PARTY SUBMISSION:

National Transportation Safety Board Investigation: Blue Line Derailment, October 12, 2021

Washington Metropolitan Area Transit Authority

300 7th Street SW, Washington, DC 20024

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Contents

I) Executive Summary

The Washington Metropolitan Area Transit Authority (WMATA or Metro) is the owner and operator of the Blue Line 7000-series train that derailed on October 12, 2021 between Rosslyn and Arlington Cemetery. Metro concurs with the National Transportation Safety Board (NTSB) report of the facts of the incident. It was an incident without injury. Metro immediately notified the state safety oversight body Washington Metrorail Safety Commission (WMSC), Federal Transit Administration (FTA), and NTSB. Metro secured the scene and NTSB took control of the investigation on the morning of October 13, 2021.

Since the derailment, Metro has taken proactive steps to improve safety and implement lessons learned. Key actions detailed in this submission cover railcar engineering and maintenance, track, and the broader organization.

From the start, the investigation into the probable cause of the derailment has been Metro's strategic and operational priority. Metro has spent over $8 million on the investigation. In the first days after the derailment, Metro's executive leadership team established an investigative team of internal specialists from railcar and track engineering, maintenance, and safety. Metro enlisted supplementary engineering expertise from Hatch-LTK. Endorsed by NTSB, on October 21, 2021 Metro awarded an emergency contract to MxV Rail (formerly Transportation Technology Center, Inc.), a leading rail industry research, consulting, testing, and training agency to investigate the probable cause and recommend corrective actions.

The probable cause of the derailment was wheel migration due to microslip induced by loss of contact pressure

Metro is grateful for the breadth and depth of expertise and resources brought to bear by other parties through the investigation, namely NTSB, FTA, WMSC, Kawasaki (the 7000-series railcar manufacturer), ORX (the wheel manufacturer), and the largest union Local 689 representing Metro operations and maintenance personnel. Metro has responded to over 470 requests for information from the parties and has led immediate post-incident actions, literature review, extensive data analysis, static testing, and dynamic testing.

The probable cause of the derailment was movement of the wheels on the axle. This conclusion derives from three separate, independent reports on the dynamic testing of 7000-series railcars in June 2022. Two reports were published by experts retained by Metro, namely Hatch-LTK and MxV, and the third report was by Kawasaki. The Hatch-LTK and Kawasaki reports both conclude the probable cause of the 7000-series wheel migration is microslip induced by loss of contact pressure. MxV's dynamic testing report posited vibration and thermal theories but did not provide a definitive finding or conclusion on the probable cause.

All parties agree that an increase to the interference fit and press tonnage of the wheels on the axle will mitigate both the microslip mechanism and other possible causal factors presented by MxV. Metro is embarking on a wheelset replacement program for the 7000-series fleet, increasing the interference fit from 4.5–6.5 mils to 6.5–8.0 mils and increasing the press tonnage from 65–95 tons to 80–120 tons.

Under the NTSB investigation, Metro continues to collect data to determine if track was a contributing factor, leading two track studies due to conclude by summer 2023. The first study is examining frogs (switch points) and the second, restraining rails. Metro will respond promptly to any findings or recommended mitigations.

Moving forward, Metro will remediate the known probable cause by increasing the interference fit and repressing the wheels and incorporate the learned safety improvements organization-wide.

II) Proactive Actions to Improve Safety Since the Derailment

Since the derailment, Metro has taken proactive steps to improve safety and implement the lessons learned. Key actions are detailed below, focusing on rail operations, engineering and maintenance, as well as the whole agency (e.g., organizational safety plan, structure, risk management, safety reporting, risk-based asset management).

A) Actions specific to rail operations, engineering and maintenance

Steps have been taken since the derailment to better identify and address safety issues across rail operations, engineering and maintenance departments.

1) **7000-Series Wheelset Measurement Program**: WMSC's December 29, 2021 order grounded the 7000-series fleet and required an approved plan to return trains to service. The Wheelset Measurement Program is at the heart of that plan. Metro's car vehicle engineers and maintainers worked closely with the Department of Safety and WMSC to design a program to enable earlier identification of deviations and implementation of remediation. Metro transitioned from using a manual gauge to a digital gauge, improving precision of measurements from 1/16" to 1/1000". The program is unprecedented, and the conservative, safety-first approach is unique in the transit industry, and includes a reduced measurement interval with oversight by specialist inspectors under contract to Metro. In addition, oversight inspections by Department of Safety and Office of Quality Assurance and Compliance staff inspected over 700 railcars to ensure compliance with procedures. 7000-series trains started returning to service in May 2022 under this enhanced wheelset measurement program. The program will continue until all wheelsets are replaced.

The safety-first, conservative Wheelset Measurement Program is unique in the transit industry

2) **Improvements in Technology:** Metro has used technology to improve safety and operations performance across its car engineering and maintenance functions, to include:

- Executing an emergency procurement to install an Automated Wayside Inspection System for real-time measurement and reporting of wheel back-to-back measurements. Procedures and application of the system is being developed. With some units installed, testing and safety certification of the system is ongoing.
- Improving railcar asset monitoring in its asset management software to track interference fit and pressing tonnage for every wheelset. The car engineers introduced additional functionality for analysis and report generation including back-to-back exception reports and movement analyses and trending.
- Enhancing the integration of the asset management with the rail performance monitoring software to improve tracking and control of railcar movements.
- Growing the capabilities and maturity of vehicle-track interaction analytical processes, which will lead the transit industry to better utilize the data gathered by 7000-series trains as they move through the system.
- Introducing electronic forms to allow operational maintenance personnel to enter real-time data using tablets, thus improving the accuracy, timeliness and efficiency of the maintenance processes. This also adds additional capability to identify and flag out-of-tolerance conditions.

3) **Attention to Wheel Pressing:** While 7000-series wheels pressed in-house by Metro proved sound, the railcar engineers took the opportunity after the derailment to take steps to proactively review and improve the quality of Metro's railcar wheel press facilities, to include the review of engineering procedures and calibration of equipment. Metro, like all U.S. transit agencies, (like all is not governed by a national standard but has embarked on the railroad industry's Association of American Railroads (AAR) Compliance Quality Standard 5000 Program.

4) **Chief Mechanical Officer Actions:** Metro's Chief Mechanical Officer leads the railcar engineering and maintenance functions. An acting appointment was made in March 2022 and confirmed as permanent in February 2023. Under the new leadership, the Rail Quality Assurance group provides direct oversight and management of the independent resident inspectors who execute the quality assurance procedures for the 7000-series wheel measurement program. That team also audits asset management data and field inspections to ensure compliance. In addition, the Chief Mechanical Officer established a dedicated Service and Delivery team for safer control and movement of railcars.

5) **Vehicle-Track Engineering Working Group:** A cross-departmental working group was formed between railcar and track engineers, railcar and track maintenance and safety staff. The group meets bi-weekly to review ongoing safety issues, collaborate on new and open research or projects, and improve data quality and process (e.g., vehicle-track interaction data). Dedicated subject matter experts continuously monitor and analyze railcar and track data, and those analyses are reviewed internally and shared with WMSC.

6) **State Safety Oversight Coordination:** In close collaboration with WMSC, railcar engineering and maintenance departments have improved the tracking of state safety oversight requests, and the associated responses and actions. The relationship has been formalized through bi-weekly meetings and logging of relevant documentation. These steps increase communication and improve coordination of information and actions related to open safety concerns.

7) **Incident Response**: Metro continues to focus on safe, prompt and effective incident response and recovery, with special focus on smoke/fire incidents and trains with passengers aboard. Improvements in rail operations control center procedures, the formal introduction of a Department of Safety official with an oversight function in the control center, as well as changes to the third rail power energization procedure all demonstrate Metro's progress in improving incident response. Dictated by the type of incident, safety investigators pay particular attention to compliance with procedures in the rail operations control center (e.g., the operation of fans), and in the field (e.g., evacuations of trains or stations). Metro continues to deliver a training and exercising program for jurisdictional fire and police agencies who are required to respond to incidents in the Metrorail system. In 2021, Metro embarked on the development of a revised approach to managing incidents, aligned with the National Incident Management System, and broadening incident management training for staff at various levels involved in incident response. Training is progressing and the new Incident Management Framework is set to launch in 2023.

8) **Transfer of Lessons to the 8000-Series Project**: This investigation identifies areas for improvement to better manage the design, quality management and safety/risk management processes associated with the acquisition of the 7000-series fleet. Critical documentation and learning from the Kawasaki 7000-series procurement, design, build, safety certification, warranty management process and this NTSB investigation is being transferred to the Hitachi 8000-series project. Consistent and open channels of communication and knowledge transfer have been established, with increased oversight from Metro's Office of Quality Assurance, Internal Compliance and Oversight. Metro's Safety Certification capability and standards have increased significantly, recently evidenced by the successful safety certification of the Silver Line Phase 2 project, and robust safety certification of the coupler replacement program that ensured the safe return of 6000-series railcars to service.

B) Organizational Safety Actions

The reporting of safety hazards at all levels must be openly encouraged, safety concerns need to be escalated to the appropriate level of the organization for action, and the response to safety concerns must be timely and proportionate to the risk associated with the hazards identified. Organizational siloes must not hinder effective safety risk management. Since the derailment, Metro has taken the following steps to improve safety risk management and safety culture.

Safety concerns need to be escalated to the appropriate level for action

1) **Acceleration of the Agency's SMS Strategy**: Metro's plan to implement its agencywide Safety Management System (SMS) strategy was outlined in its 2020 Agency Safety Plan, consistent with Federal Transit Administration requirements and aligned to industry best-practice. In the 2022 revision of the Agency Safety Plan, the strategic intent remains the same, but Metro has prioritized specific aspects of the plan to respond to lessons learned from the derailment:

   - Safety Risk Management Roll-Out: The Safety Risk Management Program builds the process and tools - and provides specialist staff embedded in operations departments – to systematically identify, assess, prioritize and mitigate safety hazards across the organization. Metro revised its roll-out plan to hire the staff and launch the safety risk management process in three rail operations departments in 2022, with an accelerated timeline to do the same for all operations and infrastructure departments by end of 2023.
   - Voluntary Reporting Program Overhaul: In 2022, Metro partnered with MITRE to complete an organizational safety culture assessment. In close collaboration with union representatives, the results are informing the design of a streamlined, more transparent voluntary reporting program in 2023. Metro intends to create an industry-leading program that builds trust and increases reporting of safety issues.
   - Enhancement of Safety Certification: Metro's Safety Certification capability and standards have increased significantly, evidenced by the successful safety certification of the Silver Line Phase 2 project in 2022. Metro has revised its Safety and Security Certification Program Plan and has increased staffing and skills. These steps lay the foundations for continuous improvement of the quality of Metro's safety certification function.

2) **Growth of Department of Safety:** Metro's Department of Safety underwent a significant restructuring and upskilling of its staff in 2021-22, working to build a more effective safety oversight culture, to include the creation of a new offices of Emergency Preparedness, and creation of more skilled and well-managed Offices of Safety Investigations and Safety Operations Oversight. Since the derailment, the department has grown by 23% from 82 to 107 full-time employees, driving increased day-to-day safety oversight of operations and construction activities, capital and operations improvement projects, incident management, preventative and corrective maintenance activities, and investigation of safety incidents. Driven by stronger relationships with operations, infrastructure and engineering staff, 2022 saw proactive identification of safety hazards that led to improvements in roadway worker protection procedures, enhancement of track-bed cleaning procedures to reduce likelihood of fires and obstructions, improved signage for Metro staff and external emergency responders while on the track, and resolution of flaws in the railcar washer equipment.

3) **Risk-Based Asset Management:** Metro's Office of Reliability Engineering Asset Management has initiated the process to identify and rank critical assets across Metro departments. Once identified, the intent is to monitor those critical assets, identify trends, take proactive action to mitigate risk (e.g., safety, performance, supply chain risk etc.), and then refine the methodology further. Ongoing review mechanisms for these assets and their condition are being established through the SMS structure, including at the Executive Safety Committee.

4) **Daily Safety Focus for Operations:** Metro's Chief Operating Officer and Senior Vice President of Rail have restructured and improved daily communication and focus on safety. The daily maintenance briefing for rail senior managers was supplemented with a post rush-hour coordination call for senior managers from all operations departments from across the agency. Reporting on safety events and safety oversight inspections are at the top of both agendas. Placing safety reporting at the center of these daily discussions increases situational awareness of critical safety issues and improves responsiveness in implementing mitigations. A key indicator of improvement in trust and the safety culture is Safety Hotline reporting. In 2022, there were a total of 319 Safety Hotline reports, which was a 31% increase on 2021. Reports from all levels of the organization related to a broad range of safety topics from station gates and signage on the roadway, to personal safety concerns and air quality at work locations.

Metro's 2023 strategic plan, #Your Metro, the Way Forward, places safety at the center of everything Metro does

5) **Executive Engagement and Direction:** Metro's Senior Executive Team works more closely than ever before with the Metro Board of Directors with an unprecedented level of understanding, engagement and oversight from the Board on safety matters. In addition to as-needed briefings on important safety issues, the Board receives quarterly briefings at the Safety and Operations Committee on the progress of the Safety Management System implementation. In February 2023, the Board adopted a new strategic transformation plan #Your Metro, the Way Forward, re-emphasizing safety as the cornerstone of all activities with. A strategic restructuring of the organization in 2022 created an expanded role for a Chief Safety and Readiness Officer, placing safety, quality and training under one executive, which is intended to reduce silos, increase collaboration and communication between safety and quality, and improve safety and quality oversight in response to lessons learned from the derailment.

III) The Investigation So Far

The NTSB investigation into the probable cause can be divided into five areas of activity:

A. Immediate Post-Incident Actions
B. Literature Review and the Exclusionary Approach
C. Data Collection and Analysis
D. Static Testing
E. Dynamic Testing

A) Immediate Post-Incident Actions

In the earliest stages, Metro secured the scene, assisted in identifying other points of derailment across the system, and was swift to respond with initial investigative actions in collaboration with all parties in the subsequent days and weeks. Some of the primary actions by Metro included, but were not limited to:

- **7000-Series Fleet Inspection:** Within the first days, Metro conducted a fleet wide inspection of wheelset assemblies on the 7000-series fleet. This inspection measured the wheelset back-to-back distance and journal bearing gap. Concurrently, Metro developed procedures for safely removing railcars with failed wheelsets, restricting these cars to the railyard. Metro also increased the frequency of periodic inspection for the 7000-series fleet from 90 to 60 days.
- **System Track Inspection**: Metro's inspection procedures require the track inspections twice weekly, with inspections of interlockings on a monthly basis. Vehicle-track interaction data from the incident train led Metro's track engineers to order a full-system inspection of all frogs, switch points, flangeway, and other special track work. As a proactive measure, several frogs were removed and replaced. The condition of turnout components was marked acceptable.

- **Incident Train Examination**: Under the supervision of NTSB investigators and in collaboration with all parties, married pair 7200/01 and their trucks were inspected at Alexandria Yard. Metro demounted three wheelset assemblies at Greenbelt rail yard. This demounting activity focused on inspection and measurement of the assembled wheelsets, measurement of the demounting forces, and measurement and inspection of the demounted wheelset assembly surfaces.
- **Data Collection**: As well as participation in NTSB-led interviews of Metro personnel, Metro downloaded all available data from various systems: the incident train's Event Recorder collects operational data such as speed, master controller position and door status; the Vehicle Monitoring and Diagnostic System detects vehicle faults; and Vehicle-Track Interaction system can help to detect track defects.
- **Early Dynamic Test**: In November-December 2021, Metro conducted an engineering test plan which operated two (2) eight car trains in simulated passenger service across all operating lines. This test served to gather preliminary investigative data – daily axle temperature and back-to-back measurements and provided information for determining an appropriate accelerated measurement interval for safe operation.
- **Systemwide Yard Restraining Rail Measurements**: Kawasaki collected dynamic data from an instrumented wheelset installed on an axle of a car of 8-car test train operated on mainlines as well as on yard tracks. Kawasaki reported high vertical and lateral wheel loads at almost all restraining rails in the Yards and secondary tracks. A special inspection was conducted of all the locations recommended by Kawasaki. Inspection results showed the restraining rail conditions to be satisfactory.

B) Literature Review and the Exclusionary Approach

The investigation reviewed existing industry research. The most informative research papers were:

- Brinkmann, P. "The Assembly of Wheelsets for Use on Railway Vehicles - Problems of Method and Design." Vol. 28. Issue 6. Translated from ETR, 1979.
- Nishimura, S., I. Sakamoto and H. Kawashima. "Study of the Adhesive Force Reduction of Press-Fitted Axle Assemblies by Ratchet Extrusion." International Conference on Engineering Design (2001).
- Nishioka, Kunio, Seiichi Nishimura and Kenji Hirakawa. "Fundamental Investigations of Fretting Fatigue." Bulletin of JSME (1968).
- Stewart, Mark. "LDK Report GO 4.3.1 - Bi-Level Wheel Migration Investigation." 1997.
- Hatch-LTK, WMATA Loose Wheel Investigation Report, LTK 041, 2015.

The literature helped to identify possible theories. Data excluded theories as the investigation progressed.

The literature review identified the leading theories, which included vibration – track induced vibratory forces and vehicle natural frequencies; press fit processes, procedures, and standards; thermal effects, and vehicle rail interaction forces to include the effects of outward and inward wheel forces and impact events due to special track work.

The investigation adopted an iterative, data-driven, exclusionary process which incorporated feedback from all parties. This process collectively and comprehensively evaluated each theory and dispositioned as: closed based on available data; open requiring additional testing, investigation, and data gathering; or a new theory added based on information from the investigative process.

C) Data Collection and Analysis

To ensure efficiency, compliance and transparency, Metro developed a Document Request Tracker at the outset of the investigation. In all, over 470 requests for information were logged and closed. The most frequent requestors were MxV (37%) and NTSB (28%). Examples of the types of information requested include design specifications for railcars and track infrastructure; wheelset measurement data for all fleets; inspection data; interview requests and subsequent follow-

up questions; draft and final investigative reports. Metro hosted biweekly calls open to all parties to prioritize and coordinate responses.

A critical piece of Metro's work in this area was the analysis of wheelset exceedance data. The key points are summarized below:

- Metro compiled and analyzed historical back-to-back and journal bearing gap exceedance records for 7000-series and 'legacy fleets' (2000, 3000 & 6000-series).
- The 7000-series wheelset data consists of 76,973 records, 57 of which were reported back-to-back exceedances and 87 journal bearing gap greater than 0.005" over a period of 5 years (2017–2021).
- 72% of the back-to-back exceedances were reported in 2021.
- All axles on the 7000-series fleet with back-to-back exceedances were pressed by ORX, the original wheelset manufacturer.
- The legacy wheelset data consists of 163,734 records, 26 of which were confirmed back-to-back exceedances and 84 journal bearing gap greater than 0.005".
- The reported back-to-back exceedances and journal bearing gap greater than 0.005" dated 2014 through 2016 (over 90%) are most likely attributable to the root causes identified in the LTK 041 report and were corrected by Metro.
- Hatch-LTK performed a review of the exceedances, which concluded that the exceedance rate of the 7000-series wheelsets decreased with increasing interference fit and press tonnage and further determined that wheelsets pressed at interference fits of 6.0 mils and greater did not fail.
- In search of critical clues, Metro continued its in depth analysis of wheelset data from May 2022 onwards, when 7000-series trains started returning to service. To date, Metro has conducted over 21,000 inspections and accumulated over 15 million miles. With no confirmed wheel movement beyond the margin of error of the procedure, no additional conclusions have been drawn.

D) Static Testing

The investigation constituted several testing elements, categorized as either static or dynamic. The static testing primarily consisted of ultrasonic testing (UT), wheelset demounting, gear unit spin testing, gear unit teardown, and journal bearing teardown.

- The ultrasonic testing utilized a specially designed probe to scan wheelsets. This non-destructive method was used to determine if there were indications of wheel migration. The results of the UT were inconclusive, and the method of evaluation deemed unlikely to be able to identify or predict mechanisms of wheel migration.
- Demounting of the wheelset assembly was conducted to determine if the press fit of the wheel was compromised and allowed visual inspection and measurement of the wheel seat and axle. The demounting process involved charting the pressing off tonnages achieved during demounting of the wheels from the wheelset assembly to quantify the forces required to initiate wheel movement. Of the wheelsets tested, the demount forces were generally within the expected range. Visual inspection of axles revealed the presence of fretting bands at the inboard wheel seat area. NTSB also conducted metallurgical testing on failed and sample wheelsets.
- The rail vehicles utilize gearbox units which are mounted to the axle. The gearbox units were production tested by the Original Equipment Manufacturer (OEM) by operating the units in the forward and reverse directions to characterize the vibration response and measure oil and bearing temperatures. This test was then repeated with the units mounted to the axle by the wheelset assembly supplier. The investigation conducted both these tests to characterize the performance of the gearbox units after a period of service to determine if there was any meaningful change in response relative to the production testing. While the units generally exhibited elevated frequency responses, it should be noted there may have been some contribution by the adjustable air springs of

the test stand. Further, the teardown and evaluation of the gearbox units did not find any definitive indications of wear or damage on the gearbox unit components.

- The journal bearings of the demounted axles were also evaluated to quantify the condition of the bearings and determine if there was any evidence of premature wear or failure indications. The teardowns concluded that all bearings were in good condition with no defects that would breach Association of American Railroads (AAR) guidelines.

E) Dynamic Testing

Metro fully supported the open, collaborative philosophy and engineering-centered approach adopted by the investigation. Consistent with that approach, all parties were provided multiple opportunities for collaborative review and development of inspection and test procedures, with full access to all resulting data throughout the investigation. This process encouraged independent assessment by the parties and allowed for divergent conclusions to be realized.

- Kawasaki and Metro performed on-track testing of instrumented 3000-series and 7000-series railcars from June 6 – June 13, 2022 throughout the Metrorail system.
- Kawasaki and Metro developed the running test procedure to measure the dynamic forces acting on the two types of wheelset. The procedure was designed to provide the necessary data to confirm or exclude the various failure theories under consideration by the investigation. The procedure was reviewed by all parties.
- Instrumented wheelsets were developed for both series of railcar to measure accelerations, axle strains and wheel forces. The respective trucks were also equipped with sensors to measure accelerations, temperatures, truck deflection and truck rotation, as well as cameras to view the wheel-rail interface.
- All parties participated in the dynamic testing and received the recorded data for further analysis.
- MxV, Kawasaki, and Hatch-LTK independently analyzed the data generated to identify differences in performance between the legacy and 7000-series fleets and identify a probable cause.

IV) The Probable Cause

The probable cause of is microslip induced by loss of contact pressure

The probable cause of the wheel movement derives from three separate, independent reports on the dynamic testing of 7000-series railcars in June 2022. Two reports were published by the experts commissioned by Metro, namely Hatch-LTK and MxV, and the third report was from Kawasaki. The Hatch-LTK and Kawasaki reports both conclude ***the probable cause of the 7000-series wheel migration is microslip induced by loss of contact pressure.*** MxV's dynamic testing report posited vibration and thermal theories but did not provide a definitive finding or conclusion on the probable cause. The three reports are summarized below:

- **Hatch LTK:** the report concludes that wheel migration is due to insufficient interference fit leading to micro-slip/ratcheting extrusion of the wheel. Hatch LTK performed a statistical analysis of the failures showing that the failure rate of the 7000-series wheelsets decreased with increasing interference fit and press tonnage; reviewed published industry standards noting that they generally recommend interference fit and press tonnage ranges greater than Metro's current practice; and compared the 7000-series interference fit with similar vehicles at other authorities that have higher interference fit ranges than used on the 7000-series fleet. Hatch LTK also reviewed published literature on wheel migration, identifying micro-slip/ratcheting extrusion as a possible wheel migration mechanism. A review of data from the on-track test and a Hatch LTK generated Finite Element Analysis (FEA) model showed that the increased lateral forces from restrained and unrestrained curves reduces the contact pressure at the press-fit interface over time, leading to microslip and ratcheting extrusion (migration) of the wheel. The Hatch LTK report recommends increasing the allowable range of interference fit and press tonnage as a mitigation for wheel migration.
- **MxV:** the report concludes that wheel migration is caused by a temporary reduction in the press-fit capacity, in combination with the application of an outward lateral force. MxV proposed two possible mechanisms for the temporary reduction in press fit capacity: (1) a vibration environment that strains the contact surface, and/or (2) a temperature differential between the wheel and axle. MxV identified that the vibration environment is the more probable cause. MxV agrees that Metro's proposed mitigation of increasing the interference fit will mitigate both proposed root causes.
- **Kawasaki:** the report concludes that wheel migration is caused by micro-slip, a mechanical phenomenon where a press-fitted wheel can begin to migrate in minute increments when the axle is subjected to the loads induced by the vehicle weight and track forces. In this scenario, the repeated application of a lateral outward force of approximately 10% of the original wheel press-fit force may lead to microslip over time. Additionally, Kawasaki submitted two supplemental reports, a physical test that duplicated the micro-slip mechanism and a finite element analysis (FEA) simulation that confirmed the mechanism analytically. While the Kawasaki on-track test report, micro-slip test report, and micro-slip FEA report provide no definitive recommended mitigations, during the all-parties meeting hosted by NTSB on January 11, 2023, Kawasaki recommended increasing the wheel/axle interference fit and also relocating restraining rails at interlockings. The latter recommendation remains under consideration as the two open track-related studies progress.

All parties agreed that increasing interference fit and increasing press tonnage would mitigate all theories under consideration

Of note, all parties agreed that a reduction in contact pressure is required for wheel migration to occur and that an increase to the interference fit and press tonnage of the wheels on the axle would mitigate both the microslip mechanism and other possible mechanisms presented by MxV.

V) Next Steps and Recommendations

A) Complete On-Going Track Investigation

The NTSB investigation has considered all possible causes from the outset. There may well be more than one probable cause. In addition to regular monitoring of the condition of the track as per standard operating procedure, Metro is leading two track studies as part of the NTSB investigation, which are due to conclude by summer 2023:

- **Evaluation of Current Frogs and Alternate Designs:** A 'frog' is a type of track structure that assists rail cars moving through switch points where one track meets another. Higher vertical and lateral loads occur at frogs as the train wheels transition. High loads may affect the vehicle suspensions and the structure under the track. There are advancements in designs and maintenance procedures of frogs which reduce the impacts on the train wheels and improve service life of frogs. A joint project between specialist consultants Jacobs and MxV is currently

investigating possible improvements to the existing turnout frog design and preventative and corrective maintenance practices that would reduce the loads on train wheels. The study should provide several new designs or improvements including maintenance practices. Validation of the new design, if required, may take 2 years.

- **Feasibility of Restraining Rails:** Restraining rails or guard rails are installed alongside the running rail in certain tight curves and at turnouts (which trains move from one track to another) to reduce wear and prevent the wheels climbing off the running rail. Restraining rails perform well but they require frequent maintenance due to hardware breakage (e.g., bolts), and replacement cost may exceed the savings in reduced high rail wear. During the NTSB investigation, Kawasaki collected load data and reported high lateral loads from the restraining rails in some yards; Kawasaki concludes in their dynamic test report that such loads may have the potential to accelerate wheel migration. A consultant will investigate the restraining rail design, to establish how maintenance and repair demands - and lateral loads – may be reduced.

Metro will closely monitor the progress of these studies and any recommended mitigations. Both reports are being coordinated through Metro's Vehicle-Track Engineering Working Group, and under the supervision of the NTSB investigation. The results will be included in the NTSB's final analysis and report.

B) Remediate the Probable Cause

All parties to the NTSB investigation agreed categorically that increasing the interference fit and increasing the press tonnage of the wheels on the axle would mitigate not only the microslip mechanism but also other possible mechanisms presented by MxV.

Metro is embarking on a wheelset replacement program for the 7000-series fleet, increasing the interference fit from 4.5–6.5 mils to 6.5–8.0 mils and increasing the press tonnage from 65–95 tons to 80–120 tons.

The solution of increasing interference fit and increasing press tonnage to mitigate against wheel movement is not new to the industry. Metro's Vehicle and Track Engineering Working Group – supported by Hatch-LTK - completed an engineering evaluation of the axle structural and fatigue strength, as well as the interaction with the track system, and concludes there are no foreseeable, adverse impacts resulting from the proposed interference and press criteria changes. To support the integrity of the wheelset replacement program, Metro's program will be supported by a safety certification process, quality assurance and control measures, and close monitoring of the track and vehicle systems to ensure any unforeseen impacts are detected immediately.

C) Enhance further the Wheelset Measurement Program

Metro now has an established, industry-leading Wheelset Measurement Program, which monitors the wheels of all 7000-series railcars in service. Metro intends to maintain, improve, and sustain this program as the primary tool to ensure safe operation of the fleet until the Wheelset Replacement Program is complete.

Metro is committed to continuously improve the accuracy and value of the process through digitization of the recording and tracking of measurements, which will enable consistent, recurrent review and statistical analysis of the wheel measurement data to identify trends and inform engineering actions. Metro will build on the work started by the new Vehicle and Track Engineering Working Group, comprised of subject matter experts from both track and vehicle engineering. This group is responsible for leading research and analysis, as well as building processes, standards and guidelines utilizing vehicle-track interaction data.

Metro has begun installation of automatic wayside inspection units, which can provide wheel and truck data, including back-to-back measurements. Metro intends to install more units which together will undergo Metro's safety certification process as one maintenance monitoring system. If successful, Metro will then incorporate this additional layer of automated monitoring into Metro's operating practices in the most optimal manner.

D) Convert Progress on Safety Actions into Systemic, Long-Term Improvement

Section II detailed the proactive safety improvements implemented by Metro following the derailment. Some of those actions are complete, but others are evolving and may require development into systemic, long-term changes to the safety culture at Metro, namely:

- **Deliver Safety Risk Management (SRM):** SRM seeks to establish the communication channels, processes and trust to identify, escalate and mitigate safety hazards up and down the organization, and across different departments and functions, so organizational siloes do not hinder effective risk management. As part of the plan to implement SMS, Metro will deliver the SRM program for all Metro's operations and infrastructure departments by end of 2023, which lays the foundation for improved hazard identification and risk management across the high-risk elements of the organization. Once established, the next phase will reinforce training and cultivate communication to establish a common understanding of risk, and ultimately change behaviors so continuous identification, prioritization and management of risk becomes entrenched in organizational culture.
- **Overhaul Employee Voluntary Safety Reporting:** As part of the plan to implement SMS, Metro will launch the industry-leading program that it is designing in 2023 in partnership with MITRE, to build trust and increase reporting of safety issues in all parts of the organization. This is a major step towards improving the safety culture, empowering employees and allowing the organization to effectively and promptly identify and mitigate safety hazards.
- **Develop automated inspection capability:** Metro will continue to thoughtfully develop and mature automated inspection technology. Metro can carefully build on what already exists in this area of the operation. For example, Metro utilizes ultrasonic testing technology, the digital gauge to measure back-to-back wheelset tolerance, a track geometry vehicle to efficiently inspect track, and is experimenting - and leading the transit industry – how to effectively utilize vehicle-track interaction data. Metro is also in the process of testing an automated wayside inspection system, which may enhance the ability to gather wheelset measurement data.
- **Enhance Risk-Based Asset Management:** Metro will complete work started by Metro's Office of Reliability Engineering Asset Management to identify and rank critical safety assets across asset owners, so critical assets can be better monitored and managed to identify trends, take proactive action to mitigate risk (e.g. safety, performance, supply chain etc), and continually refine the methodology.
- **Launch Grade of Automation Level 2:** Metro moved to manual train operation following the Fort Totten accident in 2009. Metro is preparing to move back to automated rail operations, which will not only mean safer rail movement, but will also ensure more optimal train speeds, which the track is designed to accommodate. This will improve performance, reduce maintenance of railcars and track, and reduce risk in how the railcars and track interact.
- **Take steps to integrate Safety Management System (SMS) and Quality Management System (QMS):** Building on the organizational change that brought safety and quality teams under the Chief Safety and Readiness Officer, Metro can integrate resources and processes to create complementary systems that improve safety and quality, improving organizational awareness and understanding, closing safety risk management gaps, and creating more opportunities for improved performance.
- **Enhance incident management:** In 2021, Metro embarked on the development of a revised approach to managing incidents, aligned with the National Incident Management System, and broadening incident management training for staff at various levels involved in incident response. In coordination with jurisdictional fire and police agencies, the training of Metro staff is progressing and the new Incident Management Framework is set to launch in 2023.

For WMSC:

- **Review the SSO Framework:** WMSC can take advantage of state safety oversight best practice and collaborate with Metro and a third party to build a better operating framework that facilitates more effective identification,

prioritization and management of safety hazards and risks. Together with Metro, WMSC can implement more widely the lessons learned from improved communication and information exchange on railcar safety issues.

For FTA:

- **Share best practice for safety management:** FTA can audit the progress of rail transit agencies in implementing the multiple elements of the CFR 49 Part 670 Public Transportation Safety Program, with the intent of working with American Public Transportation Association (APTA) to share best practices with rail transit agencies to effectively identify, prioritize and mitigate safety risk in partnership with state safety oversight bodies