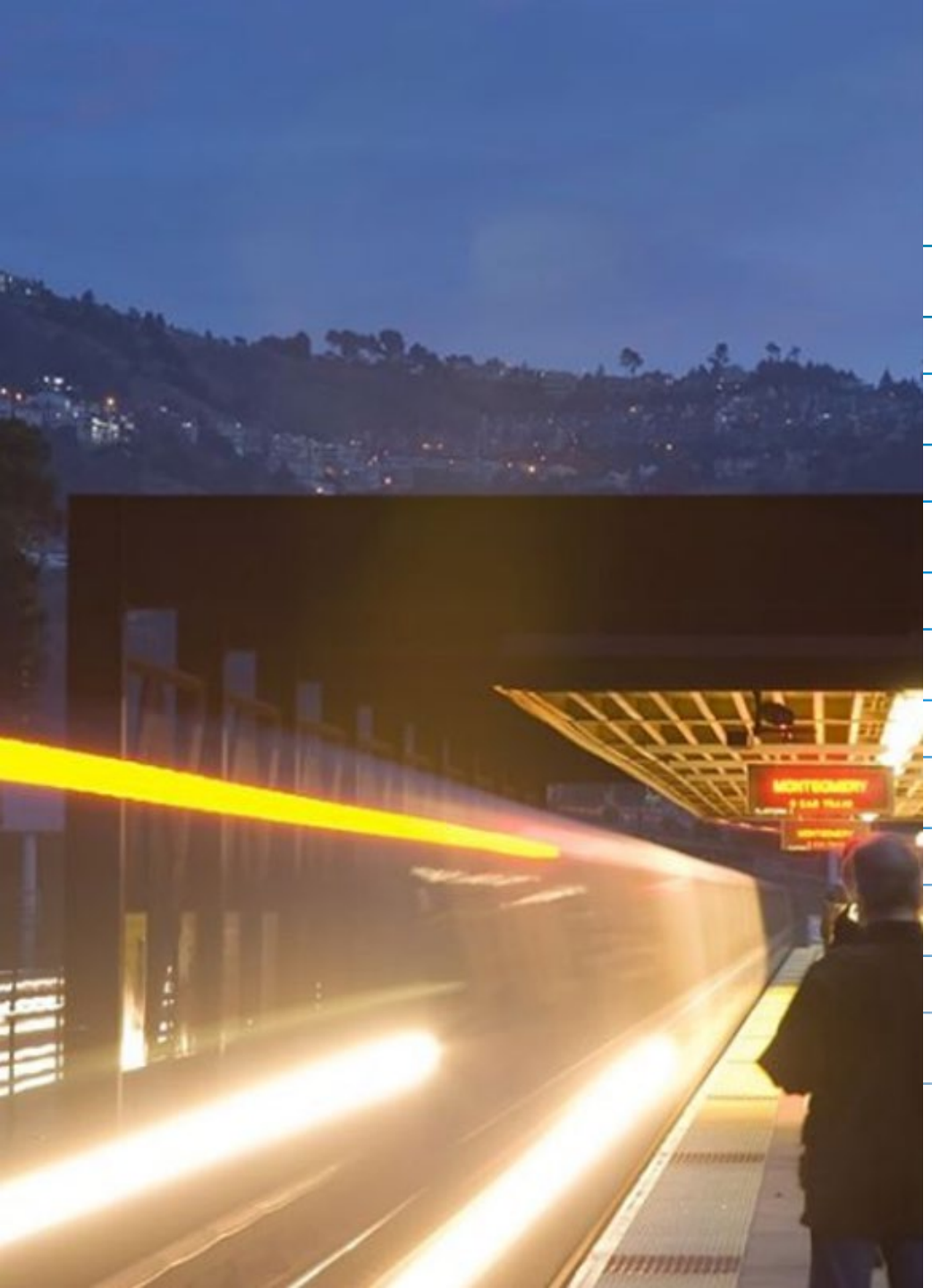
Root Cause Investigation Update on M-Line Service Disruptions

January 22, 2026 | BART Board of Directors Meeting



- Scope of Investigation
- Investigation Efforts
- Findings & Analysis
- Improvements Implemented
- Incident Hypotheses
- Next Steps
- Glossary

Scope of Investigation

- **Scope:** Investigate circumstances surrounding multiple incidents between West Oakland and Civic Center including review of events on both tracks in each directions and forensic analysis of impacted assets utilizing industry standard Root Cause Analysis (RCA) processes and techniques.
- **Timeframe:** August 29, 2025 through today

- **Focus Areas (including, but not limited to):**
  - Vehicles
  - Traction Power
  - Track & Third Rail
  - Interface between Vehicles, Track & Third Rail
  - Maintenance and Operations
  - Other Infrastructure Systems

Service Disruptions Between West Oakland and Civic Center Stations (August 29 – December 8, 2025)

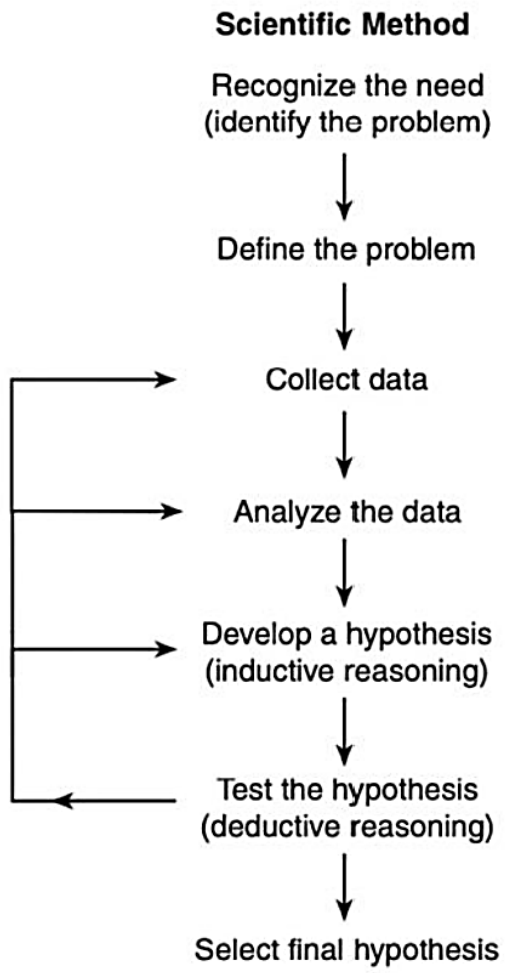
Incident No. — M- Line — BART Station

1. **August 29, 2025 at 5:50AM** (Sparks from ceiling)
2. **August 29, 2025 at 5:12PM** (Smoke/Bright Flash in TBT)
3. **September 20, 2025 at 6:40AM** (Noise/Sparks on Track)*
4. **September 29, 2025 at 11:48AM** (Insulator Flashover)
5. **October 7, 2025 at 4:35PM** (Loud Noise/Bright Flash)
6. **October 19, 2025 at 01:10AM** (Sparks)
7. **October 20, 2025 at 05:45AM** (Loud Noise/Insulator Flash)
8. **November 25, 2025 at 11:29AM** (Insulator Flash/Smoke)
9. **December 8, 2025 at 6:51AM** (Insulator Flashover/Smoke)

* *Excluded from investigation due to clear & verified root cause*

Scope of Investigation

Root Cause Analysis Methodology & Sequence

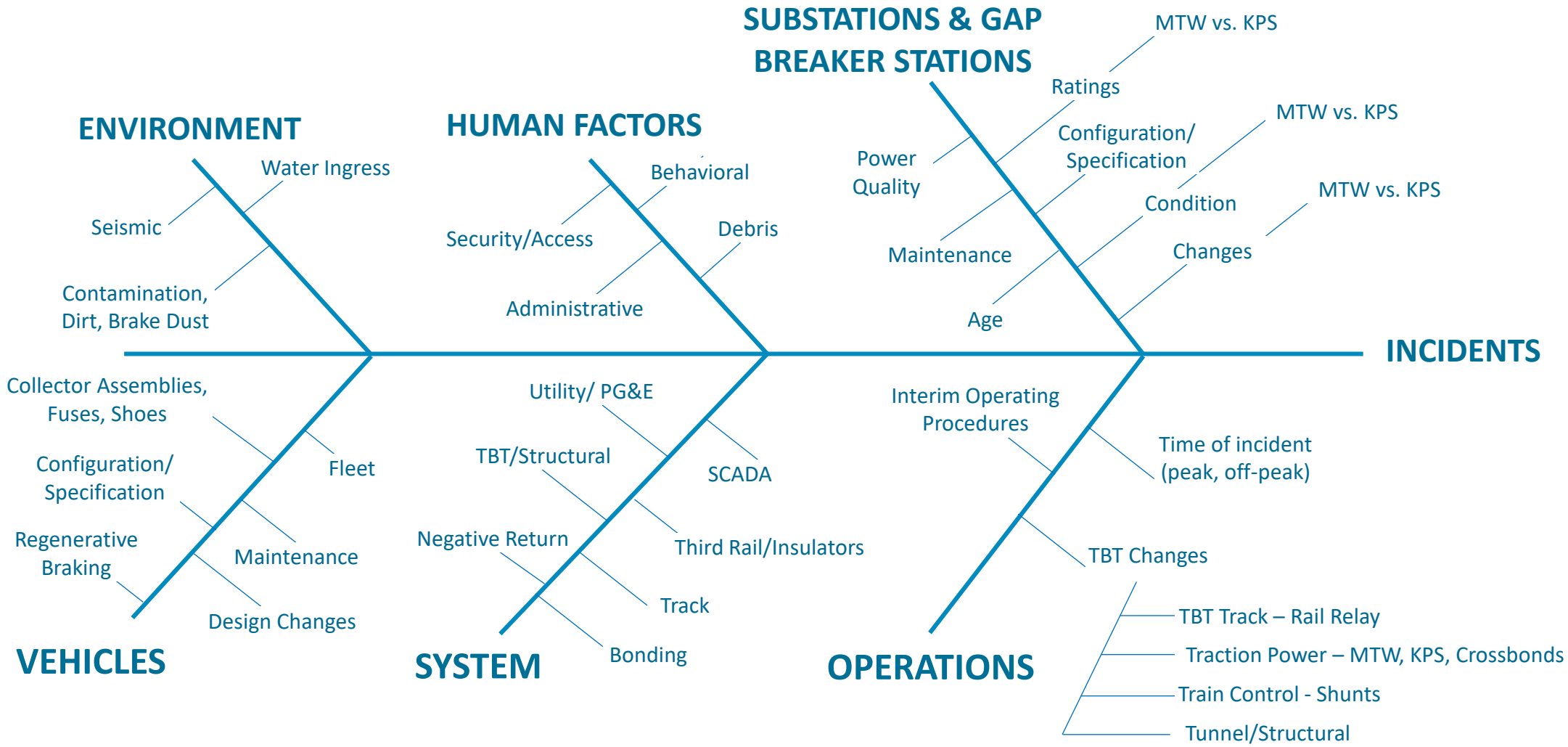


COLLECT DATA	ANALYZE DATA	
	DEVELOP/TEST HYPOTHESES	FINAL HYPOTHESES
Recent System Changes		
Vehicle Inspection Findings	Fishbone Diagrams	5-Why Diagram
Wayside Inspection Findings	Event Sequence Analysis	Root Cause Identification
Forensics & Testing	Compare & Consolidate Forensic Data With All Data Sources	Recommendations

RFIs:
Vehicle logs
SCADA/ICS logs
OCC Daily Reports
IOPs. SSWPs, Obs.
Specs, Reports
Drawings

Investigation Efforts

Fishbone Diagram



Investigation Efforts

Total Hours:
15,000+

- BART Staff
- Independent 3rd Party Investigative Teams
- External Subject Matter Experts

Total Site Visits:
37+

- Forensic Field Visual Inspections & Measurements
- Investigate Potential Cause / Hypothesis
- BART Stations, Substations, Wayside, Yards, Shops & Facilities

Subject Matter Expert Disciplines:
16+

- Vehicle Systems
- Traction Power & Electrical
- SCADA
- Track & 3rd Rail
- Structures
- Fire Life Safety
- Mechanical, Safety & Hazard Engineering
- Reliability & Maintenance
- Electromagnetic Interference/Compatibility (EMI/EMC)
- Protective Relay Schemes
- Grounding & Fault Current
- Materials, Component & Forensic Sciences
- Data Analysts
- Modeling & Simulations
- Systems Integration & Interface
- Root Cause Investigation

Vehicle Inspections:
180+

- Visual and Forensic Inspection
- Check the undercarriage equipment
- Inspect fuse & current collector cable
- Inspect 2-3 trains ahead of inspection train

Total Tests:
35+

- Negative Return System Mapping
- Power Quality Monitoring on AC and DC side
- Rail to Earth Resistance Tests
- Negative Grounding Device (NGD) Tests
- Non-Destructive Tests on Collector Shoe Assemblies, Fuses & Insulators
- Destructive Tests on Insulators

Files Reviewed:
1,500+

- Design Documents (e.g. Vehicles, Traction Power, Track)
- Maintenance Records (e.g. Maximo)
- Supervisory Control & Data Acquisition (SCADA) / Integrated Computer System (ICS) Logs
- Operations Control Center (OCC) Daily Reports, Operating Bulletins, Unusual Occurrence Reports (UOR)
- Interim Operating Procedures (IOP) & Site-Specific Work Plans (SSWP)
- Timetables & Passenger Ridership
- System/Vehicle Logs & Video Streams

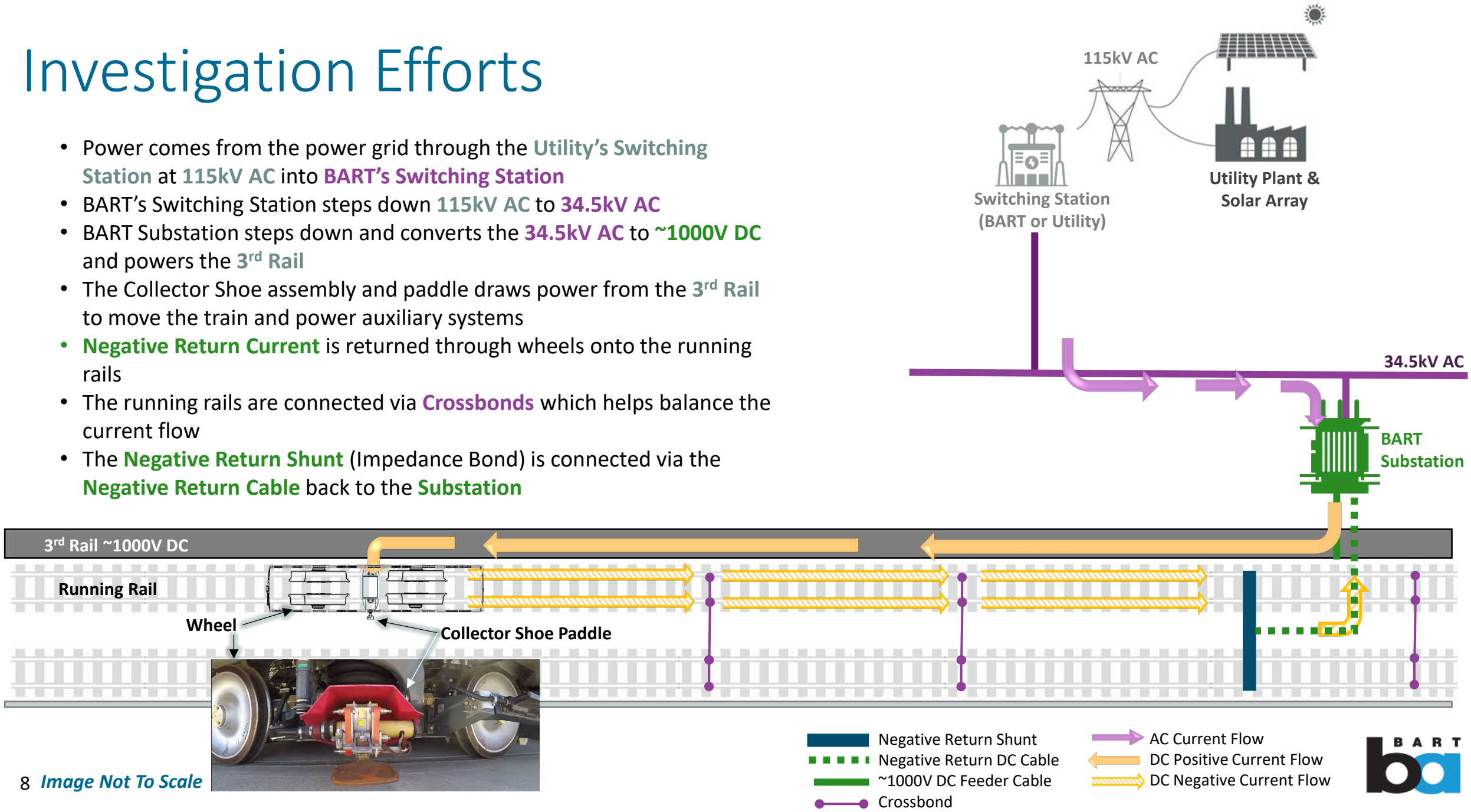
Investigation Efforts

Hypothesis Summary

	Hypothesis	Description
	**Traction Power System Transients**	Momentary changes or fluctuations in voltage or current from traction power system beyond expected limits
	**Environmental Factors**	Contamination/Dirt, Moisture & Water Ingress
	**Human or External Factors**	Initiating events due to human behavior or external factors e.g. objects and debris in the track
	**Design Specifications or Changes**	Effects of changes to the vehicle, track, or traction power designs, specifications, or installations
	**Collector Shoe Interaction with 3rd Rail**	Collector shoe relative position with respect to the energized third rail and track geometry
	**Negative Return Path, Grounding, Bonding**	Negative return system, crossbonds, grounding and bonding conditions
	**Power System Protection Scheme**	Protection scheme operation and response to fault conditions, how quickly fault current is interrupted

Investigation Efforts

- Power comes from the power grid through the **Utility's Switching Station** at **115kV AC** into **BART's Switching Station**
- BART's Switching Station steps down **115kV AC** to **34.5kV AC**
- BART Substation steps down and converts the **34.5kV AC** to **~1000V DC** and powers the **3rd Rail**
- The Collector Shoe assembly and paddle draws power from the **3rd Rail** to move the train and power auxiliary systems
- **Negative Return Current** is returned through wheels onto the running rails
- The running rails are connected via **Crossbonds** which helps balance the current flow
- The **Negative Return Shunt** (Impedance Bond) is connected via the **Negative Return Cable** back to the **Substation**



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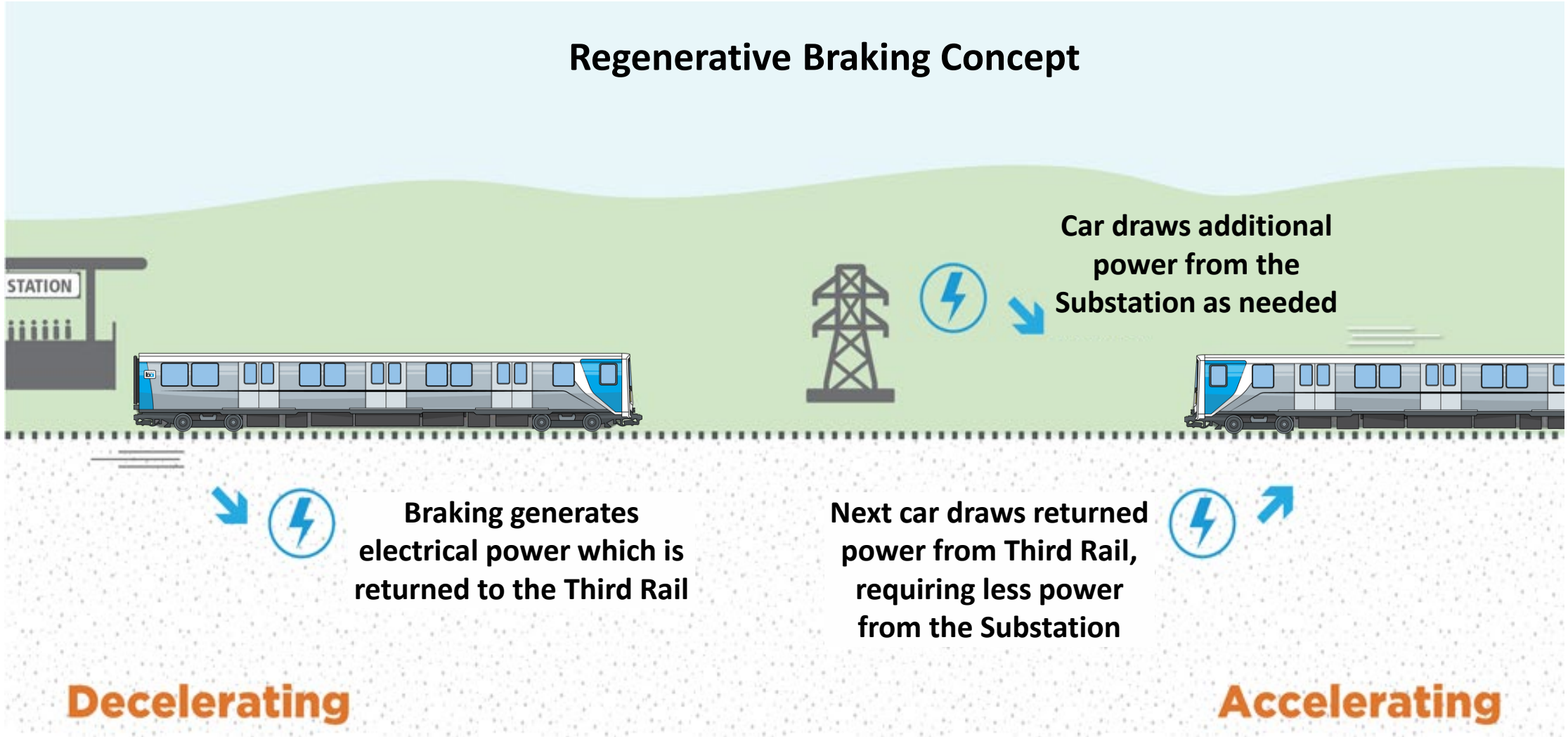
Investigation Efforts



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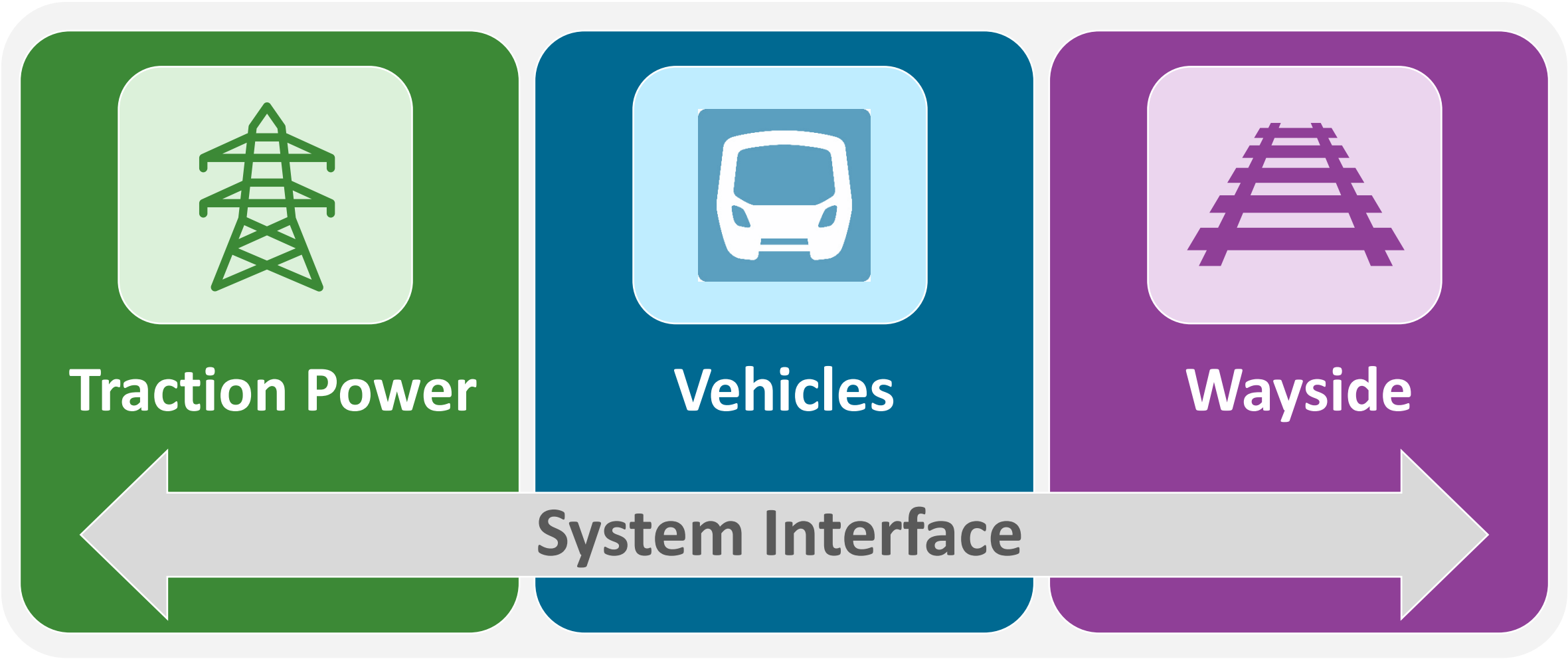
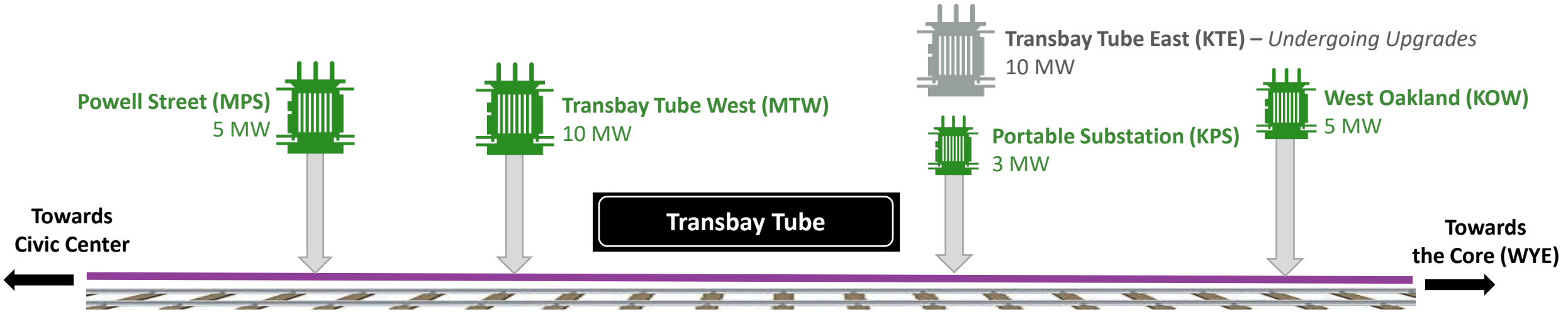


Findings & Analysis

Traction Power Substations/Power Balance

- Transbay Tube East (KTE) Substation and Transbay Tube West (MTW) Substation are original traction power substations on either side of the TBT
- In 2021 to support critical upgrade work to KTE substation a smaller portable substation, KPS, was installed and KTE taken offline
- KTE renovations are expected to complete in Spring 2026



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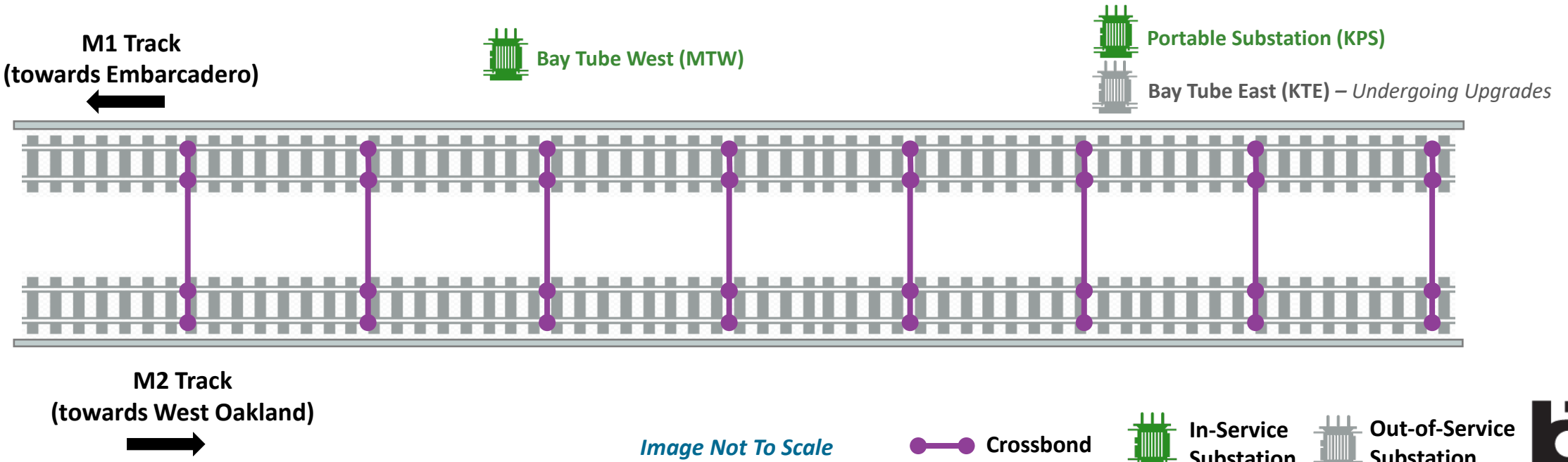
Findings & Analysis

Crossbonds

- Crossbonds were removed in the Transbay Tube (TBT) Seismic Retrofit Project in Spring 2020 to provide additional protection to personnel during single tracking
- Without Crossbonds, return current would not get distributed between both sets of tracks back to the substation
- As of November 2025, BART has restored the Crossbond system to original design



Findings & Analysis

Datalogger

Electrical Measurement Device

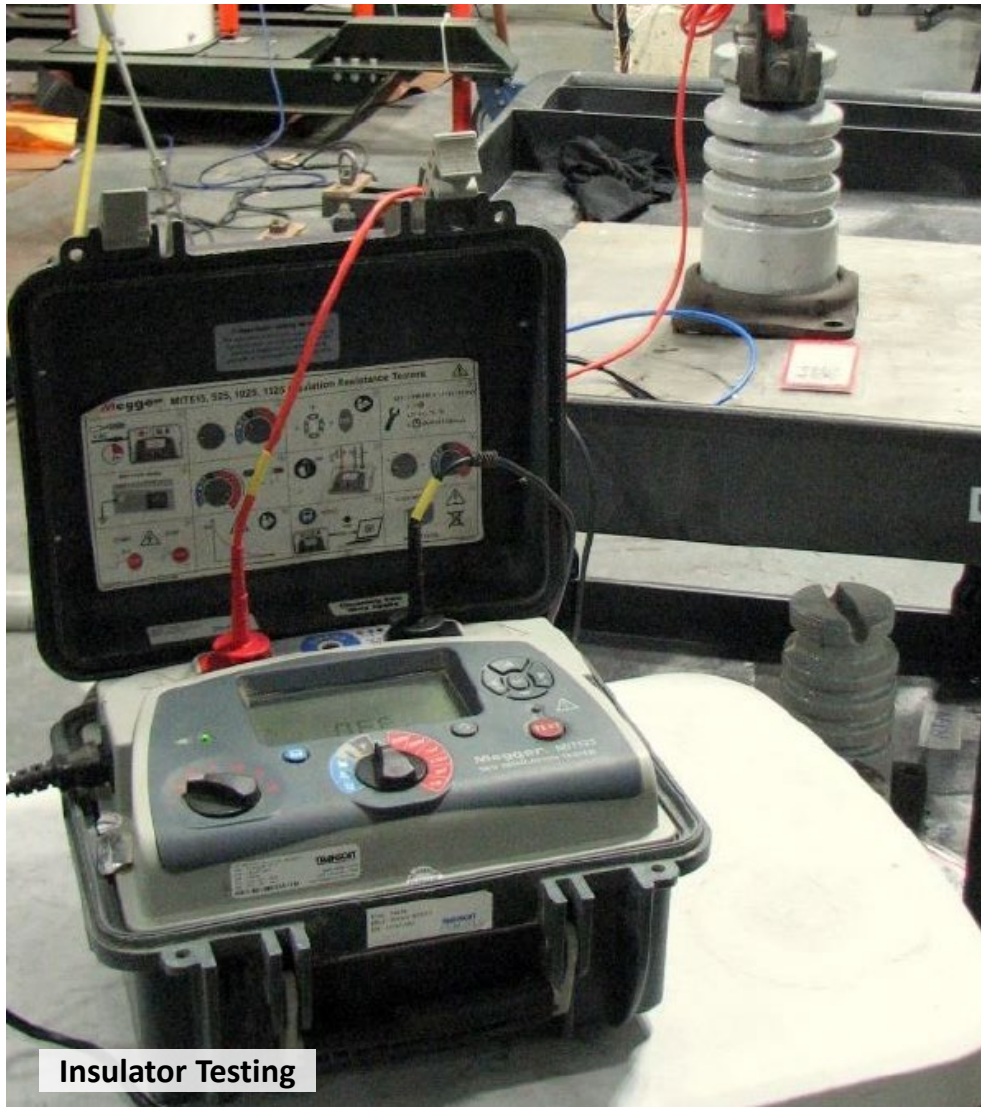
Incoming Power Quality

- Load monitoring tests were performed at BART traction power substations.
- Higher incoming medium voltage and phase unbalance from Switching Station
- Increase in DC ripple observed.

Negative Return Path, Grounding, Bonding

- Negative return mapping was performed through the TBT to field verify the connections
- Two areas of low resistance were found on the M1 and M2 track through the Transbay Tube (TBT), and have since been resolved
- Negative Grounding Device (NGD) at Powell (M30) was found to be shorted
- Crossbonds had been removed in 2020 to support TBT projects

Findings & Analysis



Insulator Testing

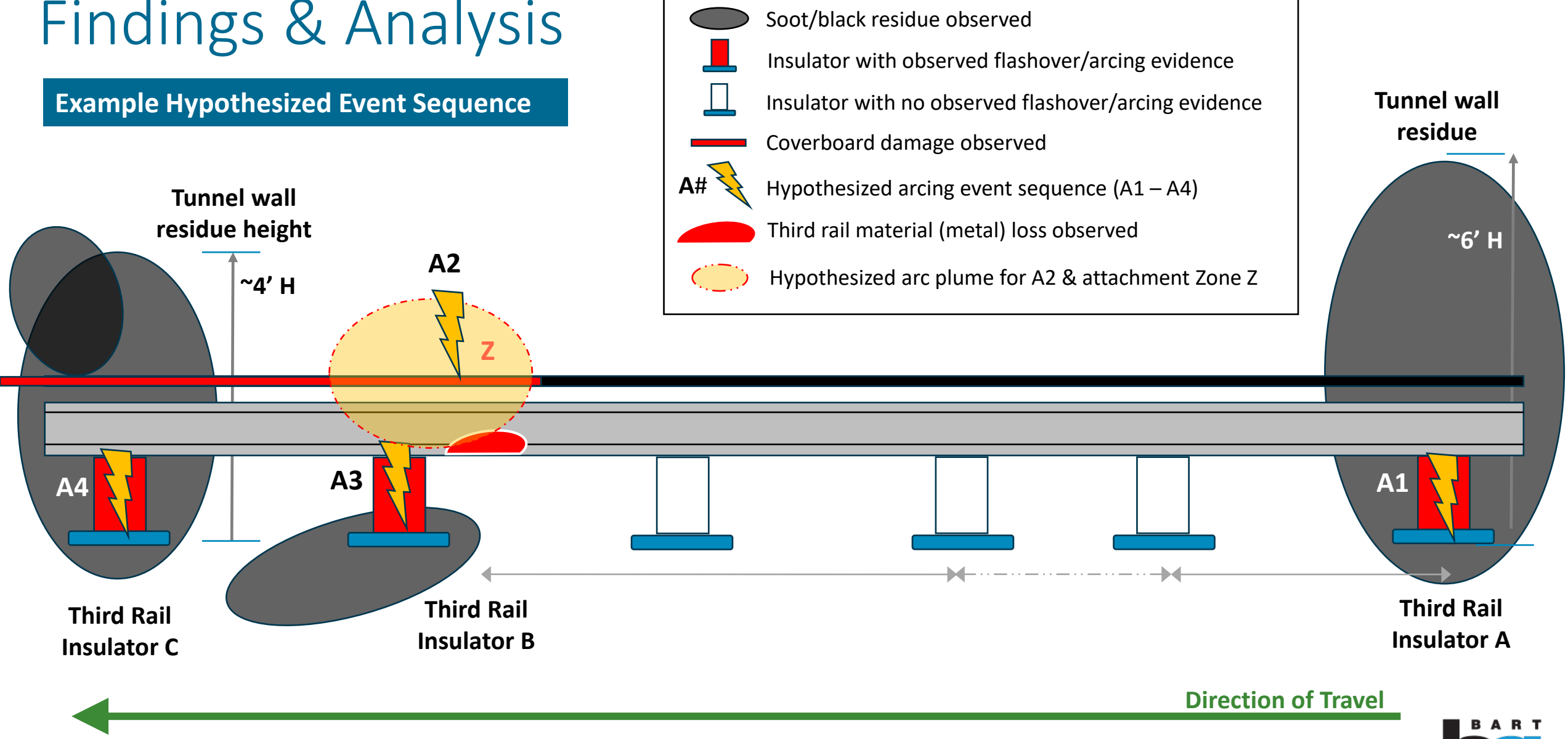
Third Rail Insulators

- Third rail insulators and associated assemblies were inspected and tested at two different offsite laboratories.
- Insulator condition is consistent with normal aging and environmental exposure expected within tunnel installations.
- Rail relay storage practices that involve cutting notches into cantilever brackets to store ribbon rail may impact insulator.
- The failure mode in incidents where insulators were involved, was carefully examined to identify the type of insulator failure.


Third Rail Insulators for Lab Testing

Findings & Analysis

Example Hypothesized Event Sequence



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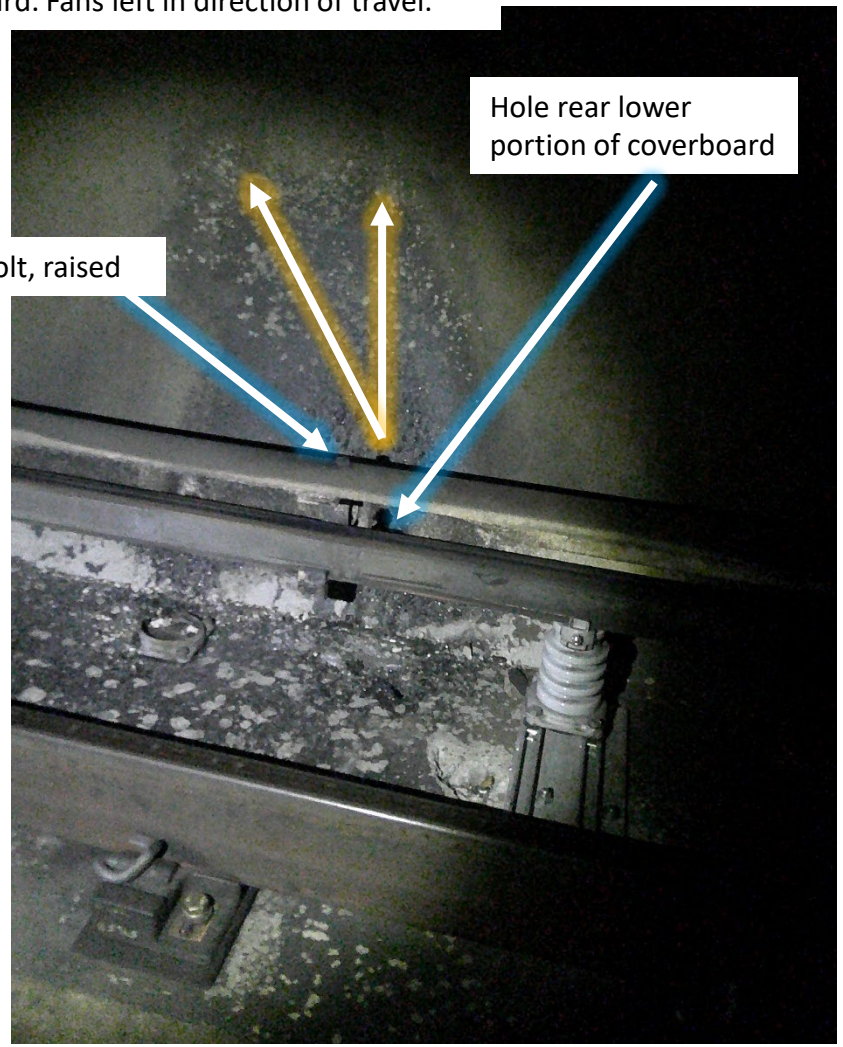
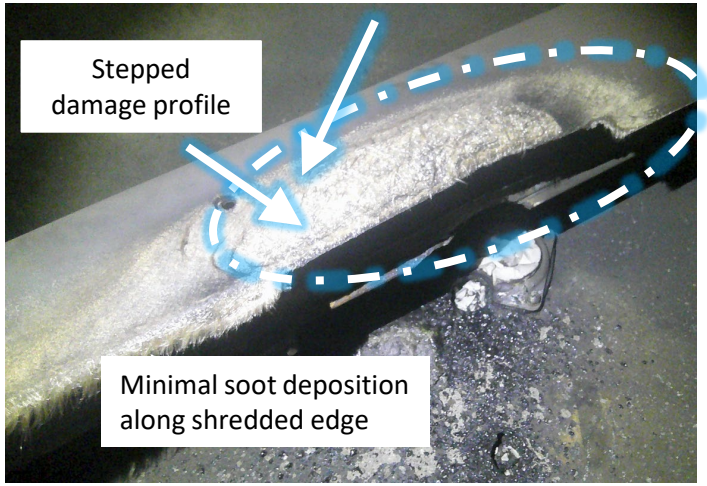
Findings & Analysis

~ 4’ H residue, vertical, aligned with hole in back of coverboard. Fans left in direction of travel.



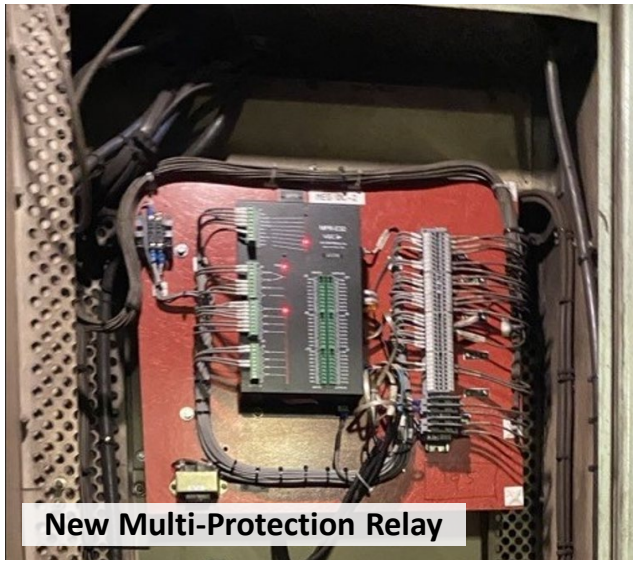
Missing coverboard bolt



Findings & Analysis


Circuit Breaker

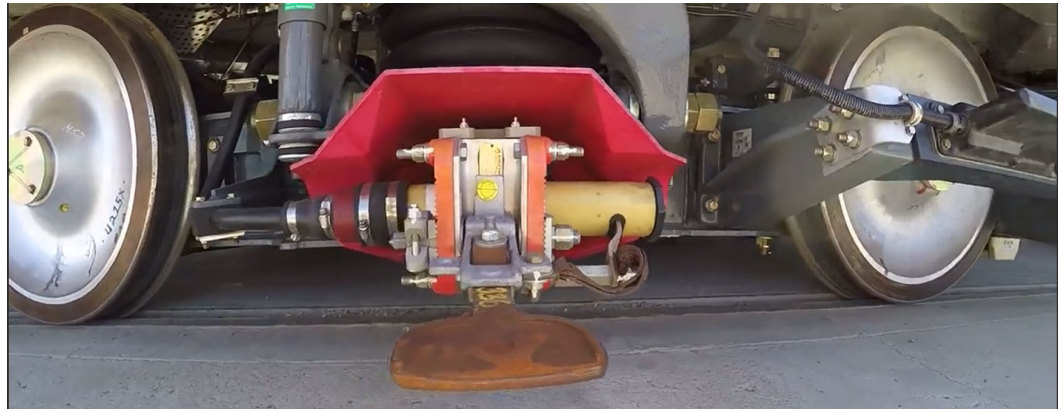

Old Multi-Protection Relay

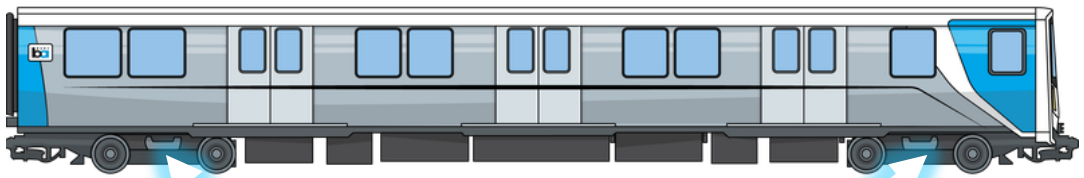

New Multi-Protection Relay

Traction Power Fault Detection & Protection System

- DC Circuit Breakers control power to 3rd rail and include integrated overload/overcurrent protection.
- Multi-Function Protection Relay (MPR's) provide advanced sensing and triggers breaker trips during specified overcurrent events.
- MPR settings at Transbay Tube (TBT) Gap Breakers were previously disabled to prevent nuisance trips, relying only on basic breaker protection.

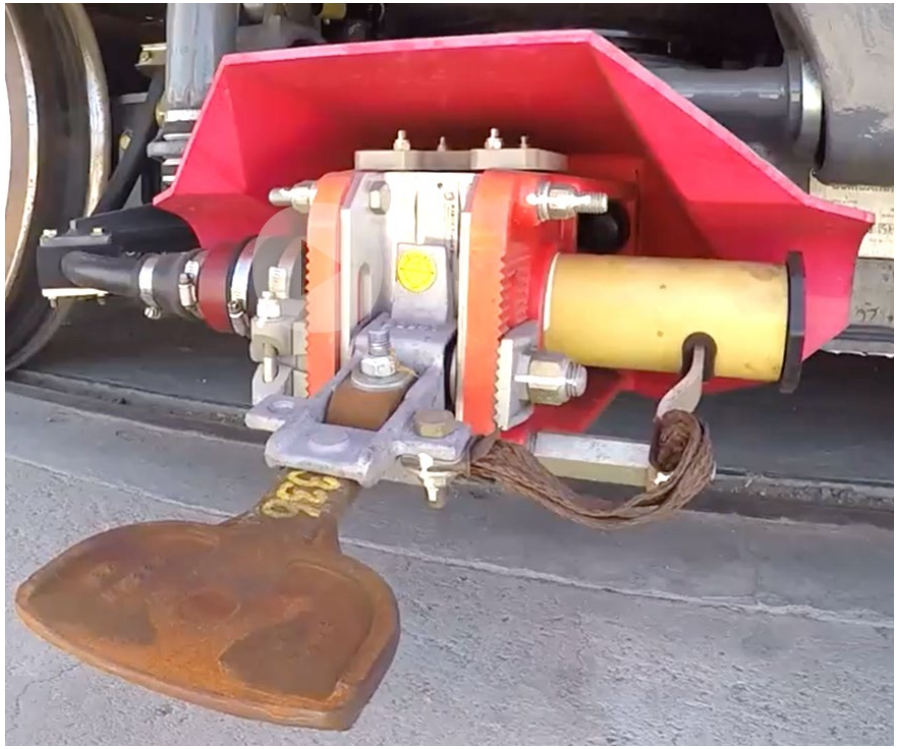
Findings & Analysis





Collector Shoe Assembly

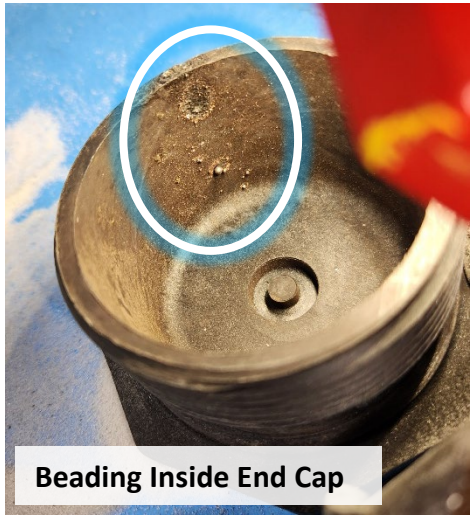
- Mounted between the wheels of each truck on both sides of the car
- The paddle rides along the 3rd rail and draws current to power the train and auxiliary equipment
- Assemblies sent to forensic laboratory for further inspection and analysis
- Assemblies include paddles and fuses



Findings & Analysis


Fusible Link & Arc Quenching Sand


Fuse Damage


Beading Inside End Cap

Fuse Assembly

- Incident vehicles and non-incident vehicles (for comparison) inspected
- Each car is equipped with four fuses, two per side, rated at 600 A RMS providing redundancy and current limiting protection.
- Four collector assemblies were sent an offsite independent laboratory for further forensic inspection and testing including x-rays and elemental analyzer tests.
- Inspection of three out of the four fuses confirmed non-standard vehicle fuse failures, not observed elsewhere on the system.
- Additional analysis of vehicle data is in progress.

Findings & Analysis


Ribbon Rail Delivery

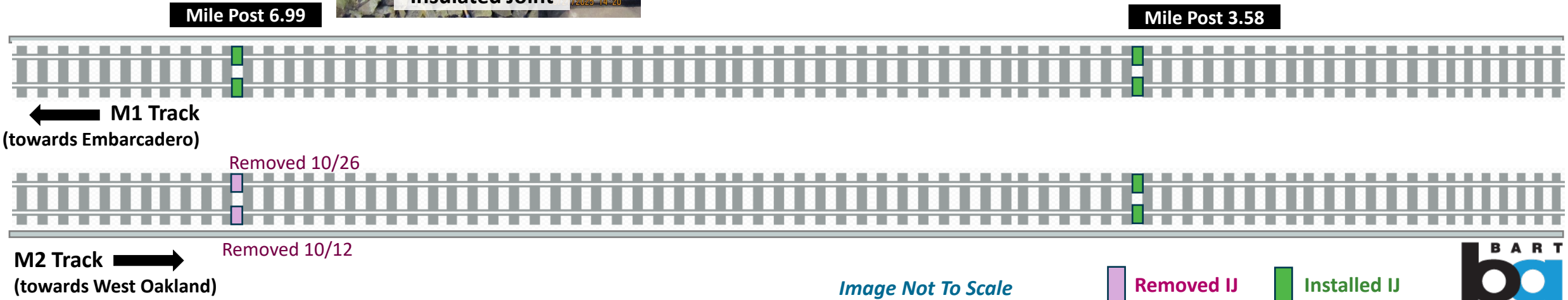

Insulated Joint

Rail Relays

- Stored ribbon rail was found in the vicinity of one of the arcing incidents.
- Third rail cantilever brackets have been occasionally cut back to accommodate ribbon rail storage for future rail replacement.

Insulated Joints (IJ)

- IJs divide the track and allow the train control system to detects if the track section is occupied by a train.
- IJs also isolate sections of track (negative return circuit) for maintenance purposes or to manage the traction power return.
- IJ locations were found to have changed in the TBT prior, during, and after the TBT incidents to facilitate rail relay projects.



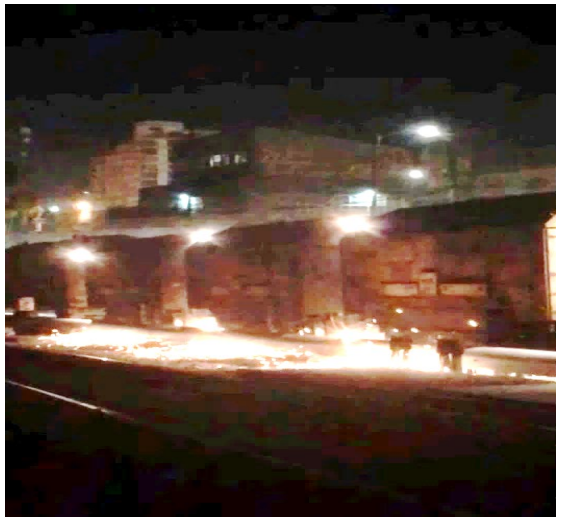
Findings & Analysis

Environmental Factors

- Rail grinding creates dust that can collect on surfaces inside of tunnels.
- Wet environment resulting from water intrusion, trackway puddling, and elevated humidity in underground stations

Human or External Factors

- Debris (e.g., garbage) especially that which contains conductive materials such as aluminum cans and mylar balloons can cause contact rail arcing.



Findings & Analysis

Track Power Vehicle Interface

- Natural movement and vibrations between the car and rail during normal operation, can briefly interrupt the interface between the Third Rail and the collector shoe paddle, resulting in normal momentary arcing.

- Potential increase in arcing between the Third Rail and paddles can be due to poor contact, rough track and contaminated surfaces, geometry misalignments or when one collectors carries most of the load.

Improvements Implemented

System Interface	Activity	Status
Traction Power 	Power Transformers at San Francisco Transition Structure returned to service (by others)	✓
	Modified Programming of Oakland Emergency Generator (OEG) Protection System	✓
	Restored Crossbonds in the Transbay Tube (TBT) for Negative Return	✓
	Upgraded Multi-Function Protective Relays (MPR's) at the TBT Gap Breaker Stations	✓
	Programming / tuning of additional MPRs at the Gap Breaker Stations	In-Progress
	Debris Cleaning - Tunnel, Station Platforms areas	✓
	Clean and/or Replace Insulators between Embarcadero and Civic Center	✓
	Survey of Crossbonds from Embarcadero to Balboa Park	✓
	Negative Return Path Mapping in the TBT	✓
	Negative Grounding Device (NGD) Repairs	In-Progress
	New Insulator Type (Fiberglass) or with Cycloaliphatic Epoxy Coating Research	In-Progress
	Complete upgrade and bring on-line KTE Substation	In-Progress
Vehicles 	Further Testing of Collector Assembly	In-Progress
	Vehicles Operation	N/A
Wayside 	Collector Shoe Third Rail Interface Review	In-Progress
	Rail Relay / Insulated Joints Review/Modification	In-Progress
	Direct Fixation Pads	In-Progress
	Removed stored ribbon rail on the M Line	✓

Incident Hypotheses

No.	Incident	Applicable Hypotheses/Common Causes		
1	**August 29, 2025 at 5:50AM** Montgomery Station – Sparks from ceiling	• **Negative Return Path, Grounding, Bonding** • **Traction Power System Transients** • **Environmental Factors**	• **Human or External Factors** • **Design Specifications or Changes**	
2	**August 29, 2025 at 5:12PM** Transbay Tube (Mile Post 6.15) – Smoke/Bright Flash	• **Traction Power System Transients** • **Environmental Factors**	• **Collector Shoe Interaction with 3rd Rail** • **Design Specifications or Changes**	
3	**September 20, 2025 at 6:40AM** Lake Merritt – Noise/Sparks on Track	• **Human or External Factors**		
4	**September 29, 2025 at 11:48AM** Transbay Tube (Mile Post 6.11) – Insulator Flashover	• **Traction Power System Transients** • **Environmental Factors**		
5	**October 7, 2025 at 4:35PM** Embarcadero – Loud Noise/Bright Flash	• **Traction Power System Transients** • **Environmental Factor**	• **Collector Shoe Interaction with 3rd Rail** • **Power System Protection Scheme**	
6	**October 19, 2025 at 01:10AM** Transbay Tube (Mile Post 2.73) – Sparks	• **Traction Power System Transients** • **Environmental Factors**	• **Negative Return Path, Grounding, Bonding** • **Power System Protection Scheme**	
7	**October 20, 2025 at 05:45AM** Embarcadero – Loud Noise/Insulator Flashover	• **Traction Power System Transients** • **Environmental Factors** • **Human or External Factors**	• **Collector Shoe Interaction with 3rd Rail** • **Power System Protection Scheme**	
8	**November 25, 2025 at 11:29AM** Civic Center – Insulator Flashover/Smoke	• **Human or External Factors** • **Environmental Factors**		
9	**December 8, 2025 at 6:51AM** Montgomery – Insulator Flashover/Smoke	**Under Evaluation**		

Next Steps

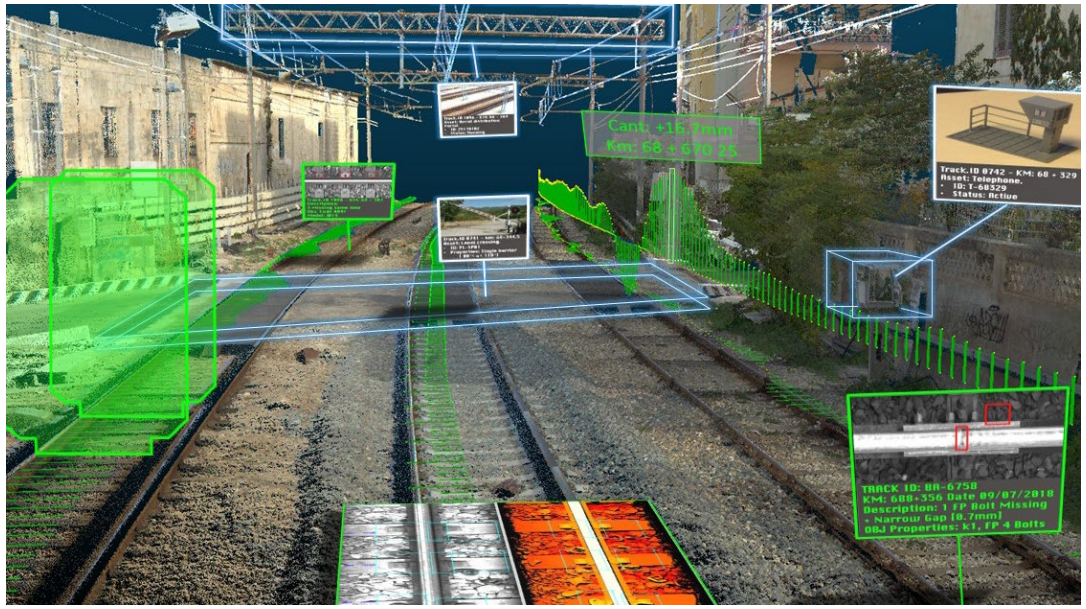
Further Analysis – Traction Power Load Flow Analysis
Load flow modeling is being utilized to re-create incidents that require analysis of complex system interfaces between track, traction power, and vehicles. Simulations are built using specialized modeling software provide insights into system loading, currents, voltages, and regenerative braking scenarios during the specific incidents that captures:

- BART's track geometry through the TBT
- Traction power system configuration
- Passenger stations
- Vehicles, including tractive effort
- Vehicle speed, consists, direction of travel, and typical passenger loading
- Peak and off-peak operational scenarios

Insulator Opportunities
Conduct additional research on Insulator designs and materials as well as cleaning practices

Vehicles
Conduct Shock and Vibration study on the fuse assembly and shunt connection
Evaluate possible collector shoe loss prevention measures

Policy and Procedure
Review / Revise / Develop procedures for approvals and signatures related to system changes which could potentially impact service
Research opportunities for additional remote monitoring and logging tools



Thank You

Glossary

AC: Alternating Current

Arcing: Arcing is a spark of electricity that jumps through the air between two points. It can cause heat and equipment damage.

Cantilever Bracket: A mechanical support for the third rail insulator that holds the insulator in place.

Circuit Breaker (Breaker): A fast-acting device that interrupts current during a fault to protect equipment. It is also used to switch sections of the third rail on and off.

Collector Shoe (Paddle): A conductive contact mounted near the wheels that slides along the third rail and transfers current to the train.

Collector Shoe Assembly: The mechanism, electrical connections, and supports that attach the collector shoe to the train. It also holds the fuse.

Coverboard
A protective cover that is installed over the third rail that helps prevent accidental contact and protects the rail from debris and damage.

Crossbond: A cable that is connected between running rails to help return current flow back to the substation through both tracks.

DC: Direct Current

Direct Fixation Pad (DF Pad): A pad installed under the running rails where track installed directly onto concrete. It cushions rail and reduces vibration.

Electromagnetic Interference (EMI) / Electromagnetic Compatibility (EMC): The ability of electrical equipment to operate properly in its electromagnetic environment without causing or being affected by interference.

Fishbone Diagram: A visual tool used to identify and organize possible causes of a problem by grouping them into categories, showing how different factors contribute to an outcome.

Fuse: An electrical component located on the train's collector assembly that melts when excessive current flows, opening the circuit to protect the vehicle.

Gap Breaker Station: A traction power facility located between substations that houses high-speed DC circuit breakers. These breakers trip during faults and are used to isolate sections of track.

Grounding/Grounding System: A **c**able and wiring system that provides a safe path for fault current to flow into the earth, helping prevent shocks and protecting equipment.

Insulated Joints (IJ): A specialized type of rail joint that connects two adjacent rails while electrically isolating them from each other. They are essential for track circuit signal systems.

Glossary

Multi-Function Protection Relay (MPR): A microprocessor-based relay used in traction power substations to monitor and protect DC circuits and trip breakers during abnormal conditions e.g. excessive currents (overcurrent).

Negative Return: The path that return current takes back to the power source, comprising of running rails and negative return cables, including crossbonds.

Negative Grounding Device (NGD): A device located at BART's substations which monitors the voltage on the running rails and grounds the running rails if this voltage is too high.

Negative Return Mapping: The process to field verify the negative return cables are installed per the record drawings.

Paddle (also known as a Collector Shoe): A conductive contact mounted near the wheels that slides along the third rail and transfers current to the train.

Paddle Force: The controlled pressure with which a vehicle's power collector shoe or paddle presses against the third rail to maintain reliable electrical contact while the train is moving.

Performance Level 4 (PL 4): A train operating mode that temporarily reduces the train's allowed speed and acceleration below normal track limits under special operating conditions.

Propulsion Control Unit (PCU): -A system that converts power from the third rail and delivers it to the train's traction motors. It controls acceleration and deceleration.

Protective Relay Scheme: The system in a BART traction power substation that detects faults (like short circuits or abnormal current) and automatically trips circuit breakers to isolate the problem and protect equipment.

Rail Relay: The process of replacing or relaying new running rail during maintenance or capital upgrade activities when the old rail has reached the end of its useful life.

Rectifier: Electrical equipment located inside the traction power substation that converts incoming alternating current (AC) into direct current (DC) . The rectifier output is connected to the DC 1000V third rail. It is part of the overall system that delivers traction power to the trains.

Regenerative Braking: During braking, the train's traction motors temporarily act as generators and send current back into the third rail, where it can be used by other trains, improving energy efficiency.

Residue: Material left behind after an incident such as soot, metal particles, or deposits that is analyzed to help determine what occurred.

Ribbon Rail: A long, continuously welded rail section that provides a smooth, uninterrupted path for train operation and electrical return current, reducing joints, vibration, and maintenance needs.

Glossary

Rail Grinding: A maintenance process that smooths and reshapes the rail surface to remove wear, reduce noise and vibration.

Shim: A thin strip of insulating material placed under third rail insulators, used to raise or adjust the height.

Shunt: A low-resistance electrical conductor used to connect the collector shoe to the fuse.

Switching Station: BART's switching stations convert 115kV from the public utility to 34.5kV for use at BART stations and traction power facilities.

Third (3rd) Rail: A third rail is an electrified rail that runs next to the track and provides traction power to the trains.

Third Rail Insulator: A component that supports the third rail and keeps it electrically separated from the ground

Traction Power Substation (TPSS): BART's substations convert incoming 34.5kV from BART's switching stations to 1000V DC. Positive cables connect the output of the traction power substation to the third rail, which delivers usable traction power to the train.

Transformer: Electrical equipment used to transform voltage either up or down. BART's traction power substation transformers step down from 34.5kV.

Voltage Fluctuation: Voltage fluctuation are variations voltage from its standard level.