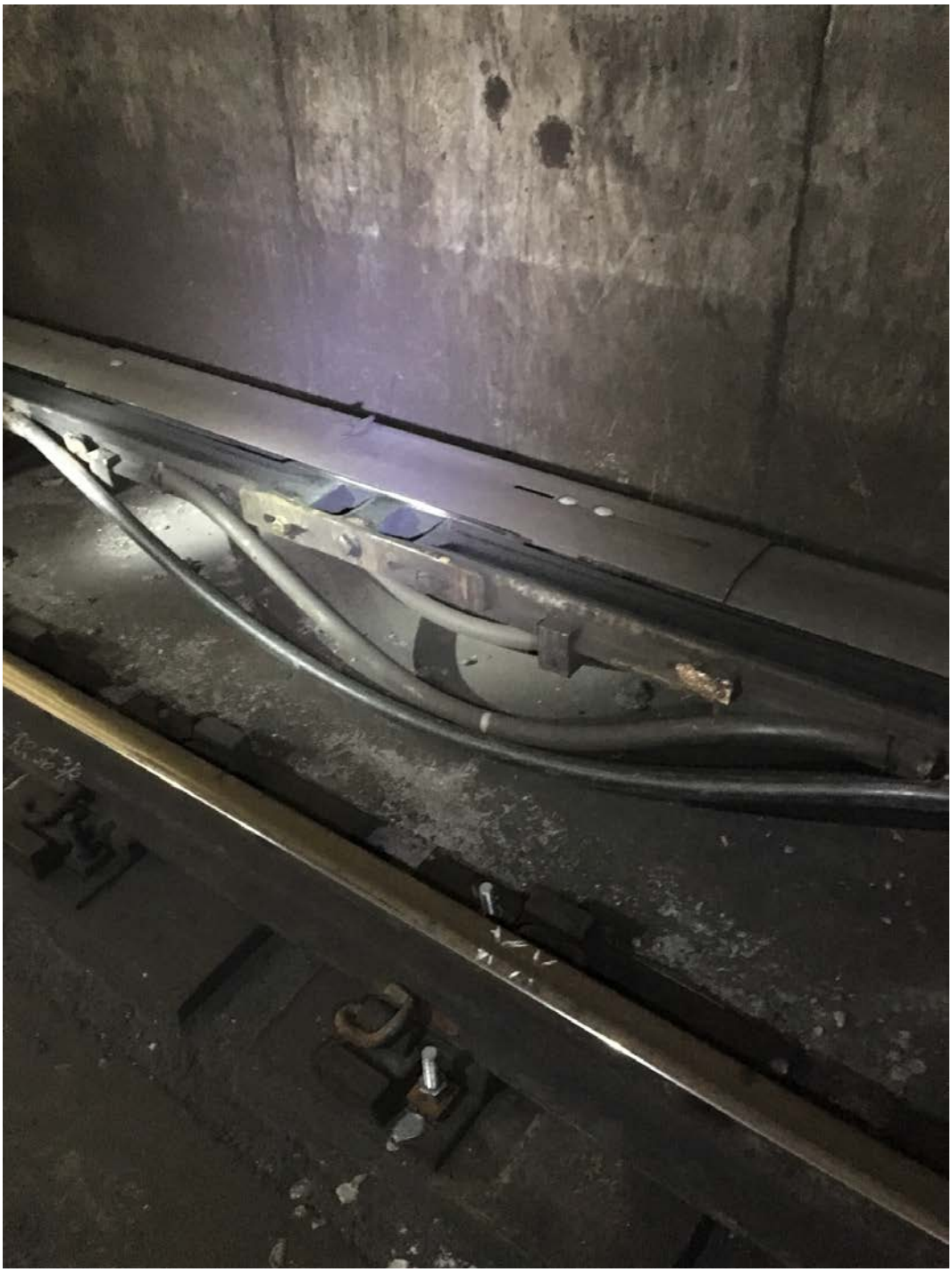

Figure 14: Cables on the Ground

Figure 15: Power Cables Loose against Tunnel Wall

- **Finding 5: WMATA does not implement a consistent program regarding the testing, inspection, and maintenance of its negative return system.**

Traction power return rail (running rail), fastening systems, and insulation are an integral part of the overall power system for DC third rail systems and provide critical protections against arcing events. Proper insulation isolates the potential for return currents to find alternate electrical paths to the substation, thereby preventing leakage currents from arcing and damaging infrastructure.

FWSO finds that WMATA's use of mechanical clamped bonds as a permanent installation on the running rail must be reevaluated since they are prone to corrosion and loosening. WMATA's most recent design standards require fastening systems that drill the running rail in the neutral axis of the web and bolt the cable via a crimped cable connection. This design standard replaces the exothermic welding of the cable to the running rail head and mechanical clamping as these methods potentially damaging or unreliable. WMATA's ATC technicians, however, are still authorized to use these methods for emergency or temporary repairs.

The final report from WMATA's peer review with APTA also directs WMATA to "re-evaluate the suitability of clamps for use in any cable termination." Specifically, the report notes, "the Polidori Clamps used to attach the ATC cables to the running rail should only be used for short-term correction of deficiencies, until time is available to install a permanent bond to the rail. The loosening of the clamp and corrosion of the connection contribute to stray current corrosion and negatively impact traction return and track/signal circuits."

In assessing this situation, FWSO finds that WMATA must appropriately train and assign personnel to install and maintain all negative return system components, including running rail bonds, which provide for a permanent connection. WMATA also must assign maintenance personnel to inspect and repair any running rail bonded joints that are physically compromised, missing, or inadequate to perform their required function.

The ability to define appropriate mitigations with respect to stray current management must be approached from a holistic perspective due to its complexity. Review of recent arcing events experienced by WMATA indicate that in addition to the cables, the running rail return and fastening systems also require corrective maintenance attention. FWSO's inspection team noted on several occasions that such defects are or will be contributors to infrastructure failures. At the current time, testing for insulating properties of third rail insulator mounting bolts and on track fasteners only occurs by exception via an independent corrosion testing firm.

Strong and effective electrical isolation (dielectric-electrical insulating material) is needed on both the third rail (positive) and running rail (negative) systems. While WMATA design standards require the running rail fastening base plate to be insulated and anchored to the structure via high resistance materials (epoxy coated bolts and epoxy sleeves), concerns with construction quality—based on FWSO observations of the third rail insulator replacement and associated fastener bolt installation—indicate that this may not always be the case in the field.

Flashovers experienced on the running rails occur when there is a difference in electrical potential between two metallic structures and an electrical arc is drawn (or established) across an air gap. This arc will remain until the arc extinguishes itself or the path is removed. Electrically,

this means that when there is a higher impedance, the voltage will rise in the running rail return system. Since the running rail is the electrical return path to the substation, when its intended path is compromised, such as when a fastening bolt is contacting with the structural rebar, the electrical return path to the substation will use the structure as its return path. This phenomena is also a major contributor to corrosion.

Finally, WMATA has been using uninsulated cinch anchors to install new insulators. This leaves a potential for a short circuit path between the third rail and invert-embedded rebar when an insulator experiences a failure (due to humidity and contamination). Until this voltage tracking occurs, the uninsulated anchors would be a hidden defect with serious potential dangers. WMATA TRPM staff recommend that this testing program be expanded to ensure this potential does not exist and the practice of using uninsulated cinch anchors must be immediately halted. FWSO further finds that uninsulated anchors must be located and replaced.

As was also noted in FTA's track integrity investigation, WMATA must document negative return system defects in the maintenance and repair trouble ticket system (Maximo) and assign responsibility for timely repairs. WMATA needs to better utilize the data and resources provided by the thermal imaging train runs and reports, as running rail bonding defects can be easily detected. This includes communicating defect reports to appropriate departments to affect repairs.

- **Finding 6: WMATA has not performed required inspections and preventive maintenance on its floating slab tunnel sections to ensure insulation resistance and the use of functioning sacrificial anodes.**

At WMATA, as discussed in Section 3 of this report, the running rails are used as the return conductor for traction current. Low resistance between the traction return rails and the ground can cause a significant part of the return current to leak into the ground. This is normally referred to as leakage current or stray current. The amount of leaking current depends on the conductance of the return tracks compared to the soil and on the quality of the insulation between the tracks and soil. Stray current creates or accelerates the electrolytic corrosion of metallic structures located on the track bed and in the proximity of the TPE system. Pipes, drains, fasteners, rail, and even support beams and other metallic structures can have a much shorter lifespan and can fail unexpectedly if the corrosion potential from stray current is not closely monitored.

Stray current control and mitigation can vary from segment to segment on WMATA's underground segments as each segment was designed and built under a different contract. While the predominant method of stray current mitigation was the use of sacrificial anodes, there were other methods used. In special locations, such as tunnels with inverts and floating slab construction, stray current can be an especially challenging concern, and the level of insulation between the tunnel system components and the tracks can be difficult to access, inspect, and maintain.

Floating slabs have been designed and installed in Metrorail's tunnels to reduce ground-borne vibration and noise transmitted to adjacent buildings. The concrete floating slabs rest on fiberglass, natural rubber, or polyurethane pads. These pads serve as cushions to isolate

structurally the floating slabs from the adjacent tunnel invert slabs. There are two basic types of floating slabs, one used in special track work areas and one used in the tunnel sections.

During its investigation, FWSO could find no clear maintenance procedure or standard on how to inspect slab installations, how to assess their asset condition, or how document and track repairs that may be needed. There are no records of inspections or assessments conducted regarding the floating slab sections of the tunnels. While substantial work was done to repair damaged polyurethane pads under floating slab sections in the 1990s, it does not appear that much preventive or corrective maintenance has been performed since that time.

In its investigation report, WMATA SAFE verifies that the floating slab design drawings indicate that the slab is bonded and connected to the adjacent track and grounded to the TPE system negative return. Sacrificial anodes were used as a method of protection to protect track and traction power components from corrosion and electrolysis. However, without records of inspection or preventative maintenance, it is impossible to know the level to which degraded or misaligned fiberglass, natural rubber, or polyurethane isolators, degraded sacrificial anodes, and water/debris accumulation contribute to stray current and electrolysis-caused deterioration of track and power components throughout the tunnel structure.

In its investigation report, WMATA SAFE confirmed that "the condition of the floating slab sections should be assumed to be poor and maintenance programs deficient. Preventive maintenance programs, such as the scheduled inspections and use of sacrificial anodes are not currently in place."

- **Finding 7: WMATA has not finalized its new requirements for third rail insulator design, procurement, installation, cleaning, and replacement.**

While WMATA has experienced extended arcing events at a variety of track fastening and cable locations, third rail insulators provide the most common location for these events. WMATA currently uses two types of third rail insulators—porcelain insulators that were installed on the original system and composite (fiberglass) insulators now used in the system. FWSO encountered a variety of analysis and assessments from WMATA technical staff regarding the durability and effectiveness of WMATA's porcelain insulators. While these insulators can last for extended periods and may resist contamination better than their fiberglass counterparts, when an extended arcing event occurs on a porcelain insulator, a flashover may result, which could forcefully explode the insulator. Fiberglass insulators, while potentially more susceptible to contamination and arcing, typically burn and release smoke but do not shatter. For this reason, WMATA recently completed a campaign to ensure that only fiberglass insulators are used at all underground station platforms.

WMATA's internal investigation into its electrical arcing events found that the specification used to procure fiberglass insulators must be updated to include additional testing and fire/life safety standards and instructions for packaging and shipping to prevent damage to the insulators during handling and transportation. WMATA also identified significant quality issues with some of the fiberglass insulators supplied by its contractor. WMATA has since worked with its contractor to develop and implement a corrective action plan to address the quality concerns.

WMATA continues to monitor the quality of its insulators through examinations and laboratory testing.

WMATA also reviewed its work instructions issued for insulator installation and found that additional guidance must be developed to address storage, transportation, and handling of replacement insulators. This guidance should also clarify that insulators should not be hit with metal hammers to position them under the contact rail or cut in any way to fit them under joint bars.

On May 11, 2016, FTA issued an immediate action letter directing WMATA to re-instate its insulator cleaning program within 30 days. FTA took this action to address concerns regarding the sustainability of improvements made in the tunnel environment to reduce the likelihood of arcing events, including insulator replacement. FWSO inspections have confirmed that local environmental regulations largely limit WMATA's cleaning options to pressurized water, and staffing challenges have made it impossible for WMATA to sustain an effective insulator cleaning program for its full tunnel environment. To address FTA's letter, the recent APTA Peer Review recommended that WMATA consider additional cleaning methods, such as curved brushes with insulated handles.

WMATA also is currently testing a two-piece fiberglass insulator that can be changed out and shipped to a separate location for cleaning and then quickly re-installed. In this configuration, a permanent base is mounted on the surface of a stone tie and the top piece of the insulator is then inserted into the permanent base. This design allows the top piece of the insulator, which is supporting the bottom of the contact rail, to be easily removed without having to disturb the permanent base. How this insulator performs in WMATA's environment, the conditions under which they can be safely changed out, and the speed of change-out remain to be determined.

Since the end of April, during early evening work outages and SafeTrack surges, WMATA has replaced thousands of insulators system-wide. An optimal insulator replacement program would entail a predictive change-out cycle based upon a variety factors such as the age of the insulator, environmental conditions, frequency of service, and cleaning programs to determine a useful life of the component. This would ideally lead to the replacement of insulators prior to failure. WMATA is still in the process of establishing a life cycle management approach for its insulators.

Finally, FWSO inspections have found that WMATA teams have been installing uninsulated steel cinch anchors while replacing insulators. If the anchor makes contact with invert rebar, a hidden defect is potentially created. Once insulators become dirty and arcing/voltage tracking occurs, high voltage would be induced into the rebar grid creating a hazardous condition, which could result in fire or explosion.

- **Finding 8: WMATA has not consistently implemented its third rail insulator grout pad repair and replacement plan.**

FWSO's team noted numerous third rail insulator grout pads in poor condition. WMATA does not have program in place for replacing third rail gout pads for supporting insulators and

reinforcing insulation resistance. FWSO finds that WMATA could easily adopt requirements consistent with the agency's track fastening plinth replacement requirements.

- **Finding 9: There is insufficient dielectric insulation for cable terminations used in the traction power system.**

WMATA's program to replace all cable connector assemblies in response to the NTSB recommendation R-15-25 is well underway. At the time of this report, WMATA has repaired all power cable connector assemblies in the tunnels and 95 percent of them on the aboveground mainline track, including installation of the weather tight seals that prevent intrusion by contaminants and moisture. There are other opportunities to improve dielectric insulation for cable terminations, including non-tracking heat shrink, utilizing alternative products for cable transitions at duct lines such as products and specifications used for the Dulles Line extension project, and providing additional physical barriers where there is close clearance to metallic structures utilizing GPO3 boards or similar products.

- **Finding 10: WMATA does not take full advantage of substation circuit breaker settings to better prevent and detect low fault trips.**

Traction power supply and distribution standards typically require modern relay protection for substation feeder circuit breakers, which normally includes instantaneous overcurrent, short-time overcurrent, long-time overcurrent, and current rate-of-rise detection. The purpose of the rate-of-rise detection is to discriminate between fault currents and the load currents of accelerating trains, since the load currents can be higher than the current resulting from remote faults (such as arcing faults). Concerns over nuisance faults, which would trip the relay protection and de-energize sections of the TPE system are significant for modern heavy rail systems like WMATA, as trains would lose power, impacting service reliability and potentially leaving trains stranded in tunnels or other locations.

WMATA's current relay settings can detect both near faults and remote faults to isolate DC system faults by tripping corresponding DC circuit breakers. Low-level faults of certain magnitudes are very difficult to detect by the protective relay because those types of faults have the similar characteristics of the hotel load (Heating, Ventilation Air-Conditioner (HVAC) system) of trains. The settings used in this system can be refined to provide greater opportunities to identify better protection against remote faults but may have only limited effectiveness against certain low-level faults. WMATA recently tasked a contractor with conducting traction power substations short circuit and relay coordination studies that will provide optimum relay settings.

FWSO finds that part of this assessment should determine whether the protection settings can be refined to provide greater level of protection from remote faults and greater ability to potentially identify low-level faults. The rate-of-rise relay functionality should include change in current and time delay settings; these can be adjusted to provide improve the circuit breaker protection from nuisance trips caused by rolling stock electrical characteristics.

Another approach used in some traction power systems employs transfer tripping in the protective scheme for feeder breakers that automatically de-energize the entire section of the

contact rail between substations and or circuit breaker substations. One benefit to utilizing this protection system would be the automatic removal of power in the event a low-level fault is not detected by the current relay protection system. The negative operational impacts can be mitigated if the circuit breaker that originates the trip signal is permitted, under appropriate conditions, to perform the normal auto-reclosing cycle before sending the transfer trip signal. The communications used for transfer tripping must be dedicated, point-to-point type circuits or channels.

FWSO believes that WMATA should consider refining its current circuit breaker settings to optimize the equipment's ability to detect various trackside conditions including instantaneous short circuit ratings that closely matched the train's maximum current, time-over-current settings, and rate-of-rise settings. WMATA also should consider adding transfer trip circuitry for de-energizing feeds from adjacent power stations during emergencies or refine the power dispatchers' situational awareness to remove power to track sections that experience failures such as smoke conditions and power failures.

- **Finding 11: Power cable insulation is contaminated.**

WMATA has conducted laboratory testing that has shown that power cable insulation that is affected by dust and mud conditions significantly regains its electrical resistance by cleaning and drying of the insulation. FWSO's team finds that WMATA may be able to restore some of the insulation resistance of its traction power cable feeder system through hand cleaning and drying of the cables.

5.2.2 Findings and Required Actions

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
Finding 4	Traction power cables are often loose on the ground, subjecting them to contamination, vibration, and damage from movement.	FTA-TPE-17-004-a	WMATA must implement its program to secure traction power cables off the ground.
Finding 5	WMATA does not implement a consistent program regarding the testing, inspection, and maintenance of its negative return system.	FTA-TPE-17-005-a	WMATA must discontinue the practice of using clamped bonds as a permanent installation.
		FTA-TPE-17-005-b	WMATA must locate and replace all clamped bonds with drilled rail web/bolted crimped cable connections, suitable for permanent installations.
		FTA-TPE-17-005-c	WMATA must appropriately train and assign personnel to correctly install and maintain all negative return system components, including drilled rail web running rail bonds.

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
		FTA-TPE-17-005-d	WMATA must assign maintenance personnel to inspect and repair any running rail bonded joints that are physically compromised, missing, or inadequate to perform their required function.
		FTA-TPE-17-005-e	WMATA must document negative return system defects in the maintenance and repair trouble ticket system (Maximo) and assign responsibility for timely repairs.
Finding 6	WMATA has not performed required inspections and preventive maintenance on its floating slab tunnel sections to ensure insulation resistance and the use of functioning sacrificial anodes.	FTA-TPE-17-006-a	WMATA must establish and implement an inspection, testing, maintenance, and repair program for its floating slab track, running rail insulation and sacrificial anodes.
Finding 7	WMATA has not finalized its new requirements for third rail insulator design, procurement, installation, cleaning, and replacement.	FTA-TPE-17-007-a	WMATA must establish its new insulator design specifications for composite (fiberglass) and porcelain insulators, including the two-piece insulator discussed with FWSO to facilitate more efficient and economical insulator replacement activities.
		FTA-TPE-17-007-b	WMATA must revise the current insulator replacement work instruction to include proper storage, transportation, and handling of insulators to reduce damage to new insulators before and during installation.
		FTA-TPE-17-007-c	Based on the design specifications established in FTA-TPE-17-007-a, WMATA must establish insulator mortality rates and implement cyclical replacement program for each type of insulator used on the Metrorail system.
		FTA-TPE-17-007-d	Based on the design specifications established in FTA-TPE-17-003-a, WMATA must develop and implement a formal program for cleaning insulators, including proposed work instructions to ensure the safety of WMATA employees.
		FTA-TPE-17-007-e	WMATA must establish a formal quality testing and inspection program to ensure conformance of the delivered insulators with WMATA's specifications and requirements.

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
		FTA-TPE-17-007-f	Based on the design specifications established in FTA-TPE-17-003-a, WMATA must ensure new insulator anchors are installed to WMATA standards including providing epoxy insulating dielectric material to ensure that the anchor bolts do not provide an electrical path to structural ground. (See WMATA's Track Standards TRST 1000 section 13- Contact Rail).
		FTA-TPE-17-007-g	WMATA must develop a plan to identify and correct the installation of insulator anchors without appropriate epoxy insulating dielectric material.
Finding 8	WMATA has not consistently implemented its third rail insulator grout pad repair and replacement plan.	FTA-TPE-17-008-a	Consistent with WMATA's track fastening plinth replacement requirements, WMATA must develop and implement a third rail grout pad replacement program for supporting insulators.
Finding 9	There is insufficient dielectric insulation for cable terminations used in the traction power system.	FTA-TPE-17-009-a	WMATA must conduct an assessment and implement results regarding the identification of additional methods to provide improved dielectric insulation in the area of cable terminations, such as non-tracking heat shrink, utilizing alternative products for cable transitions at duct lines, and providing additional physical barriers where there is close clearance to metallic structures.
Finding 10	WMATA does not take full advantage of substation circuit breaker settings to better prevent and detect low fault trips.	FTA-TPE-17-010-a	WMATA must evaluate the traction power DC feeder breaker settings at substations and tie breakers to determine the optimal settings for various track side conditions including instantaneous short circuit ratings, time over current settings, and rate of rise settings.
		FTA-TPE-17-010-b	WMATA must provide criteria and test results for circuit breaker relay settings to FWSO for evaluation.
		FTA-TPE-17-010-c	WMATA must develop and submit to FWSO its program plan for installing, testing, and evaluating the effectiveness of the use of MPR relays for detecting low level faults.
		FTA-TPE-17-010-d	WMATA must evaluate the addition of transfer trip circuitry for de-energizing feeds from adjacent power stations during troubled conditions and implement results.
Finding 11	Power cable insulation is contaminated.	FTA-TPE-17-011-a	WMATA must develop and submit to FWSO its program for cleaning and drying contaminated cables to improve surface resistivity, including proposed work instructions to ensure the safety of WMATA employees.

5.3 Testing and Inspection

FWSO's investigation found that testing and inspection to assess and monitor the condition of the TPE system and the corresponding preventive and corrective maintenance were not occurring as required. FWSO's team identified 3 findings and 7 required actions regarding this topic.

5.3.1 Situation

As noted in the final report released by the NTSB in response to the January 12, 2015 smoke and fire event at L'Enfant Plaza, incidents of cable fires in the rail transit tunnel environment present a smoke and fire hazard to the riding public, employees, and first responders. TPE systems require an ongoing program to inspect, test, maintain, and replace aging or damaged components. Without dedicated implementation of such a program, TPE systems will continue to experience fires and system shut downs and be prone to potential injuries, potential fatalities, and a loss of public trust.

As discussed in FWSO's Track Integrity Investigation report, FWSO believes that WMATA can achieve far more benefits from its automated inspection technology. Other inspection and testing program elements will assist WMATA in monitoring the condition of its TPE system.

- **Finding 12: WMATA does not do enough to ensure the effectiveness of its manual and automated inspection programs.**

FWSO finds that WMATA must clearly identify ownership of defects and provide timely notification to the appropriate department. WMATA must do more to integrate automated inspection technology into its TPE inspection program. Track geometry vehicle reports for third rail gauging and thermal imaging reports for hot spots are not submitted in a timely manner for action.

For example, the thermal imaging reports reviewed by FWSO appear to identify Wee-Z impedance bonds from the signal and train control system as hot spots in the return system. WMATA needs to review these conditions carefully to determine if the condition is related to the Wee-Z bonds or negative return cables associated with impedance bonds. WMATA should consider including representatives from the line departments to participate in riding the thermal imaging vehicle to enhance the operator/evaluator's ability to identify irregularities. WMATA needs to better utilize the data and resources provided by the thermal imaging train runs and reports because running rail bonding defects can be easily detected. This includes communicating defect reports to appropriate departments to initiate repairs.

The WMATA thermal imaging summary report document lacks comparisons to previous reports, therefore misses the opportunity to identify repetitive hot spots or determine if a past condition will become a larger concern. WMATA needs to include comparison reports from past thermal imaging runs in the current reports.

- **Finding 13: WMATA does not currently test cables to ensure insulation resistance.**

WMATA initially instituted a cable testing program for positive traction power feeder cables located in the tunnel environment to assess insulation resistance and predict failure. After results consistently showed weaknesses in insulation resistance, the program was suspended and transitioned to a 100 percent cable replacement program. However, as discussed in other sections of this report, WMATA only got to 80 percent replacement of its positive feeder cables before suspending the replacement program, and almost all of the secondary cables (jumper, transition, expansion) are original to the system, as is the negative return cabling. Under these circumstances, FWSO's team is concerned that WMATA plans to rely only on replacement, which will require many years, rather than testing to predict failure—particularly for cross bonded cables and tunnel areas that are prone to water and muck infiltration—to determine their integrity.

- **Finding 14: WMATA's corrosion testing program is currently limited to interlockings, signal system components, and special requests.**

The WMATA system utilizes the running rail to serve as the negative return for the DC system, which makes the transit system inherently susceptible to stray currents. The insulating properties of the fastening system provide a level of isolation from the effects of stray current provided they are maintained. The WMATA underground system has experienced deterioration and in many sections there is poor electrical isolation that requires remedial action to correct these deficiencies. WMATA must establish a maintenance plan that improves the insulation properties to reduce the high level of potential between the running rail and earth ground to mitigate the effect from stray current.

During tunnel inspections, FWSO observed many areas where it appears that stray current may be accelerating the corrosion of nearby metallic structures. WMATA must establish a testing program that proactively identifies locations where stray current is occurring and establish maintenance programs that mitigate these areas of poor isolation, such as track fastening systems. As a result of internal assessments, and work to address FTA's SMI finding requiring a systemwide stray current testing program, WMATA is taking steps to expand its corrosion-testing program beyond interlockings and signal system components to the mainline.

5.3.2 Findings and Required Actions

TPE Investigation Category 3: Inspection and Testing			
Finding		**Required Action**	
Finding 12	WMATA does not do enough to ensure the effectiveness of its manual and automated inspection programs.	FTA-TPE-17-012-a	WMATA must establish grading criteria for TPE system defects, similar to the defect system established for track, and must instruct inspection personnel in how to use them. These grading criteria must also address thermal imaging anomalies and include acceptable thermal variation criteria and action levels.
		FTA-TPE-17-012-b	WMATA must establish a procedure to ensure that thermal imaging data is reviewed with all stakeholders and that automated inspections, which include data collection and analysis of TPE system components, are used collectively to identify trends and target areas for preventive maintenance or monitoring.
		FTA-TPE-17-012-c	To enhance usefulness, WMATA must revise its thermal imaging summary report to include comparison reports from past thermal imaging runs.
		FTA-TPE-17-012-d	WMATA must establish a procedure to ensure that TGV third rail data is compared with the reports filed by track inspectors and with previous TGV data to identify trends. Specifically, this procedure must ensure the geometry data from the TGV is reviewed for third rail gauge exceptions, especially in super-elevated track areas and floating slab construction; assess the re-gauging of the third rail per WMATA's Track Standards TRST 1000 section 13 - Contact Rail; and evaluate the need for corrective repairs when the system is out of tolerance.
Finding 13	WMATA does not currently test cables to ensure insulation resistance.	FTA-TPE-17-013-a	WMATA must develop a meggering plan for cross bonded cables, especially in tunnel areas that are prone to water and muck infiltration, to determine their integrity.
		FTA-TPE-17-013-b	WMATA must institute a cable testing program for jumper and transition cables located in the tunnel environment until these cables are upgraded and/or replaced.
Finding 14	WMATA's corrosion testing program is currently limited to interlockings, signal system components, and special requests.	FTA-TPE-17-014-a	WMATA must implement a regular program of stray current and corrosion control testing, which should include, at a minimum, the following: track to earth electrical isolation, track to earth voltage, yard to mainline electrical isolation, shop to yard electrical isolation, mainline segregation, and cathodic protection systems.

5.4 Capital Projects

FWSO's investigation found that capital projects to replace and upgrade WMATA's TPE system have been deferred, delayed or suspended. FWSO's team identified 8 findings and 10 required actions regarding this topic.

5.4.1 Situation

During the investigation, FWSO confirmed that programs to replace and upgrade critical TPE infrastructure, including tiebreakers and cable plant, have not been sufficient for the age of the system or the demand placed on it. Capital project plans have stalled or are just now being re-examined and re-configured to prepare the system for 100 percent 8-car train operations. Further, information that the system has regarding power load and cabling needs for the future is based on incomplete modeling assumptions about the condition of the infrastructure and the compatibility of old and new equipment.

- **Finding 15: WMATA's load studies for 100 percent 8-car train operation were based on design criteria and did not include field assessments to confirm the actual condition of the TPE system infrastructure.**

WMATA utilizes capital funds to upgrade its system for improved service and reliability and for State of Good Repair programs for end of life cyclical replacement of infrastructure. The WMATA Capital Programs Group has upgraded power infrastructure assets in preparation for 8-car trains and to support additional service associated with increased ridership. This program includes wayside to traction power substation and tiebreaker cable replacement, substation rectifier upgrades and increased Megawatt (MW) output, tiebreaker station upgrades to higher amperage DC circuit breakers, and impedance bond replacement to high current bonds at substations.

WMATA's load study for 100 percent operation of 8-car trains conducted computer simulation to assess a series of options for enhancing the system. Voltage scatter plots resulting from this assessment demonstrate that raising the system nominal DC voltage immediately improves the voltage profile, minimizing the quantity of locations where the voltage falls below acceptable operating limits.

WMATA's negative return system (at traction power substations) has not been upgraded to address plans for 8-car trains. FWSO found that power load studies and assessments, which were conducted by WMATA to support engineering studies to determine power requirements for 100 percent 8-car train operation, do not accurately represent the deteriorated condition of WMATA's cable plant. Incomplete modeling assumptions outlined in these studies indicate that additional upgrades and cable replacement will be required to realistically and safely power 100 percent 8-car train operation. WMATA must revisit its cable upgrade program for 50 percent and 100 percent 8-car operational plan and develop a capital cable replacement program for substation negative return and wayside cross bonding.

The equipment recommendations also do not take into consideration the possibility that some of the older DC switchgear may have positive and negative DC bus ratings below the current WMATA standard of 15,000 A. Substations with bus ratings below 15,000 A may require upgrade of the negative switchboard as well as positive and negative bus work.

- **Finding 16: WMATA does not have a formal program for assessing the condition of relays at traction power substations prior to proposed upgrades.**

WMATA is considering a proposal to use new multi-function relays (MFRs) to detect low level faults as part of the upgrade of its aging TPSS infrastructure on the mainline system. A significant reduction in the amount of protective and control devices (and associated wiring) has been achieved by introduction of MFRs, which are capable of replacing a whole group of relays used for equipment protection and automated control. For example, one MFR may perform the functions of overcurrent and ground fault protection, over and under-voltage protection, fault sensing, and reclosing. WMATA used MFRs on its new Silver Line construction.

The FWSO team and WMATA discussed the challenges of this transition to such new technology given the age and historic performance of the WMATA TPE system. However, as this transition is approached, a full accounting of the condition of the relays at traction power substations will be critical to prioritizing upgrades, replacement and repairs, and to ensuring compatibility during the transition.

- **Finding 17: The cable replacement and upgrade program for 8-car train roll out has been deferred.**
- **Finding 18: WMATA's negative return system (at traction power substations) has not been upgraded to address plans for 50 percent and 100 percent operation of 8-car trains.**
- **Finding 19: WMATA has suspended its contact rail expansion joint elimination program until further analysis is completed.**
- **Finding 20: WMATA has deferred its third rail composite replacement program.**
- **Finding 21: WMATA is not maintaining its cover board repair program.**

Through the course of this investigation, FWSO confirmed that programs to replace and upgrade critical TPE infrastructure—including the cable plant (both positive and negative return system), contact rail, protection cover boards—and programs to perform third rail joint elimination have stopped, deferred, stalled, or not been sufficient to address the full TPE system.

While approximately 80 percent of primary positive feeder cables have been replaced on the Metrorail system in the last 15 years, most secondary cables, which connect the primary cables to the contact rail or traction power substations or which bridge engineered gaps in the contact rail system, are original with the Metrorail system. The age and degraded condition of this secondary cabling system now presents a potential point of failure for sustained electrical arcing events and fires. Also, negative return power cables are similarly found in degraded condition and in direct contact with the ground and ballast. Therefore, once the positive cables are fully addressed, negative cables must be addressed as well.

Currently, the only funded element of the 100%, 8-car train program is on the Orange and Blue Lines (New Carrollton to Vienna and Franconia to Largo). Overall, 75% of the needed cable additions (positive and negative feeder cables) are complete on these segments. The remaining 25% are on schedule to be completed no later than fiscal year 2020.

WMATA's third rail power system currently utilizes two types of rail: AREMA 150 pound steel rail or composite third rail, which is comprised of steel with an aluminum alloy strip to promote electrical conductivity. The minimum voltage scatter plots prepared for WMATA's power load study demonstrate the benefits of replacing the existing 150 pound steel rail with composite contact rail. The resistance of the composite rail is significantly lower than that of the 150 pound steel rail, providing an improved voltage profile and reduced contact rail voltage drop. The combination of both raising the system voltage through the TPSS and cable plant upgrade and installing composite contact rail demonstrates even more significant improvement in the voltage profile. While WMATA initially moved in this direction, FWSO found that interest in this replacement program has dissipated over time, due to concerns regarding return on investment. WMATA reports that, while beneficial, replacement of 150 pound steel rails with composite contact rails is not required to run 100 percent, 8-car trains, and that internal studies show this change only results in a voltage gain of 7V or less.

WMATA also identified locations in the system where gaps in the third rail can be eliminated, such as third rail joints, and has started to remove them to reduce the volume of jumpers in the system. WMATA developed an Engineering Modification Instruction (EMI) for this activity, which was shared with FWSO and is currently in the process of being approved. FWSO inspectors recently learned that work to eliminate expansion joints has stopped.

Cover board replacement has been a consistent concern raised by FWSO, and while WMATA is replacing cover boards in SafeTrack work areas, FWSO has not received the long-term plan proposed in response to FTA's immediate action letter from April 18, 2016 on fire/life safety concerns. FWSO also expects this plan to address options for compliance with the enhanced National Fire Protection Association (NFPA) 130 standard.

- **Finding 22: Fastener failures, linked to stray current, have resulted in fault conditions at stud bolts.**

Figure 16 shows the damaged running rail fastener (tie plate) and stud mounting bolt recovered from a WMATA electrical arcing event at Gallery Place Station on June 27, 2016.

In this instance, the damaged stud bolt, circled in red, was located in the running rail farthest from the third rail, which indicates that this event was a traction power return system (negative) failure and not a flashover from the contact rail (positive). As discussed in earlier findings related to the deteriorated corrosion control features in the floating slab tunnel sections, stray current leakage is a critical concern that WMATA must investigate and resolve through its stray current corrosion control plan and enhanced attention to the inspection, maintenance, and repair of its tunnel sections, and also through increased insulation resistance in rail fasteners.

Figure 16: Track Fastener Involved in Gallery Place Electrical Arcing Incident, June 27, 2016

5.4.2 Findings and Required Actions

TPE Investigation Category 4: Capital Projects			
Finding		**Required Action**	
Finding 15	WMATA's load studies for 100 percent 8-car train operation were based on design criteria and did not include field assessments to confirm the actual condition of the TPE system infrastructure.	FTA-TPE-17-015-a	WMATA must re-evaluate previous current draw and load calculations to include field surveys to ensure that the actual condition of the cables and bonds are considered in the requirements analysis for 100 percent 8-car train operation.
Finding 16	WMATA does not have a formal program for assessing the condition of relays at traction power substations prior to proposed upgrades.	FTA-TPE-17-016-a	WMATA must develop and implement a program for assessing the condition of relays at traction power substations to prioritize upgrade, replacement and/or repair.
Finding 17	The cable replacement and upgrade program for 8-car train roll out has been deferred.	FTA-TPE-17-017-a	WMATA must re-instate its program for cable replacement to support 100 percent 8-car train operations, including the replacement of all primary and secondary TPE system cables, and must provide FTA with a timeline and project plan.
Finding 18	WMATA's negative return system (at traction power substations) has not been upgraded to address plans for 50 percent and 100 percent operation of 8-car trains.	FTA-TPE-17-018-a	WMATA must revisit its cable upgrade program for 50 percent and 100 percent 8-car operational plan and develop a capital cable replacement program for substation negative return and wayside cross bonding.
Finding 19	WMATA has suspended its contact rail expansion joint elimination program until further analysis is completed.	FTA-TPE-17-019-a	WMATA must provide FWSO with a written explanation regarding the suspension of this program.
Finding 20	WMATA has deferred its third rail composite replacement program.	FTA-TPE-17-020-a	WMATA must explain the original intent of this replacement program, define the rationale for stopping the program, and clarify intentions to re-instate this program.
		FTA-TPE-17-020-b	WMATA must review fault detection relay settings and determine if adjustments are required due to the new electrical properties for composite third rail.
Finding 21	WMATA is not maintaining its cover board repair program.	FTA-TPE-17-021-a	WMATA must provide FWSO with its revised schedule for repairing all missing cover boards in the tunnel segments of the WMATA system.
		FTA-TPE-17-021-b	WMATA must evaluate the current protection board design specification and enhance it to meet the NFPA 130 standard.
Finding 22	Fastener failures, linked to stray current, have resulted in fault conditions at stud bolts.	FTA-TPE-17-022-a	WMATA must establish criteria for its fastener replacement program to improve insulation resistance.

Appendix A: TPE Investigation Findings and Required Actions Matrix

TPE Investigation Category 1: Roles, Responsibilities and Resources			
Finding		**Required Action**	
Finding 1	Multiple WMATA departments have responsibility for critical TPE system inspection, maintenance, and repair activities, preventing clear ownership of the TPE system and identification of systemic issues and priorities.	FTA-TPE-17-001-a	WMATA must conduct an assessment to determine if all TPE system program components should be integrated into a single department with sole responsibility for managing, inspecting, maintaining, repairing, and upgrading the TPE system. At a minimum, this assessment must include those elements of TPE system inspection, maintenance, and repair currently performed by TRPM; third rail inspection and maintenance work currently performed by TRST; negative return system inspection and maintenance activities performed by ATC; cable replacement activity performed by IRCM; engineering services provided by PWRS; and lock-out/tag-out procedures implemented by the ROCC and MOC.
		FTA-TPE-17-001-b	WMATA must implement the results of the assessment conducted to address FTA-TPE-17-001-a following a schedule reviewed and approved by FTA.
Finding 2	WMATA ROCC and MOC personnel are not sufficiently proactive in managing TPE concerns during emergencies.	FTA-TPE-17-002-a	WMATA must develop and provide TPE system awareness training for ROCC and MOC personnel.
		FTA-TPE-17-002-b	WMATA must revisit SOP #2: Emergency Removal and Restoration of Third Rail Power Mainline to consider: 1) removal of power during smoke conditions, especially with corresponding third rail power outages caused by unknown conditions, and 2) a requirement to de-energize third rail power at the adjacent power substation or tie breaker, provided the situation does not strand a train that needs to be moved from the smoke condition.
Finding 3	Insufficient resources are available to support the testing, inspection, and maintenance of WMATA's TPE system.	FTA-TPE-17-003-a	WMATA must amend or update the TRPM workload assessment completed by the HNTB Corporation to address the results of FTA-TPE-17-001-a.
		FTA-TPE-17-003-b	WMATA must develop a 5-year plan for staffing to implement results of the revised workload assessment, reflecting the results of FTA-TPE-17-001-a.
		FTA-TPE-17-003-c	WMATA must evaluate options for using contractors to complete its TPE system corrective maintenance backlog and outstanding preventive maintenance requirements in the near-term and implement results.

TPE Investigation Category 1: Roles, Responsibilities and Resources		
Finding	**Required Action**	
	FTA-TPE-17-003-d	WMATA must perform a cost benefit analysis with regard to repairing or replacing the out-of-service vacuum vehicle and implement the results.
	FTA-TPE-17-003-e	WMATA must improve the functionality of the thermal imaging car to more accurately pick up cable hot spots.

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
Finding 4	Traction power cables are often loose on the ground, subjecting them to contamination, vibration, and damage from movement.	FTA-TPE-17-004-a	WMATA must implement its program to secure traction power cables off the ground.
Finding 5	WMATA does not implement a consistent program regarding the testing, inspection, and maintenance of its negative return system.	FTA-TPE-17-005-a	WMATA must discontinue the practice of using clamped bonds as a permanent installation.
		FTA-TPE-17-005-b	WMATA must locate and replace all clamped bonds with drilled rail web/bolted crimped cable connections, suitable for permanent installations.
		FTA-TPE-17-005-c	WMATA must appropriately train and assign personnel to correctly install and maintain all negative return system components, including drilled rail web running rail bonds.
		FTA-TPE-17-005-d	WMATA must assign maintenance personnel to inspect and repair any running rail bonded joints that are physically compromised, missing, or inadequate to perform their required function.
		FTA-TPE-17-005-e	WMATA must document negative return system defects in the maintenance and repair trouble ticket system (Maximo) and assign responsibility for timely repairs.
Finding 6	WMATA has not performed required inspections and preventive maintenance on its floating slab tunnel sections to ensure insulation resistance and the use of functioning sacrificial anodes.	FTA-TPE-17-006-a	WMATA must establish and implement an inspection, testing, maintenance, and repair program for its floating slab track, running rail insulation and sacrificial anodes.

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
Finding 7	WMATA has not finalized its new requirements for third rail insulator design, procurement, installation, cleaning, and replacement.	FTA-TPE-17-007-a	WMATA must establish its new insulator design specifications for composite (fiberglass) and porcelain insulators, including the two-piece insulator discussed with FWSO to facilitate more efficient and economical insulator replacement activities.
		FTA-TPE-17-007-b	WMATA must revise the current insulator replacement work instruction to include proper storage, transportation, and handling of insulators to reduce damage to new insulators before and during installation.
		FTA-TPE-17-007-c	Based on the design specifications established in FTA-TPE-17-007-a, WMATA must establish insulator mortality rates and implement cyclical replacement program for each type of insulator used on the Metrorail system.
		FTA-TPE-17-007-d	Based on the design specifications established in FTA-TPE-17-003-a, WMATA must develop and implement a formal program for cleaning insulators, including proposed work instructions to ensure the safety of WMATA employees.
		FTA-TPE-17-007-e	WMATA must establish a formal quality testing and inspection program to ensure conformance of the delivered insulators with WMATA's specifications and requirements.
		FTA-TPE-17-007-f	Based on the design specifications established in FTA-TPE-17-003-a, WMATA must ensure new insulator anchors are installed to WMATA standards including providing epoxy insulating dielectric material to ensure that the anchor bolts do not provide an electrical path to structural ground. (See WMATA's Track Standards TRST 1000 section 13- Contact Rail).
		FTA-TPE-17-007-g	WMATA must develop a plan to identify and correct the installation of insulator anchors without appropriate epoxy insulating dielectric material.
Finding 8	WMATA has not consistently implemented its third rail insulator grout pad repair and replacement plan.	FTA-TPE-17-008-a	Consistent with WMATA's track fastening plinth replacement requirements, WMATA must develop and implement a third rail grout pad replacement program for supporting insulators.

TPE Investigation Category 2: Infrastructure			
Finding		**Required Action**	
Finding 9	There is insufficient dielectric insulation for cable terminations used in the traction power system.	FTA-TPE-17-009-a	WMATA must conduct an assessment and implement results regarding the identification of additional methods to provide improved dielectric insulation in the area of cable terminations, such as non-tracking heat shrink, utilizing alternative products for cable transitions at duct lines, and providing additional physical barriers where there is close clearance to metallic structures.
Finding 10	WMATA does not take full advantage of substation circuit breaker settings to better prevent and detect low fault trips.	FTA-TPE-17-010-a	WMATA must evaluate the traction power DC feeder breaker settings at substations and tie breakers to determine the optimal settings for various track side conditions, including instantaneous short circuit ratings, time over current settings, and rate of rise settings.
		FTA-TPE-17-010-b	WMATA must provide criteria and test results for circuit breaker relay settings to FWSO for evaluation.
		FTA-TPE-17-010-c	WMATA must develop and submit to FWSO its program plan for installing, testing, and evaluating the effectiveness of the use of MPR relays for detecting low level faults.
		FTA-TPE-17-010-d	WMATA must evaluate the addition of transfer trip circuitry for de-energizing feeds from adjacent power stations during troubled conditions and implement results.
Finding 11	Power cable insulation is contaminated.	FTA-TPE-17-011-a	WMATA must develop and submit to FWSO its program for cleaning and drying contaminated cables to improve surface resistivity, including proposed work instructions to ensure the safety of WMATA employees.

TPE Investigation Category 3: Inspection and Testing			
Finding		**Required Action**	
Finding 12	WMATA does not do enough to ensure the effectiveness of its manual and automated inspection programs.	FTA-TPE-17-012-a	WMATA must establish grading criteria for TPE system defects, similar to the defect system established for track, and must instruct inspection personnel in how to use them. These grading criteria must also address thermal imaging anomalies and include acceptable thermal variation criteria and action levels.
		FTA-TPE-17-012-b	WMATA must establish a procedure to ensure that thermal imaging data is reviewed with all stakeholders and that automated inspections, which include data collection and analysis of TPE system components, are used collectively to identify trends and target areas for preventive maintenance or monitoring.

TPE Investigation Category 3: Inspection and Testing			
Finding		**Required Action**	
		FTA-TPE-17-012-c	To enhance usefulness, WMATA must revise its thermal imaging summary report to include comparison reports from past thermal imaging runs.
		FTA-TPE-17-012-d	WMATA must establish a procedure to ensure that TGV third rail data is compared with the reports filed by track inspectors and with previous TGV data to identify trends. Specifically, this procedure must ensure the geometry data from the TGV is reviewed for third rail gauge exceptions, especially in super-elevated track areas and floating slab construction; assess the re-gauging of the third rail per WMATA's Track Standards TRST 1000 section 13 - Contact Rail; and evaluate the need for corrective repairs when the system is out of tolerance.
Finding 13	WMATA does not currently test cables to ensure insulation resistance.	FTA-TPE-17-013-a	WMATA must develop a meggering plan for cross bonded cables, especially in tunnel areas that are prone to water and muck infiltration, to determine their integrity.
		FTA-TPE-17-013-b	WMATA must institute a cable testing program for jumper and transition cables located in the tunnel environment until these cables are upgraded and/or replaced.
Finding 14	WMATA's corrosion testing program is currently limited to interlockings, signal system components, and special requests.	FTA-TPE-17-014-a	WMATA must implement a regular program of stray current and corrosion control testing, which should include, at a minimum, the following: track to earth electrical isolation, track to earth voltage, yard to mainline electrical isolation, shop to yard electrical isolation, mainline segregation, and cathodic protection systems.

TPE Investigation Category 4: Capital Projects			
Finding		**Required Action**	
Finding 15	WMATA's load studies for 100 percent 8-car train operation were based on design criteria and did not include field assessments to confirm the actual condition of the TPE system infrastructure.	FTA-TPE-17-015-a	WMATA must re-evaluate previous current draw and load calculations to include field surveys to ensure that the actual condition of the cables and bonds are considered in the requirements analysis for 100 percent 8-car train operation.
Finding 16	WMATA does not have a formal program for assessing the condition of relays at traction power substations prior to proposed upgrades.	FTA-TPE-17-016-a	WMATA must develop and implement a program for assessing the condition of relays at traction power substations to prioritize upgrade, replacement and/or repair.
Finding 17	The cable replacement and upgrade program for 8-car train roll out has been deferred.	FTA-TPE-17-017-a	WMATA must re-instate its program for cable replacement to support 100 percent 8-car train operations, including the replacement of all primary and secondary TPE system cables, and must provide FTA with a timeline and project plan.
Finding 18	WMATA's negative return system (at traction power substations) has not been upgraded to address plans for 50 percent and 100 percent operation of 8-car trains.	FTA-TPE-17-018-a	WMATA must revisit its cable upgrade program for 50 percent and 100 percent 8-car operational plan and develop a capital cable replacement program for substation negative return and wayside cross bonding.
Finding 19	WMATA has suspended its contact rail expansion joint elimination program until further analysis is completed.	FTA-TPE-17-019-a	WMATA must provide FWSO with a written explanation regarding the suspension of this program.
Finding 20	WMATA has deferred its third rail composite replacement program.	FTA-TPE-17-020-a	WMATA must explain the original intent of this replacement program, define the rationale for stopping the program, and clarify intentions to re-instate this program.
		FTA-TPE-17-020-b	WMATA must review fault detection relay settings and determine if adjustments are required due to the new electrical properties for composite third rail.
Finding 21	WMATA is not maintaining its cover board repair program.	FTA-TPE-17-021-a	WMATA must provide FWSO with its revised schedule for repairing all missing cover boards in the tunnel segments of the WMATA system.
		FTA-TPE-17-021-b	WMATA must evaluate the current protection board design specification and enhance it to meet the NFPA 130 standard.
Finding 22	Fastener failures, linked to stray current, have resulted in fault conditions at stud bolts.	FTA-TPE-17-022-a	WMATA must establish criteria for its fastener replacement program to improve insulation resistance.

Appendix B: Crosswalk with WMATA Safety Recommendations

***Safety Recommendations excerpted from: *Traction Power System Report, Assessment of Recent Electrical Fire and Arcing Incidents, Final Draft Report*, Washington Metropolitan Area Transit Authority, Department of Safety and Environmental Management, issued on October 20, 2016

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
Insulator Recommendations			
SAFE TPS 16-001	QICO should arrange for independent testing of insulators manufactured under the process described in the Delta Corrective Action Request/Report to confirm the effectiveness of the process improvement.	FTA-TPE-17-007-e	WMATA must establish a formal quality testing and inspection program to ensure conformance of the delivered insulators with WMATA's specifications and requirements.
SAFE TPS 16-002	With regard to receiving insulator shipments and transporting them to their final destination, this taskforce recommends that the designated COTR perform the following: • Create an incoming inspection checklist • Create an insulator handling process and distribute to relevant groups within TRST • Set up a sampling scheme and testing protocol for future batches of insulators • Engage QICO for support in the incoming inspection process		
SAFE TPS 16-003	Procurement in conjunction with PWRS, evaluate revising insulator design specifications for composite (fiberglass) and porcelain insulators to incorporate industry best standards.	FTA-TPE-17-007-a	WMATA must establish its new insulator design specifications for composite (fiberglass) and porcelain insulators, including the two-piece insulator discussed with FWSO to facilitate more efficient and economical insulator replacement activities.
SAFE TPS 16-004	TRST should revise the current insulator replacement Work Instruction to include proper storage, transportation and handling of insulators to reduce damage to new insulators	FTA-TPE-17-007-b	WMATA must revise the current insulator replacement work instruction to include proper storage, transportation and handling of insulators

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
	before and during installation.		to reduce damage to new insulators before and during installation.
SAFE TPS 16-005	TRST in conjunction with PWRS, should pursue a two-piece insulator to facilitate more efficient and economical insulator replacement activities.	See FTA-TPE-17-007-a	
SAFE TPS 16-006	PWRS should perform an analysis to determine insulator mortality rates that establishes a baseline for cyclical replacement programs.	FTA-TPE-17-007-c	Based on the design specifications established in FTA-TPE-17-007-a, WMATA must establish insulator mortality rates and implement cyclical replacement program for each type of insulator used on the Metrorail system.
SAFE TPS 16-007	TRST should evaluate alternative insulator cleaning methods, such as those outlined in the APTA Peer review, while remaining in compliance with local environmental requirements.	FTA-TPE-17-007-d	Based on the design specifications established in FTA-TPE-17-007-a, WMATA must develop and implement a formal program for cleaning insulators, including proposed work instructions to ensure the safety of WMATA employees.
SAFE TPS 16-008	TRST, in conjunction with SAFE, should perform a job task assessment to determine appropriate practices (i.e., Supervisory vs. Red Tag third rail power outage) in order to safely and efficiently perform both insulator cleaning and replacement activities.		
Other FTA Required Action relating to insulators	N/A	FTA-TPE-17-007-f	Based on the design specifications established in FTA-TPE-17-007-a, WMATA must ensure new insulator anchors are installed to WMATA standards including providing epoxy insulating dielectric material to ensure that the anchor bolts do not provide an electrical path to structural ground. (See WMATA's Track Standards TRST 1000 section 13- Contact Rail).
	N/A	FTA-TPE-17-007-g	WMATA must develop a plan to identify and correct the installation of insulator anchors without appropriate epoxy insulating dielectric material.
Other FTA Required Action relating to insulators (grout pads)	N/A	FTA-TPE-17-008-a	Consistent with WMATA's track fastening plinth replacement requirements, WMATA must develop and implement a third rail grout pad replacement program for supporting insulators.

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
Power Cable Recommendations			
SAFE TPS 16-009	IRCM and TRPM re-evaluate the current Capital Program strategy to upgrade cables system-wide to include secondary TPS cables and ATC bonds within the scope of project.	FTA-TPE-17-017-a	WMATA must re-instate its program for cable replacement to support 100 percent 8-car train operations, including the replacement of all primary and secondary TPE system cables, and must provide FTA with a timeline and project plan.
		FTA-TPE-17-018-a	WMATA must revisit its cable upgrade program for 50 percent and 100 percent 8-car operational plan and develop a capital cable replacement program for substation negative return and wayside cross bonding.
		FTA-TPE-17-003-c	WMATA must evaluate options for using contractors to complete its TPE system corrective maintenance backlog and outstanding preventive maintenance requirements in the near-term and implement results.
		FTA-TPE-17-019-a	WMATA must provide FWSO with a written explanation regarding the suspension of this program (third rail joint and jumper cable elimination program).
Other FTA Required Action relating to cable connection and replacement, including ATC bonds and negative return system	N/A	FTA-TPE-17-005-a	WMATA must discontinue the practice of using clamped bonds as a permanent installation.
	N/A	FTA-TPE-17-005-b	WMATA must locate and replace all clamped bonds with drilled rail web/bolted crimped cable connections, suitable for permanent installations.
	N/A	FTA-TPE-17-005-c	WMATA must appropriately train and assign personnel to correctly install and maintain all negative return system components, including drilled rail web running rail bonds.
	N/A	FTA-TPE-17-005-d	WMATA must assign maintenance personnel to inspect and repair any running rail bonded joints that are physically compromised, missing, or inadequate to perform their required function.
	N/A	FTA-TPE-17-005-e	WMATA must document negative return system defects in the maintenance and repair trouble ticket system (Maximo) and assign responsibility for timely repairs.

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
SAFE TPS 16-010	IRCM and PWRS re-evaluate previous current draw and load calculations to include field surveys to ensure that the actual condition of the cables and bonds are considered when performing this activity.	FTA-TPE-17-015-a	WMATA must re-evaluate previous current draw and load calculations to include field surveys to ensure that the actual condition of the cables and bonds are considered in the requirements analysis for 100 percent 8-car train operation.
SAFE TPS 16-011	TRPM complete the initiative to permanently raise power cables off the ground as well as prevent contact with running rail and other track components. In addition, ensure that negative cables are also addressed as part of this activity.	FTA-TPE-17-004-a	WMATA must implement its program to secure traction power cables off the ground.
SAFE TPS 16-012	PWRS evaluate whether the current cable connector design (orange) can be improved by elimination, addition of a junction box or similar component.	FTA-TPE-17-009-a	WMATA must conduct an assessment and implement results regarding the identification of additional methods to provide improved dielectric insulation in the area of cable terminations, such as non-tracking heat shrink, utilizing alternative products for cable transitions at duct lines, and providing additional physical barriers where there is close clearance to metallic structures.
SAFE TPS 16-013	TRPM evaluate conditions under which cleaning and drying "dirty" cables is an acceptable mitigation to improve surface resistivity. If added to Preventive Maintenance Instruction, coordinate with SAFE to ensure appropriate hazard analysis and mitigation occurs.	FTA-TPE-17-011-a	WMATA must develop and submit to FWSO its program for cleaning and drying contaminated cables to improve surface resistivity, including proposed work instructions to ensure the safety of WMATA employees.
Third Rail Protection Board Recommendations			
SAFE TPS 16-014	TRPM in conjunction with PWRS review the current methodology and hardware for securing third rail protection boards and evaluate modifying to improve track inspectors ability to identify defects.	FTA-TPE-17-021-a	WMATA must provide FWSO with its revised schedule for repairing all missing cover boards in the tunnel segments of the WMATA system.
SAFE TPS 15	PWRS evaluate the current protection board design specification and enhance it to meet the NFPA 130 standard.	FTA-TPE-17-021-b	WMATA must evaluate the current protection board design specification and enhance it to meet the NFPA 130 standard.
Other FTA Required Actions related to third rail replacement program	N/A	FTA-TPE-17-020-a	WMATA must explain the original intent of this replacement program, define the rationale for stopping the program, and clarify intentions to re-instate this program.
	N/A	FTA-TPE-17-020-b	WMATA must review fault detection relay settings and determine if adjustments are required

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
			due to the new electrical properties for composite third rail.
Inspection and Maintenance Recommendations			
SAFE TPS 16-016	TRST and TRPM management should evaluate and adopt where appropriate the training recommendations made by HNTB Corporation.	FTA-TPE-17-003-a	WMATA must amend or update the TRPM workload assessment completed by the HNTB Corporation to address the results of FTA-TPE-17-001-a (single TPE department).
		FTA-TPE-17-003-b	WMATA must develop a 5-year plan for staffing to implement results of the revised workload assessment, reflecting the results of FTA-TPE-17-001-a (single TPE department).
SAFE TPS 16-017	TRST should revise the existing TRST-1000 manual to include specific and easily understood TPS grading criteria (priority/action levels similar to the color codes used for track conditions) that is based on industry standards and best practices.	FTA-TPE-17-012-a	WMATA must establish grading criteria for TPE system defects, similar to the defect system established for track, and must instruct inspection personnel in how to use them. These grading criteria must also address thermal imaging anomalies and include acceptable thermal variation criteria and action levels.
SAFE TPS 16-018	TRST should evaluate funding dedicated cleaning crews to improve safety, reliability and improve the longevity of system assets.	See Safety Directive 16-4, Track Integrity Investigation, Required Actions T-7, T-8, T-9 and T-10.	
SAFE TPS 16-019	TRST management should perform a cost benefit analysis with regard to repairing or replacing the out of service vacuum vehicle.	FTA-TPE-17-003-d	WMATA must perform a cost benefit analysis with regard to repairing or replacing the out-of-service vacuum vehicle and implement the results.
Traction Power System Inspection Recommendations			
SAFE TPS 16-020	CENV develop processes and procedures to make available and review thermal imaging results with stakeholders including the SAFE, TRST and PWRS.	FTA-TPE-17-012-b	WMATA must establish a procedure to ensure that thermal imaging data is reviewed with all stakeholders and that automated inspections, which include data collection and analysis of TPE system components, are used collectively to identify trends and target areas for preventive maintenance or monitoring.
		FTA-TPE-17-012-c	To enhance usefulness, WMATA must revise its thermal imaging summary report to include comparison reports from past thermal imaging runs.

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
		FTA-TPE-17-003-e	WMATA must ensure the thermal imaging car adequately picks up cable hot spots.
SAFE TPS 16-021	CENV leverage existing technologies to ensure that TGV third rail data is compared with the reports filed by track inspectors and with previous TGV data to identify trends.	FTA-TPE-17-012-d	WMATA must establish a procedure to ensure that TGV third rail data is compared with the reports filed by track inspectors and with previous TGV data to identify trends. Specifically, this procedure must ensure the geometry data from the TGV is reviewed for third rail gauge exceptions, especially in super-elevated track areas and floating slab construction; assess the re-gauging of the third rail per WMATA's Track Standards TRST 1000 section 13 - Contact Rail; and evaluate the need for corrective repairs when the system is out of tolerance.
SAFE TPS 16-022	TRST, TRPM, and ATC Maintenance (ATCM) collaborate with the CENV thermal imaging team to develop acceptable thermal variation criteria and action levels.	See FTA-TPE-17-012-a	
Other FTA Required Action related to Traction Power System Inspection	N/A	FTA-TPE-17-010-a	WMATA must evaluate the traction power DC feeder breaker settings at substations and tie breakers to determine the optimal settings for various track side conditions including instantaneous short circuit ratings, time over current settings, and rate of rise settings.
	N/A	FTA-TPE-17-010-b	WMATA must provide criteria and test results for circuit breaker settings to FWSO for evaluation.
	N/A	FTA-TPE-17-010-c	WMATA must develop and submit to FWSO its program plan for installing, testing, and evaluating the effectiveness of the use of MPR relays for detecting low level faults.
	N/A	FTA-TPE-17-010-d	WMATA must evaluate the addition of transfer trip circuitry for de-energizing feeds from adjacent power stations during troubled conditions and implement results.
	N/A	FTA-TPE-17-013-a	WMATA must develop a meggering plan for cross bonded cables, especially in tunnel areas that are prone to water and muck infiltration, to

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
			determine their integrity.
SAFE TPS 16-023	TRST and TRPM collaboratively evaluate whether more focused, less frequent inspections of TPS components would add value to the existing inspection programs.	FTA-TPE-17-013-b	WMATA must institute a cable testing program for jumper and transition cables located in the tunnel environment until these cables are upgraded and/or replaced.
Corrosion Control Programs Recommendations			
SAFE TPS 16-024	TRST implement the corrective actions recommended in the September 20, 2016 Russell Corrosion Consultant's report regarding conditions found between D02 and D04.	FTA-TPE-17-014-a	WMATA must implement a regular program of stray current and corrosion control testing, which should include, at a minimum, the following: track to earth electrical isolation, track to earth voltage, yard to mainline electrical isolation, shop to yard electrical isolation, mainline segregation, and cathodic protection systems.
SAFE TPS 16-025	PWRS, CENI and TRST or an external consultant perform a risk based assessment to determine the best path forward in implementing a fastener replacement program. The assessment should consider a variety of factors to determine prioritization of fastener renewal, i.e. underground stations with the oldest fasteners and the highest volume of service, adverse environmental conditions, floating slab track territories.	FTA-TPE-17-022-a	WMATA must establish criteria for its fastener replacement program to improve insulation resistance.
SAFE TPS 16-026	PWRS expand the Russell Corrosion Consultants contract to include testing other areas of the system.	See FTA-TPS-17-014-a above.	
SAFE TPS 16-027	CENI, PWRS, TRST and ATCM adopt and implement a system-wide global corrosion control program to include all stakeholders and encompass all of the elements recommended by CENI.		
SAFE TPS 728	CENI, PWRS, TRST evaluate what modifications/improvements can be made in floating slab track territories to address corrosion control/stray current.	FTA-TPE-17-006-a	WMATA must establish and implement an inspection, testing, maintenance, and repair program for its floating slab track, running rail insulation and sacrificial anodes.
SAFE TPS 16-029	CENI, PWRS and TRST develop a maintenance procedure and check list to address inspection, maintenance and repair of floating slab track.		
Data Collection and Analysis Recommendations			
SAFE TPS 16-030	TRPM evaluate forming an independent TPS department that would have sole responsibility for inspecting, maintaining, and repairing all components of the TPS system. Include HNTB recommendations as part of evaluation criteria,	FTA-TPE-17-001-a	WMATA must conduct an assessment to determine if all TPE system program components should be integrated into a single department with sole responsibility for managing, inspecting,

WMATA ID	WMATA Safety Recommendation	FTA ID	FTA Required Action
	specifically: "overall evaluation of assets to determine whether there are efficiencies to be obtained through the re-allocation of assets to different maintenance department, e.g., having TRPM responsible for the third rail insulators and cover board installation and maintenance to align responsibility and accountability with Engineering." Their responsibilities would also include collection, review and analysis of data.		maintaining, repairing, and upgrading the TPE system. At a minimum, this assessment must include those elements of TPE system inspection, maintenance, and repair currently performed by TRPM; third rail inspection and maintenance work currently performed by TRST; negative return system inspection and maintenance activities performed by ATC; cable replacement activity performed by IRCM; engineering services provided by PWRS; and lock-out/tag-out procedures implemented by the ROCC and MOC.
		FTA-TPE-17-001-b	WMATA must implement the results of the assessment conducted to address FTA-TPE-17-001-a following a schedule reviewed and approved by FTA.
Other FTA Required Actions related to personnel and roles and responsibilities	N/A	FTA-TPE-17-002-a	WMATA must develop and provide TPE system awareness training for ROCC and MOC personnel.
	N/A	FTA-TPE-17-002-b	WMATA must revisit SOP #2: Emergency Removal and Restoration of Third Rail Power Mainline to consider: 1) removal of power during smoke conditions, especially with corresponding third rail power outages caused by unknown conditions, and 2) a requirement to de-energize third rail power at the adjacent power substation or tie breaker, provided the situation does not strand a train that needs to be moved from the smoke condition.
SAFE TPS 16-031	If the recommendation above is rejected, form an interdepartmental working group to clarify roles and responsibilities, data sharing, resource allocation and capital planning.	N/A	
SAFE TPS 16-032	TRPM evaluate the various recommendations flowing out of TPS incidents, APTA peer review, consultant studies, FWSO input, and internal findings. Assure effective coordination. Monitor and track action items to resolution.	N/A	

Appendix C List of Electrical Arcing Events Reported by WMATA

Event Identification	Event Date	Event Location
E15023	12/14/15	A2-387+00
E15006	12/16/15	Bethesda
E15007	12/16/15	Friendship Heights
E15008	12/17/15	Bethesda
E15010	12/22/15	A1-433+00
E15014	12/23/15	A1-407+90
E15015	12/26/15	B1-632+00
E15021	12/26/15	A2-386+00
E16004	1/5/16	D&G Junction
E16035	2/3/16	A2-320+00
E16047	2/21/16	A2-339+95
E16048	2/21/16	B2 625+50
E16050	2/24/16	A1-269+00 and A1-296+00
E16053	3/1/16	A1-407+00, Track #1
E16057	3/14/16	McPherson Square
E16066	3/28/16	A1-435+00 (Track #1)
E16071	4/13/16	Bethesda Track 2
E16077	4/21/16	K2-510+00
E16079	4/23/16	Bethesda Rail Station
E16081	4/26/16	Woodley Park Station
E16084	4/26/16	CM A2 466+00 (Medical Center)
E16083	4/27/16	A2 306+00 (Friendship Heights)
E16089	5/2/16	A2 443+00
E16090	5/2/16	A1-406+70
E16086	5/5/16	Federal Center Station, Track 1
E16091	5/5/16	Federal Center SW
E16092	5/9/16	Benning Road
E16093	5/10/16	Courthouse Station
E16094	5/11/16	D&G Junction CM D1-281+00; Track 1
E16095	5/12/16	A2 296+00
E16096	5/13/16	Friendship Heights
E16100	5/15/16	A2-351+00
E16103	5/20/16	A1 88+90
E16110	5/23/16	Woodley Park - CM A1 127+00
E16115	5/23/16	A1-314+60
E16111	5/24/16	A1-444+00
E16112	5/24/16	Woodley Park
E16114	5/24/16	Dunn Loring
E16122	5/27/16	K1-579+00
E16125	5/30/16	F2-197+30
E16126	5/31/16	Rosslyn
E16128	5/31/16	L'Enfant Plaza

Event Identification	Event Date	Event Location
E16129	5/31/16	Rosslyn Station
E16133	6/2/16	A2 83+80
E16134	6/2/16	Woodley Park
E16135	6/3/16	Woodley Park
E16137	6/4/16	A2 102+00
E16139	6/4/16	C1 131+00
E16140	6/5/16	A1 467+00
E16141	6/5/16	A1 656+20
E16147	6/9/16	E2 546+00
E16158	6/15/16	Forest Glen
E16159	6/16/16	Friendship Heights
E16160	6/16/16	Grosvenor-Strathmore
E16175	6/27/16	CM A2 371+50
E16178	6/27/16	Gallery Place Station
E16180	6/28/16	Medical Center
E16188	7/8/16	Bethesda
E16216	8/1/16	Van Ness Station
E16220	8/2/16	Medical Center Station
E16241	8/10/16	CM A2 314+00
E16242	8/11/16	Woodley Park
E16259	8/15/16	Medical Center
E16265	8/16/16	Woodley Park Station
E16375	9/18/16	Cleveland Park
E16385	9/23/16	Metro Center
E16391	9/25/16	Metro Center
E16430	10/8/16	Between Tenleytown and Friendship Heights
E16467	10/18/16	Medical Center
E16478	10/21/16	Woodley Park

Appendix D: SMI Findings and CAP Status

- R-2-16-a: WMATA must conduct a coordinated study to prioritize technical training needs for maintenance personnel and operations training for Rail Traffic Controller, Train Operators, and Field Supervisors. (Status: Work underway, due August 2017.)

- R-2-16-b: WMATA must evaluate whether re-organization or consolidation of training functions would improve the agency's ability to manage, schedule, budget for, develop, oversee and assess training, and ensure that training material remains up-to-date. (Status: Submitted to FWSO for closure.)

- R-2-16-c: WMATA must establish a comprehensive training program to communicate the new "Fire Life Safety 1000 – Inspection, Testing and Maintenance Procedure" to WMATA Operations and Maintenance personnel. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-2-16-d WMATA must establish formal guidance for maintenance employees responsible for providing on-the-job training. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-4-27-a: For all major departments with inspection and maintenance responsibilities for critical infrastructure, WMATA must establish and/or update a preventive maintenance and inspection testing quality audit process to ensure compliance with established maintenance and testing practices and monitor missed or incomplete preventive maintenance activities and/or inspections. (Status: Work underway, due December 2017.)

- R-4-28-a: WMATA must review the workload and inspection territory assigned to track inspectors and leverage non-track inspectors to perform watchman duties. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-4-32-a: WMATA must ensure that each department within Transit Infrastructure and Engineering Services creates a formal program of supervisory inspections to observe maintenance, look at quality of work in the field, and formally intervene to evaluate, re-train (if necessary), and enhance the professional development of employees. (Status: Closure request under FWSO review.)

- R-7-42-a: WMATA operating and maintenance departments must work together to develop a strategy to more actively analyze, review, and assess rail operation and maintenance data from a safety perspective. (Status: Work underway, due March 2018.)

- R-2-16-a: WMATA must conduct a coordinated study to prioritize technical training needs for maintenance personnel and operations training for Rail Traffic Controller, Train Operators, and Field Supervisors. (Status: Work underway, due August 2017.)

- R-2-16-d: WMATA must establish formal guidance for maintenance employees responsible for providing on-the-job training. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-3-23-a: WMATA must ensure that a process is in place for identifying and scheduling sufficient track time to complete required inspection, testing, and maintenance activities. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-3-24-a: WMATA must establish firm limits on minimum track time for inspection, testing, and maintenance activities per month and revisit limits annually. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-3-25-a: WMATA must develop and implement staffing plans to eliminate maintenance work orders backlogs and manage on-going workload in track and structures, traction power, communications, and automated train control. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-3-26-a: WMATA must improve interdepartmental coordination and communication to take full advantage of track time. (Status: Submitted to FWSO for closure; FWSO is requesting additional action.)

- R-4-30-A: WMATA must develop a plan to document roles and responsibilities, activities, and points of coordination regarding its program to measure, document, and mitigate the impacts of stray negative return current. (Status: Work underway, due October 31, 2016.)

Appendix E: NTSB Safety Recommendations to FTA and WMATA

To the Federal Transit Administration:

- Issue regulatory standards for tunnel infrastructure inspection, maintenance, and repair, incorporating applicable industry consensus standards into those standards. (R-16-01)
- Issue regulatory safety standards for emergency egress in tunnel environments. (R-16-02)

To the Washington Metropolitan Area Transit Authority:

- Review and revise your tunnel inspection, maintenance, and repair procedures to mitigate water intrusion into tunnels. (R-16-08)

- When the revision of tunnel inspection, maintenance, and repair procedures recommended in Safety Recommendation R-16-08 has been completed, train maintenance employees on the new procedures, and ensure that the procedures are implemented. (R-16-09)

- Improve the capacity of tunnel ventilation fans to conform to the requirements of National Fire Protection Association (NFPA) 130. (R-16-10)

- Develop location-specific emergency ventilation configurations based on engineering studies of the Washington Metropolitan Area Transit Authority tunnel ventilation system. (R-16-11)

- Develop and implement procedures for actions to be taken by Rail Operations Control Center personnel when smoke detectors alarm. (R-16-12)

- Once action to address Safety Recommendation R-16-12 is completed, train all Rail Operations Control Center personnel on the new procedures for responding to smoke alarms. This training should include regular refresher training. (R-16-13)

- Incorporate smoke alarms in periodic emergency drills and exercises. (R-16-14)

- Include in your efficiency testing program (rules compliance testing program) a specific test to ensure appropriate emergency actions are taken by Rail Operations Control Center supervisors and control operators in response to an alarm. (R-16-15)

- Install and maintain a system that will detect the presence and location of fire and smoke throughout the Washington Metropolitan Area Transit Authority tunnel and station network. (R-16-16)

- Develop procedures for regular testing of all smoke detectors. (R-16-17)

- Conduct a risk assessment before any preventive maintenance program is initiated, changed, or discontinued. (R-16-18)

- Ensure that all train operators are trained and regularly tested on the appropriate procedure for emergency shutdown of railcar ventilation. (R-16-19)

- Incorporate a specific test in your efficiency testing program to ensure that train operators understand the procedure for emergency shutdown of railcar ventilation. (R-16-20)

- Revise Standard Operating Procedure #6 to clarify which trains should be stopped until the source of smoke is identified. (R-16-21)

- Revise your standard operating procedures to require that (1) suitably trained, qualified, and properly equipped personnel investigate reports of wayside fire or smoke and (2) these reports are not investigated using trains with revenue passengers. (R-16-22)

- Review and revise as necessary your Rail Operations Control Center emergency response procedures for smoke and fire. (R-16-23)

- Retrain Rail Operations Control Center supervisors on all standard operating procedures for emergencies. (R-16-24)

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

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

- Install line identification and direction signage at tunnel entrances and inside tunnels. (R-16-27)

- Implement a regular schedule for the inspection and removal of obstructions from safety walkways and track bed floors to ensure safe passageways for passengers to use during a tunnel evacuation. (R-16-28)

- Conduct emergency response drills with local emergency response agencies in accordance with National Fire Protection Association (NFPA) 130, document lessons learned, and develop and implement additional procedures as necessary to effectively respond to emergencies. (R-16-29)

- Revise your standard operating procedures to require that an after-action review be conducted of all emergency responses to events with passenger or employee fatalities, and publish the results, including both the successes and the potential deficiencies of your responses, to help ensure that deficiencies are appropriately remediated. (R-16-30)

- Review and revise your quality assurance program to ensure that regular quality assurance audits are included to identify and correct any elements of procedural noncompliance. (R-16-31)