Los Angeles County
Metropolitan Transportation Authority
Office of the Inspector General

Review of Metro Rail Service Disruptions

Report No. 18-AUD-03 October 24, 2017

Metro

Metro
Los Angeles County
Metropolitan Transportation Authority
Office of the Inspector General
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October 24, 2017

Metro Board

RE: Review of Metro Rail Service Disruptions

Dear Metro Board Directors:

The Office of the Inspector General conducted a customer impact focused study on the State of Good Repair budget to determine if priorities address rail service disruptions and how we might improve the customer experience. Historically, Metro has based capital investments on the priorities of the agency, expertise of asset managers, and age of transit assets and infrastructure. Recently, the agency has begun conducting asset condition surveys, which will allow better capital investment priorities. We understand that these efforts may take several years. Therefore, we conducted this study with the assistance of a rail expert, The Wathen Group, to first identify and evaluate the top three service disruption categories for each rail line, and then determine if the issues causing delays are being addressed and appropriate state of good repair (SGR) investments are being made to reduce their reoccurrence. This study is complementary to the agency's on-going asset condition surveys as it re-prioritizes its capital repair and replacement plans.

The review analyzed service disruption incidents in five major categories: rail vehicles, rail operations, traction power, yard controls, and signals. In 2016, rail vehicle and rail operations incidents were the most frequent categories of service delay incidents accounting for nearly 82% of the total delay incidents. Overall findings include:

- Metro does not currently have a good system or complete information to identify root cause for service delays.
- There is currently a lack of asset condition surveys for each asset class. These surveys are essential for identifying and rating the condition of each asset and its component parts as a guidepost to SGR investment decisions.
- In the absence of consistent root cause information and support from complementary asset condition surveys, the ability to ensure that capital and maintenance programs are adequately and timely addressing critical needs is significantly limited.
- Performing rail vehicle overhauls is critical.
- Traction power failures including the centenaries are causing canceled trips on the Blue Line. There is a budget to address this, but it should be reviewed for adequacy.

The review found that Metro is in the midst of implementing important improvements to its SGR program. In this regard, Metro is:

- Implementing asset condition surveys across all assets, which will allow better investment priorities to be set to address safety and reliability needs.
- Redesigning the M3 maintenance system, which promises to combine diverse incident databases and provide a platform for tracking root cause of incidents.

The report makes 57 recommendations which Metro can take to better identify, track, and reduce incidents that result in service disruptions. Those recommendations can be found in Appendix B of the report.

Metro management will spend several months to fully review the report, but provided a preliminary response (attached) that stated Operations and Risk, Safety & Asset Management Departments will begin the process to implement the recommendations over the coming year.

Sincerely,

Karen Gorman
Inspector General

cc: Phillip Washington
Stephanie Wiggins
James Gallagher
Greg Kildare
Board Deputies

Metro

Interoffice Memo

Date	October 19, 2017
To	Karen Gorman Inspector General
From	James T. Gallagher Chief Operations Officer
CC	Greg Kildare Chief Risk, Safety & Asset Management Officer
Subject	Management Response to the Draft Rail Service Disruption Review Report

Operations Management has received and reviewed the Rail Service Disruption Review Report issued by the Office of Inspector General. The report includes a total of 57 recommendations relative to Metro assets, State of Good Repair (SGR) efforts and projects, Enterprise Asset Management Plan initiatives, rail vehicles, rail operations, yard control, signals, traction power, and the mitigation, identification, tracking, and investigation processes of incidents that result in service delays.

The Operations and Risk, Safety & Asset Management Departments will begin the process to implement change recommendations over the next year; joining efforts with the Safety Culture Initiative that was launched in May 2017. Staff will provide regular updates to the OIG as recommendations are addressed and/or closed out.

Cc: Phillip Washington, Metro Chief Executive Officer
Metro Board of Directors
Andrew Lin, Audit Manager
Bernard Jackson, Sr. EO, Rail Operations
Errol Taylor, Sr. EO, Rail Maintenance & Engineering
Bob Spadafora, Sr. EO, Rail Fleet Services
Diane Corral-Lopez, EO, Operations Administration
Vijay Khawani, EO, Corporate Safety
Nancy Alberto-Saravia, Sr. Manager, Transportation Planning

24 October 2017

Review of Metro Rail Service Disruptions

THE WATHEN GROUP

Metro™

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Executive Summary

Introduction

The Metro Inspector General retained The Wathen Group (TWG) to first identify and evaluate the top three incident delay categories for each rail line, and then determine if the issues causing delays are being addressed and appropriate state of good repair (SGR) investments are being made to reduce their reoccurrence. Essentially an "impact based" capital assessment. The Inspector General recognized a primary goal of the Los Angeles County Metropolitan Transportation Authority (Metro) and its Board is to improve the customer experience. For the Operations Department, this means developing and improving in-service on-time performance, and implementing efficient and effective transit service. The Operations Department supports this agency goal by implementing an industry leading SGR program that will improve reliability, prioritize the performance of scheduled and preventive maintenance of assets, meet SGR goals, reduce breakdowns, and better meet the daily transit needs of customers.

The data set provided to TWG includes 2,585 service delay incidents within LA Metro Rail in 2016 on all rail lines. These delay incidents were categorized into 15 major incident types. Since the primary goal of this review was to determine whether the capital and maintenance programs are adequately and timely addressing critical needs as identified through incidents that have caused delays on the system, the analysis focused on delay incidents within Metro's control and therefore excluded 441 delay incidents categorized as Police/Health. While these delays were not included in the analysis, it should be noted that Police/Health delay incidents represented 17% of the total delay incidents, 28% of total cancelled trips, and 17% of late trips, with an average maximum delay of nearly 20 minutes. Since Police/Health incidents account for a significant portion of total delay incidents, Metro should review its approach to these incidents in partnership with responding law enforcement agencies to ensure its new transit security focus protects both the health and safety of the public as well as promotes the service reliability on which they depend.

Of the remaining 2,144 incidents that were part of this analysis, the major incidents were those categorized as: rail vehicles, rail operations, traction power, yard control, and signals. In 2016, rail vehicle incidents and rail operations incidents were the top two most frequent service delay incidents across all rail lines, accounting for nearly 82% of the delay incidents. The third leading category of incident delays was different for each line.

- For the Metro Blue Line (MBL), traction power was the third top cause of delays analyzed by TWG; while rail accidents exceeded traction power in frequency on MBL by three incidents, given the goal of evaluating capital/maintenance related events, TWG reviewed traction power incidents.

- For the Metro Expo Line (Expo) and Metro Gold Line (MGDL), yard control was the third top cause of delays.

- For the Metro Green Line (MGL) and Metro Red Line (MRL), signals were the third top cause of delays.

These incidents all caused delays of varying magnitude, inconveniencing customers at all hours of the day throughout the year. In addition to these delay incidents, Metro managers also recorded hundreds of additional incidents that occurred throughout the year that did not result in delays; but if the underlying causes are not addressed now, delays could occur in the future. Reducing these incidents to the extent they are within Metro's control promises improved service for all riders.

Key Findings

The report findings provide insights into the overall difficulty of evaluating delay data in a meaningful way to assess trends and mitigations. The report also evaluates each of the top three categories of delay by line and discusses specific findings and recommendations. The summary below is structured in six sections: 1. Overall; 2. Rail Vehicle Delays; 3. Rail Operations Delays; 4. Yard Control Delays; 5. Signal Delays; and 6. Traction Power Delays.

1. Overall Findings Applicable to All Delay Incidents

- The root cause for many delay incidents was not identified in Metro's records. In order to achieve a reduction in delay incidents, Metro must identify the root cause of these delays and then ensure that investments, both capital and operating, are in place to address the root cause problems. This presents the primary challenge for Metro to consistently identify the root cause of the problem. Since these incidents typically occur in the field, Metro staff are appropriately focused on returning to normal service as soon as possible. Field and time constraints limit the ability to fully assess the cause of the problem.

- For incidents that generate a work order, further review of the work order often identifies the root cause since the maintainer replaces/repairs the damaged component. However, mining that information from the work order to capture the root cause of the failure is a time consuming process. There is no consistent nomenclature or location for recording this information on the work order. As a consequence, incidents were grouped into broad and often meaningless categories. Capturing the root cause in a clear and prominent way would create a direct path to understand what, if any, investments would address those causes and mitigate those incidents.

- The difficulty in determining the root cause is further complicated by the current lack of asset condition surveys for each asset class. These surveys identify and rate the condition of each asset and its component parts as a guidepost to state of good repair investment decisions. More specifically, the surveys identify those components most at risk for causing safety and/or service impacts. Pending completion of these surveys, Metro tends to respond to incidents reactively, in response to an actual failure, as opposed to proactively addressing components identified through surveys.

- In the absence of consistent root cause information and support from complementary asset condition inventories, the ability to ensure that the capital and maintenance programs are adequately and timely addressing critical needs is significantly limited. The expertise of Metro's personnel and knowledge of their areas of responsibility ensure that maintenance and investments generally meet their current needs but do not provide an understanding of progress toward State of Good Repair or resolution of root cause failure trends.

- Metro currently does not have a good system to identify root cause for service delays. Therefore, it is difficult to determine if the issues causing the delays are being addressed and appropriate SGR investments are being made to reduce their reoccurrence.

2. Rail Vehicle Incidents Findings

- Rail Vehicle Service Delay Incidents are a small subset of maintenance shop statistics on fleet incidents, indicating that the majority of issues do not result in delay. However, determining failure trends and areas warranting investment should rely on all this available data.

- 27% of Rail Vehicle Incident reports resulted in no problem being found by maintainers trouble shooting the issue. Without a root cause identified in incident reports, the incident data cannot be evaluated for mitigations.

- Midlife overhauls were not conducted on the P865/2020 cars (40% of the light rail vehicle (LRV) fleet) and the Base Buy subway cars (29% of subway fleet), which are now the oldest cars in their respective fleets. With these cars remaining in service longer than anticipated, they are experiencing more component failures and are kept in service by as needed maintenance. These component upgrades will need to continue to ensure fleet reliability until these cars are replaced.

- The P2000 fleet (31% of LRVs) has the most incidents per car (2.48 during 2016) but is about to undergo a midlife overhaul.

- The P2550 cars (29% of LRVs), only 10 years old, are the most reliable LRV vehicles (.84 incidents per car). These cars have a diagnostic system and display, which help reduce incident-causing delays.

3. Rail Operations Incidents Findings

- Service incident delays attributed to Rail Operations represents a small percentage of the total Metro Rail service delays; and even then, not all incidents resulting in service delays that are designated as Rail Operations can be controlled within that Division.

- Operator non-availability and lateness for schedule pullouts were key contributors to those factors attributed to Rail Operations service related delays.

- The impact of service recovery delays (delays due to other problems on the line, such as trains with no movement or terminal delays) creates challenges in managing the Operator workforce. Rail Operations' Operator Extraboard staffing levels may not be sufficient as a mitigation resource to address the scope and impact of Metro service incident delays. The initiation of effective service recovery contingency plans is key to minimizing the impact of all Rail Operations incidents.

4. Yard Control Incidents Findings

- Yard related service delays were largely not specific to the yards.

- The top three incidents due to Yard Control were late pull out (46%), no equipment (21%), and operator related (18%), mostly operator not available.

5. Signal Incidents Findings

- The low number of identified signal incidents (72 during 2016) did not include the estimated hundreds of additional signal failures that did not cause delay. As a result, it is difficult to provide an objective analysis of the root causes and assess the current process for allocating capital funds to progress the state of good repair for signal installations.

- Signal failures that do not cause service disruptions are still likely to impact normal train operation and could require a train to operate in a degraded mode of operation. These failures were not captured in incident reports but should be part of Metro's data analysis of root causes of incidents.

- MGL has a relatively new signal system that should be in a state of good repair. On the MGL, 7 out of the 16 incidents (44%) were attributed to "False Occupancy," which caused 2 cancelled trips and 27 late trips. A "False Occupancy" occurs when a track circuit falsely indicates the presence of a train within its boundaries. The reports and associated work orders did not reveal a systemic issue or a pattern of failures that is out of industry norm.

- The MRL cab-based signaling system, completed in 1993, should be in a state of good repair. On the MRL, there were 10 incidents that caused 11 cancelled trips and 20 late trips during 2016. The incident reports and associated work orders on the MRL did not identify a pattern of failure either in specific components or as part of system functions.

6. Traction Power Incidents Findings

- Traction power failures on the MBL resulted in 357 cancelled trips and 107 late trips.

- The largest contributor to traction power incidents with significant impact on train service was the failures or interference with the catenary infrastructure. The second largest contributor to the incidents was related to failures in the Traction Power Substation equipment. Since catenary failure/interference has a significant impact on train service, it should have a high priority with respect to the State of Good Repair schedule. As part of a State of Good Repair project, Metro should assess the design of the catenary system as well as condition of the installation.

Mitigating Delay Incidents through State of Good Repair Investment

Interviews with the Metro staff described an agency in the midst of implementing important improvements to their State of Good Repair program. Metro is implementing asset condition surveys across all assets, which will allow better investment priorities to be set to address safety and reliability needs. Metro is also redesigning its Maintenance and Material Management System (M3), which promises to combine diverse incident databases and provide a platform for tracking root cause of incidents, and is taking other steps to implement a robust Enterprise Asset Management System. In the interim, maintenance activities address most incidents that occur during daily service; and capital investments are based on the priorities of the agency, departments, and expertise of the asset managers. While this analysis did not find any systemic failures, opportunities for improvement have been noted, particularly in this interim period before these ongoing improvements are fully implemented.

The $4.8 billion dedicated to state of good repair over ten years as described in the Short Range Transportation Plan demonstrates Metro's focus on SGR. However, this amount comes to $480 million per year, which needs to cover many assets. In addition to addressing new rolling stock for bus and rail, it also must address the needs of an aging infrastructure. Metro will need to reevaluate whether its investment strategy is sufficient once the asset inventories are completed and priorities for investments to achieve a state of good repair are set. While expansion of the system is critical, it cannot take place at the expense of maintaining the existing system. Setting this balance, however, requires a firmer understanding of the condition of the core infrastructure. Expediting the work currently under way will position Metro to better make these tradeoffs.

Recommendations

1. Overall recommendations that cut across all asset classes and all rail lines involve expediting critical projects currently underway. These include:

    - Finish the asset inventories in an expedited fashion, and establish a timely process for their periodic refreshing (every 3 years is Metro's goal).

    - Use these inventories to lay the foundation to revise the SGR plan, supplemented by information on the useful life of installation, failure rate, service needs, and available funding, with clear goals as to the expected reduction in assets not in SGR. This revised plan needs to be multi-year based, recognizing that as assets and their components are brought into SGR, others are falling out.

    - Evaluate funding for state of good repair to ensure that it is enough to cover annual SGR goals, including new rolling stock, as well as tending to the aging infrastructure.

    - Expedite funding for and implement the redesign of the M3 system, so that all databases can be probed for root cause trends allowing Metro to better mitigate causes of incidents and improve reliability.

In the interim, steps can be taken to improve the understanding of root cause and to set investment priorities, including:

- Instruct personnel on providing consistent and complete detailed information related to failures in the work order (WO) reports.

- Perform more thorough investigations and analysis to determine the root causes for high frequency failures (the top three on each line) even if they do not result in service delays to allow Metro to develop mitigations that promise to significantly reduce total delays.

- Establish a procedure for operating personnel to record the cause of any failure in normal operations even if it does not result in a service delay.

- Conduct periodic condition surveys in advance of, and complementary to, the asset inventory that is being undertaken.

- Attend to rail vehicle delays, which were the highest cause of delay across all lines, by setting priorities based on Metro's asset condition assessment as soon as it is complete to reduce these incidents.

During this interim period, improvements can also be made in the Rail Operations Control (ROC) process for recording delay incidents and in the information included in related work orders. These include:

- Improve Operators instruction to report any and all alert indications shown on the console.

- Establish a Mechanical Desk with a dedicated, 24/7 "super-tech" maintenance team in the ROC to provide expert support to the ROC for equipment, systems and infrastructure faults.

- Establish a process that requires the applicable asset department to ascertain and record root cause for failures.

In addition to the above overarching recommendations, the analysis yielded specific recommendations for each of the top three causes of delay incidents by line: rail vehicles, rail operations, yard control, signals, and traction power.

2. Rail Vehicle recommendations for each vehicle fleet follow:

Recommendations for the P865/P2020 Fleet (69 cars representing 40% of all LRVs, deployed on the MBL and Expo line).

- Identify the cars in the worst condition for decommissioning and use them as spare parts supply.

- Keep a large enough base fleet as floats to improve availability of P2000 vehicles for refurbishment, which have a higher delay incident rate.

- Maintain the remaining P865 cars only out of the MBL shop, which has the best logistics to maintain the P865 fleet.

- Continue with the component upgrades to keep a reduced fleet with increased reliability in service until replaced by the P3010 cars.

- Keep the refurbishment program started by Metro to reduce fuse failures. Metro started this program to minimize fuse failures by replacing worn components that can lead to failures.

- No major capital investment is needed for the P865/P2020 fleet.

Recommendations for the P2000 fleet (52 cars representing 31% of the LRVs, deployed on MBL, Expo, and MGL).

- Plan the midlife overhaul to first upgrade the cars in the worst condition.

- Analyze the float vehicle needs for the P2000 midlife overhaul and assure enough cars to expedite the overhaul.

- Improve the diagnostic capabilities of the new propulsion system.

Recommendations for the P2550 fleet (50 cars representing 29% of all LRVs, deployed on MGDL).

- Modify incident reports to include the information provided by the Train Operator Display (TOD).

- Report the time of the incident as shown on the TOD.

- Use the diagnostic system of a car to provide further valuable information to the maintainer investigating the incident.

Recommendations for Base Buy subway cars (30 cars representing 29% of the subway fleet).

- Keep the cars running by continuing funding to maintain this fleet. Even though new cars have been ordered, this funding should not be cut back.

- Assure that the knowledge of the chopper control unit is not lost before the new cars arrive. The chopper converts fixed direct current (DC) input voltage to a variable DC output voltage for the traction motor, which is controlled by these voltage variations. The base buy cars have a chopper propulsion and DC motors. Since this technology is over 50 years old and not used any more, Metro must maintain the existing expertise of these controls. Modern vehicles use an inverter, which works very differently from a chopper.

- Take Base Buy cars out of service as early as possible to reduce maintenance costs.

Recommendation for the A650 General Electric (GE) subway fleet (74 cars representing 71% of the subway fleet).

- Perform the midlife overhaul as planned.

3. Rail Operations Recommendations:

- Limit the designation of Rail Operations only to incidents that are accountable to that Division.

- Re-assess the level, allocation, and scheduling of Rail Operations Extraboard Operators as an opportunity to mitigate the impact of all service incident related delays resulting from Operator late or no show, Station Terminal and Yard Operator related delays, and "gap trains" staffing (extra trains to supplement capacity when needed).

- Assess the impact of Operator absenteeism and late/missed trips on service and current remedial measures to mitigate the level of occurrences.

- Evaluate Station Terminal operations and staffing needs to support on-time performance.

- Increase Rail Operators' vehicle troubleshooting training as a means to reduce vehicle related defect delays.

- Continue to assess the application of service contingency plans and related staff training required to implement these plans.

- Assess the adequacy of Rail Operations' schedule layover/recovery time at station terminals.

4. Yard Control Recommendations:

- Limit the designation of Yard Control incidents to those actually attributed to yards.

- Apply the Operator availability recommendations noted under "Rail Operations" above to those same issues associated with Yard service delays.

- Review Yard vehicle availability constraints and evaluate options designed to further support the consistent achievement of 100% equipment schedule availability.

5. Signals Recommendations:

- Instruct signal maintenance personnel on providing consistent and complete detailed information related to signal failures in the WO reports.

- Perform more investigations and analysis to determine the root causes for high frequency failures even if they do not result in service delays.

- Establish a procedure for Operations personnel to record the impact of any signal failure on normal operation even if it does not result in service delay.

- Conduct periodic condition surveys on signal installations in advance of, and complementary to, the asset inventory that will be undertaken soon.

- Establish a process and a criterion for replacement of existing signal installations that includes useful life of installation, failure rate, obsolescence, service needs and available funding.

6. Traction Power Recommendations:

- Perform more investigations and analysis to determine the root causes for traction power failures.

- Establish a procedure to instruct traction power maintenance personnel on providing complete detailed information related to traction power failures in the WO reports.

- Investigate the high level of failures that occurred at San Pedro Traction Power Substation.

- Conduct periodic condition surveys on traction power equipment in advance of, and complementary to, the asset inventory that will be undertaken soon.
- Establish a process and a criterion for replacement of existing traction power equipment that includes useful life of installation, failure rate, obsolescence, service needs, and available funding.

Next Steps

This report provides steps that Metro can take to be in a position to better identify, track, and reduce incidents occurring now. In addition, as Metro advances its initiatives related to its Enterprise Asset Management Plan, its ability to mine its data for root cause, track trends, identify mitigations, and prioritize investments will become increasingly effective. Metro should expedite those steps currently underway and the recommendations discussed in this report to yield immediate and long term benefits.

Section I

Background, Objectives, Statement of Work, Methodology

Background

The Metro Inspector General retained The Wathen Group (TWG) to first identify and evaluate the top three incident delay categories for each rail line, and then determine if the issues causing delays are being addressed and appropriate SGR investments are being made to reduce their reoccurrence.

One of the primary goals of Los Angeles County Metropolitan Transportation Authority (Metro) is to improve the customer experience. For the Operations Department, this means developing and improving in-service on-time performance, and implementing efficient and effective bus and rail service. This service goal is supported by the agency's goal to implement an industry leading state of good repair program, which the Operating Department implements by improving reliability, prioritizing the performance of scheduled and preventive maintenance of assets, meeting SGR goals, reducing breakdowns, and better meeting the daily service needs of customers.

Rail System: Metro operates six rail lines including two subway lines (Red and Purple) and four light rail lines (Blue, Green, Gold and Expo lines) serving 93 stations. (For this report, the two subway lines will be treated as one line.) These lines vary in age of infrastructure, rolling stock, and in distance as shown in the table below; these differences affect system service performance.

Table 1: Metro Rail Line Characteristics

Rail Line	Opened	Miles	Type	Stations
Metro Red/Purple Lines (MRL)	1993 MacArthur Park, 1993 Wilshire/ Western, 1996 Hollywood, 1999 North Hollywood, 2000	17.4	Subway/ Subway	16 (Inc. 6 shared)
Metro Blue Line (MBL)	1990	22	Light Rail	22 (Inc. 3 shared)
Metro Green Line (MGL)	1995	20	Light Rail	14 (Inc. 1 shared)
Metro Gold Line (MGDL)	2003 Eastside Extension, 2009 Azusa Extension, 2016	31	Light Rail	27 (Inc. 1 shared)
Metro Expo Line (Expo)	2012 Extension to Santa Monica, 2016	15.1	Light Rail	19 (Inc. 2 shared)

In 2016, 2,144 service disruption/delay incidents were reported on all Metro rail lines from the data set that the OIG provided, with 14 major incident types as listed below:

Table 2: Rail Incidents in 2016

Incident Type	Expo	MBL	MGDL	MGL	Subtotal Light Rail	MRL	Subtotal Subway	Grand Total
Rail Vehicles	237	456	323	272	**1.288**	134	**134**	**1.422**
Rail Operations	76	97	74	57	**304**	26	**26**	**330**
Traction Power	19	30	19	15	**83**	9	**9**	**92**
Yard Control	25	17	25	13	**80**	1	**1**	**81**
Signals	13	18	14	17	**62**	10	**10**	**72**
Rail Accident	13	33	18	4	**68**	4	**4**	**72**
Extra Service/ Missed Car Cut		25			**25**		**0**	**25**
Fire / Emergency		9	4		**13**	4	**4**	**17**
Track	2	2	10		**14**		**0**	**14**
TSE SCADA	1	1		2	**4**	6	**6**	**10**
Communication		1		2	**3**		**0**	**3**
Passenger Conduct			2	1	**3**		**0**	**3**
Fire Equipment					**0**	2	**2**	**2**
FM Contract Svc				1	**1**		**0**	**1**
Grand Total	**386**	**689**	**489**	**384**	**1.948**	**196**	**196**	**2.144**

(This data set excludes 441 incidents related to Police/Health incidents that are not within Metro's control since the primary goal of this review was to determine whether the capital and maintenance program are adequately and timely addressing critical needs as identified through incidents in Metro's control that have caused delays on the system.)

These incidents all caused delays of varying magnitude, inconveniencing customers at all hours of the day throughout the year. Reducing these delay incidents to the extent they are within Metro's control promises improved service for all riders. To achieve a reduction, Metro must identify the root cause of these delays and then ensure that investments, both capital and operating, are in place to address the root cause of problems.

Objectives of Review of Service Delays

The objectives of this project are to conduct a review and analysis of Metro Rail Service Disruptions by determining:

- The three major causes for Metro Rail service disruptions by line from the data provided; and
- Whether the causes are being properly addressed and, if capital, prioritized in Metro's State of Good Repair (SGR) Report.

The primary goal of this review is to ensure that the capital and maintenance programs are adequately and timely addressing critical needs as identified through incidents that have caused delays on the system. Therefore, the focus of this review is on delays caused by incidents involving equipment, systems or infrastructure and not on operations or incidents outside the control of Metro, although this review will include operational issues to the extent they are identified in the top three categories of delay by line.

Statement of Work

TWG was engaged by the Office of the Inspector General (OIG) to perform this review. Pursuant to the Statement of Work prepared by the OIG, TWG performed the following tasks:

- Reviewed the service disruption log and other reports of Metro Rail for calendar year 2016, and determined the top three major causes, including the total number of disruptions per line, the apparent or reported nature of the disruption, the period of disruption and actions taken to remedy the disruption.

- Reviewed the incident reports, work orders, and corrective actions.

- Interviewed Metro management and staff in rail operations, safety, risk management, and other relevant departments to determine root causes and ultimate remedies necessary to resolve the disruptions and if those remedies are in progress.

- Determined whether Metro's vehicle repair or replacement plan and overall SGR schedule adequately prioritized and scheduled replacement or repair of high impact capital equipment.

Methodology

The data on frequency of incidents was used to identify the top three broad causes of delay on each rail line of the system.

1. A statistically significant random sample of incidents for each of the top three causes of delay on each rail line was drawn from the data provided, treating the light rail lines as one for creating samples and the subway lines as a separate data set. While the constraints on this project did not allow for a statistically significant sample to be drawn for each individual line, this distinction between light rail and subway allowed TWG to evaluate potential differences in causes and mitigations between these two distinct operating systems. Furthermore, since light rail lines do not have an equal distribution of specific incidents, the sample size for each line was determined based on the frequency of that incident type on that line. That is, a weighted sample was used to get a better representation of each incident across the four light rail lines. The number of incidents included in this study and the number of incidents sampled (highlighted in gray) are as follows:

Table 3: Sample Size Calculations for Light Rail and Subway Lines at 95% Confidence Level

Top 3 Incident Types	Expo	MBL	MGDL	MGL	Subtotal Light Rail	Sample Light Rail (95% C.I.)	Subway (MRL)	Sample Subway (95% C.I.)
Rail Vehicle	237	456	323	272	1.288		134	
Percent of Total	18%	35%	25%	21%				
Weighed Sample by Line	54	105	74	63		296		100
Rail Operations	76	97	74	57	304		26	
Percent of Total	25%	32%	24%	19%				
Weighed Sample by Line	43	54	41	32		170		24
Traction Power		30			30			
Sample by Line		28				28		
Yard Control	25		25		50			
Sample by Line	22		22			44		
Signals				17	17		10	
Sample by Line				16		16		10
Grand Total						**554**		**134**

2. Incident reports were reviewed for each incident in the sample, which provided a generalized description of the incident, the maximum duration of the delay, and the location of sample incidents. Although this information was attributable only to the sample of incidents under review, these demonstrate the nature of the incident as described by the operator and recorded by the Rail Operations Control (ROC). The findings and recommendations as to the data captured by the Incident Reports are discussed in the next section of the report.

3. When an Incident Report from the sample included a work order, the work order was also reviewed to determine the root cause of the incident. While the next section of the report captures the causes identified in the work orders, a lack of common nomenclature for identifying root cause limited the ability to comprehensively identify common failures and thus limited the ability to evaluate capital investment needs to address and reduce those delay failures. The findings and recommendations as to the data captured by the work orders are discussed in the next section of the report.

4. To better understand the process for generating and populating the incident reports and work orders, TWG conducted interviews with representatives of the ROC and Information Technology (IT) representatives developing a new logging system for the ROC, supplemented by the interviews conducted for each asset class as identified below. Participants in these interviews are shown in Appendix C List of Interview Participants.

5. To evaluate the extent to which Metro's Capital Program includes investments to reduce the causes of delay, TWG reviewed capital investments during its interviews with each asset group; reviewed available material on Metro's Capital Program including the Long-Range Transportation Plan, the Short-Range Transportation Plan and the Annual Budget; and conducted interviews with the Asset Management Group and the Office of Management and Budget, Finance Division. See Appendix C for List of Interview Participants.

This process was then applied to the analysis of each specific cause of delay for the top three causes by line as discussed below.

Top Three Causes of Delays by Line

Based on our review, we identified the following top three causes for each line:

a. Rail vehicle delays on all lines
b. Rail operations delays on all lines
c. Yard control delays on Metro Expo and Gold Lines
d. Signal delays on Metro Green and Red Lines
e. Traction power delays on Metro Blue Line

Based upon these major causes of delays, TWG selected samples for each category. Through interviews and review of Metro documents, TWG assessed the current situation and made recommendations for action.

Specific Methodology for Top Three Causes of Delays by Line

1. Sample Size and Methodology

   a. *Rail Vehicle Delays: First Major Cause of Delays (by frequency) on all five lines.*

   Total rail vehicle incidents: 1,422 identified in the data provided; 1,288 on the light rail lines and 134 on the subway lines.

   TWG conducted a thorough analysis of 296 light rail vehicle delays and 100 subway vehicle delays, both statistically significant samples at the 95% confidence level, to determine specific cause of failure and steps taken to correct. The sample of 296 is from the total number of incidents across all four light rail lines, not a statistically significant sample by each light rail line.

   A review of the incident reports for these delays found a significant number of failures attributable to general faults that provided insufficient information as to the root cause of the problem, e.g. propulsion faults which actually meant door not closed, brake stuck on, no automatic train control signal code, or lack of overhead catenary voltage, but not a propulsion system failure. Therefore, TWG evaluated every work order generated for each incident report to attempt to identify the root cause of the delay incident.

   In addition, TWG conducted interviews with representatives of Rail Vehicles to clarify information, address issues from the data, and describe the process and comprehensiveness of the investment program to address these delay incidents. See Appendix C for List of Interview Participants.

   b. *Rail Operations: Second Major Cause of Delays (by frequency) on all five lines.*

   Total rail operations incidents: 330 identified in the data provided; 304 on the light rail lines and 26 on the subway.

   TWG conducted a thorough analysis of 170 light rail operations delays and 24 subway operations delays, both statistically significant samples at the 95% confidence level, to determine specific causes and steps taken to correct. This does not represent a statistically significant sample by light rail line. Since these incidents did not generate work orders, TWG relied on interviews with representatives of Rail Operations to clarify information, address issues from the data and describe the process for addressing and reducing these delay incidents. See Appendix C for List of Interview Participants.

c. *Yard Control: Third Major Cause of Delays (by frequency) for Expo Line and Metro Gold Line (MGDL).*

Total yard control incidents for these two lines: 50 identified in the data provided; 25 of these incidents from Expo and 25 from MGDL.

TWG conducted a thorough analysis of 44 traction power delays, 22 Expo incidents, and 22 MGDL incidents, statistically significant samples at the 95% confidence level, to determine specific causes and steps taken to correct. The associated work orders were also analyzed.

TWG relied on interviews with representatives of Operations and Yards to clarify information, address issues from the data and describe the process for addressing and reducing these delay incidents. See Appendix C for List of Interview Participants.

d. *Signals: Third Major Cause of Delays (by frequency) for Metro Green Line (MGL) (light rail) and Metro Red Line (MRL) (subway).*

Total signal incidents on these two lines: 27 identified in the data provided; 17 of these incidents on MGL and 10 on MRL.

TWG conducted a thorough analysis of 16 signal delays on MGL and 10 MRL incidents, statistically significant samples at the 95% confidence level, to determine specific causes and steps taken to correct. The associated work orders were also analyzed.

TWG relied on interviews with representatives of Signals to clarify information, address issues from the data, and describe the process for addressing and reducing these delay incidents.

e. *Traction Power: Third Major Cause of Delays (by frequency) for Metro Blue Line (MBL).*

Total Traction Power Incidents for MBL: 30 identified in the data provided.

While rail accidents exceed traction power in frequency on MBL by two incidents, given the goal of evaluating capital/maintenance related events, TWG reviewed traction power incidents.

TWG conducted a thorough analysis of 28 traction power delays on the MBL, a statistically significant sample at the 95% confidence level, to determine specific causes and steps taken to correct. The associated work orders were also analyzed.

TWG relied on interviews with representatives of Traction Power to clarify information, address issues from the data, and describe the process for addressing and reducing these delay incidents. See Appendix C for List of Interview Participants.

2. Mitigations and State of Good Repair Plans

TWG evaluated the mitigations deployed by Metro and attempted to review the mitigations against existing policies, operating rules, and training for operating issues and the SGR capital plan to determine whether they were appropriately funded and prioritized. Data on the investment resources allocated to the specific areas of root cause identified by TWG were not available. However, the approach to capital funding for these asset classes was identified and evaluated for its comprehensiveness in addressing and reducing these failures and their associated delays moving forward.

Section II

Findings and Recommendations

Based on the targeted sample of delays across lines by causes, TWG analyzed incident reports and associated work orders, and conducted interviews to determine root causes of delays to the extent possible. This report summarizes the areas reviewed by TWG, the findings related to those areas and recommendations for addressing those findings.

A. Reporting Root Cause of Service Delay Incidents: Incident Reports and Work Orders

Incident Reports and Work Orders: Incident reports are generated by the ROC from information relayed to them by the Operator. This information may also be supplemented by a supervisor and/or maintenance technician when they arrive on the scene. When an incident report includes an associated work order, additional information is provided by the maintenance crews and the parts summary included in the work order.

Findings Related to Reporting Root Cause of Service Delay Incidents

A1. Generally, the information for the incident report comes from the operator who often just describes the condition experienced (e.g. no movement, no propulsion, etc.), which may be too general to determine the root cause.

A2. The generality of descriptions in the incident reports often results in no specific problem being found when the maintenance crews review the work orders (27% of Rail Vehicle Incidents).

A3. In addition, this system generates variability in what operators report and in what controllers record, compromising the ability to identify common failures and sometimes resulting in the mischaracterization of incidents (e.g. 14.4% of Rail Operator Incidents describe Rail Vehicle faults).

A4. The descriptions of service delay incidents can and should be prompted by alerts displayed on the train console, but often they are not. For example, many reports cited "no movement," but there is no console alert called "no movement." As a problem code, this provided very little information from which to evaluate root cause.

A5. While the technician in the field who has a better sense of the problem could be a resource in the reporting process, the technician is appropriately more focused on getting the problem vehicle out of the way. In a similar vein, to better respond to incidents by quickly identifying and addressing problems, the ROC is assigning a rail fleet vehicle technician to the ROC, who can ask relevant questions to determine the system where the problem occurred. (The ROC has also invited signals, Maintenance of Way (MOW) and traction power to send personnel to the ROC if personnel levels allow.) However, the ROC is only "borrowing" this one technician from the MBL/MGDL who will continue to have ongoing fleet responsibilities.

A6. Not knowing the root cause of the incident severely limits the ability to determine the best mitigation, whether operating or capital. In addition, while these reports provide the work order number if a work order is generated, they do not provide a mechanism to capture a causal code from the maintenance department's resolution of the incident.

A7. When an incident report includes an associated work order, the root cause of the problem can often be found in the additional information provided in the work order; however, since the incident report generates the introductory information in the work order, the work order may not consistently identify the system, subsystem, and subsystem component that represents the root cause of the incident.

A8. The lack of common nomenclature for identifying root cause limits the ability to comprehensively identify common failures and thus limits the ability to evaluate investment needs to address and reduce those delay failures.

A9. Metro's project to replace the M3 System logging module, used by the ROC to create the chronological entry of each service delay incident, will provide better information on the causes of delay incidents. The Information Technology Services (ITS) department has hired a consultant to develop the requirements for the new system. The requirements design consultant is meeting with ITS to identify the type of system Metro wants, connecting incident reports and work orders. All the asset managers have been meeting with the requirements consultant to provide their specific requirements for the module. For example, Rail Fleet is working with them with the goal of creating a nested drop-down listing with codes for every system on the train, then sub-codes for components within those systems, and sub-sub codes of subcomponents of those components.

Recommendations Related to Reporting Root Cause of Service Delay Incidents: Incident Reports and Work Orders

The effective identification of root cause is key to using the service delay reporting system to identify trends and then developing appropriate capital and operating strategies to reduce the reoccurrence of these incidents. There are several recommendations for improving the process to better capture the cause of the incident; many of these recommendations are currently underway at Metro.

1. Instruct Operators to report all alert indications shown on the console. This is especially important given the amount of information that is available on the console of the new trains. In addition, operators should assess whether passenger behavior caused an indication as opposed to a problem with the equipment. (A door indication, for example, may signal that a passenger is holding the door open.)

2. Establish a dedicated, 24/7 "super-tech" maintenance team full time in the ROC to provide expert support to the ROC for equipment, systems and infrastructure faults. This will improve service with the ability to quickly relay troubleshooting approaches to the operator as well as the expertise to more accurately identify the problem. Unlike the new approach being taken by the ROC to "borrow" a vehicle technician to assist with incidents, this recommendation calls for a technical desk with dedicated full-time staff.

3. Ensure the Rail Vehicle Department records root cause for rail vehicle delay incidents, which are the highest number of incidents across all five rail lines. Instruct the ROC to record "Rail Vehicle Event." After the WO is completed, Fleet Services should add the root cause in a designated location on the form. As an alternative, the root cause can be tracked at a weekly reconciliation meeting between staff from the ROC and staff from Fleet Vehicles or at the regular morning meetings; however, this may be too time consuming to be feasible.

4. Maximize the redesign of the M3 software program logging module. All departments should work with the design expert to create a drop-down listing that would capture the most meaningful root cause categories for their area of responsibility. Ideally, the ITS department should also bring all fault reports into one environment, so that internal department reports of failures can be tracked along with those recorded through the ROC. This redesign of the M3 module should allow for automated tracking of delays and their root causes, reporting delay trends, identifying mitigations, and tracking their impact.

5. Include Train Operator Display (TOD) information, such as time of the incident, in the reporting of incidents.

B. Overall: Top Three Causes of Delay by Line

The original data set provided to TWG recorded 2,585 delay incidents within LA Metro Rail in 2016 on all lines. These delay incidents were categorized into 15 major incident types. Since the primary goal of this review is to determine whether the capital and maintenance program are adequately and timely addressing critical needs as identified through incidents that have caused delays on the system, the analysis focused on delay incidents within Metro's control and therefore excluded the 441 delays categorized as

Police/Health. Therefore, the final data set reviewed by TWG included 2,144 service disruption/delay incidents with 14 major incident types.

Finding Related to Police/Health Incidents

B1. While these delays were not included in the analysis, it should be noted that Police/Health delay incidents represented 17% of the total delay incidents, 28% of total cancelled trips and 17% of late trips, with an average maximum delay of nearly 20 minutes.

This category of delay includes a range of causes such as possible criminal activity, disorder, threats (including bombs/terrorism), weapons, pedestrians/cars on tracks, and sick passengers. The transit industry is implementing and testing various strategies to address these issues. Agencies, including Metro, are using a variety of strategies to reduce these types of delays, such as the use of public service campaigns suggesting passengers not board trains if they feel sick, working with communities around targeted community policing, and making arrangements with local emergency services support.

Since police/health incidents represent 17% of total delay incidents with an average delay of 20 minutes, Metro should strategize with responding law enforcement agencies to ensure the process employed by them protects both the health and safety of the public as well as the service reliability on which they depend. However, without a more in-depth analysis of the specific causes for the delays and the magnitude of those causes, it is a challenge to analyze and identify specific strategies for mitigating Police/Health related delays at this time.

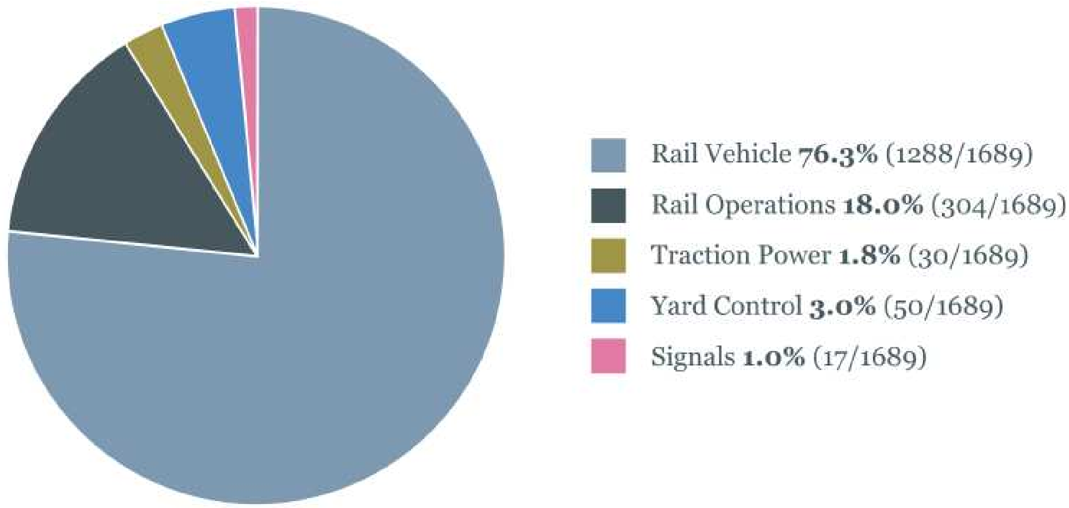
Findings Related to Top Three Categories of Delay

The top three light rail incident categories by line comprised 86.7% of the total number of incidents in calendar year 2016 (less Police/Health incidents) as identified from the data provided (1,689 light rail incidents of the total 1,948 light rail incidents).

B2. Rail vehicle incidents and rail operations incidents were the top two service delay incidents across each of the four light rail lines, accounting for nearly 95% of the 1,689 delay incidents (76.3% rail vehicle incidents and 18.0% rail operations incidents). See Figure 1.

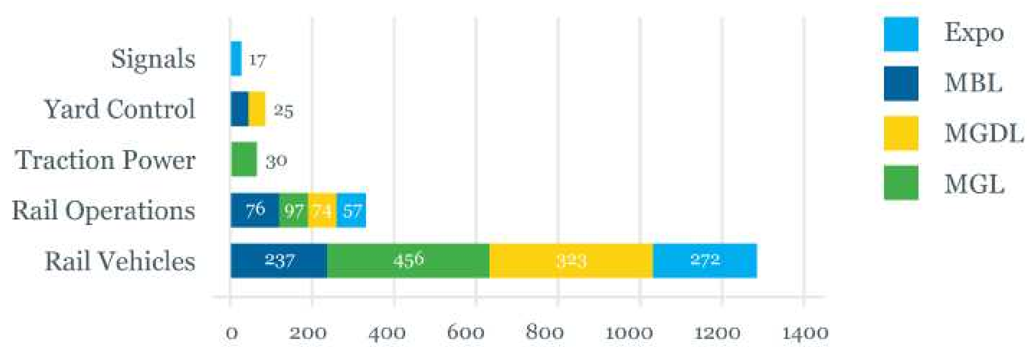
B3. For the MBL, traction power was the third top cause of delay; for the Expo and MGDL, yard controls were the third top cause of delay; and for the MGL, signals were the third top cause of the delay.

Figure 1: Distribution of Top Three Light Rail Incidents



B4. Of all the light rail lines, the MBL had the largest number of rail vehicle incidents and rail operations incidents. (see Figure 2 below.)

Figure 2: Distribution of Top Three Incidents on each Light Rail Line

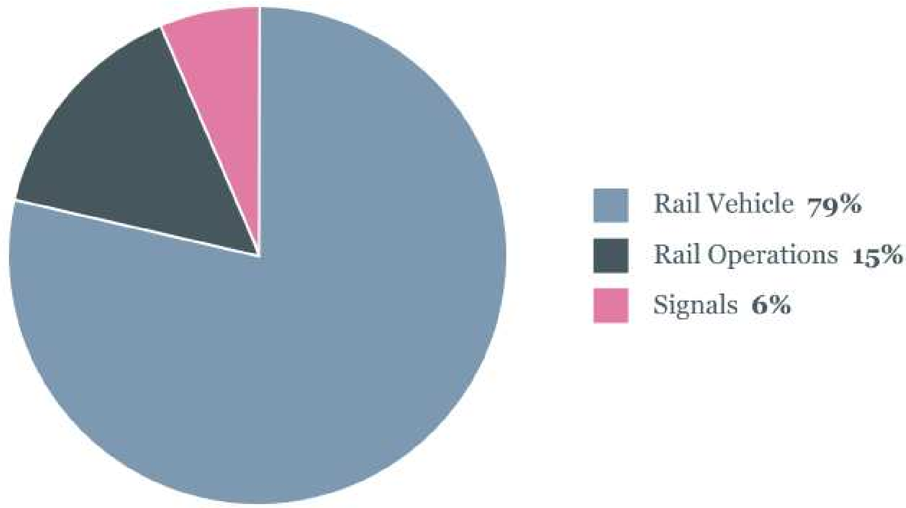


The Metro Red Line presents a similar portrait.

B5. The top three causes of delay on MRL represented 86.7% of total number of MRL delay incidents in 2016 as identified in the data provided (170 incidents of the 196 total).

B6. Rail vehicle delays comprised 79% of the top three causes, as shown in Figure 3:

Figure 3: Distribution of Top Three Subway Incidents



B7. Rail vehicle service delays and rail operation service delays were also the two causes of delay responsible for the largest total number of cancelled and late trains and the highest total of maximum delay minutes. (The ROC records the longest delay from amongst those trains delayed by an incident in the delay incident report as the maximum delay minutes for each incident.) See Figure 4.

Figure 4: Total Cancelled and Late Trains by Top Three Incident Types

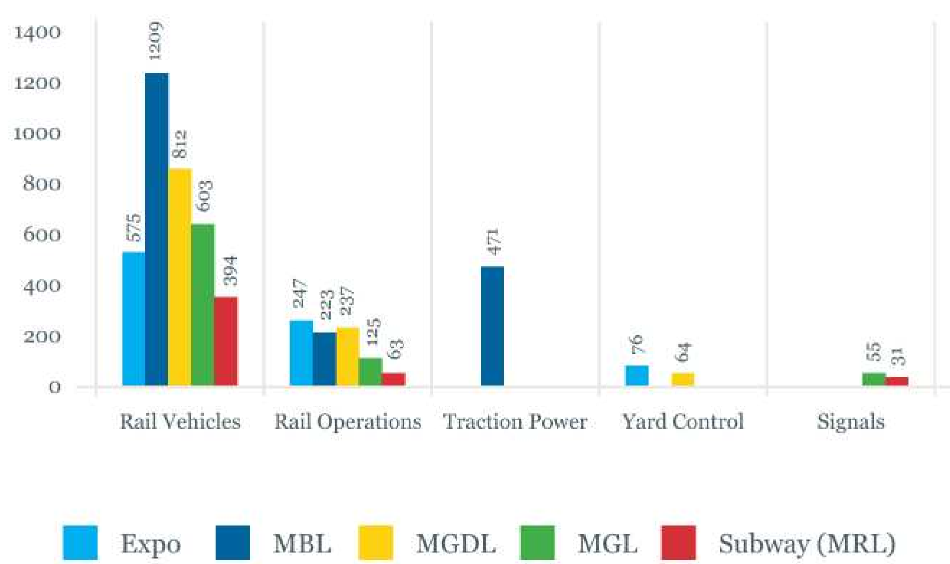


Table 4: Total 'Maximum Delay' Minutes for Top Three Incidents Per Line

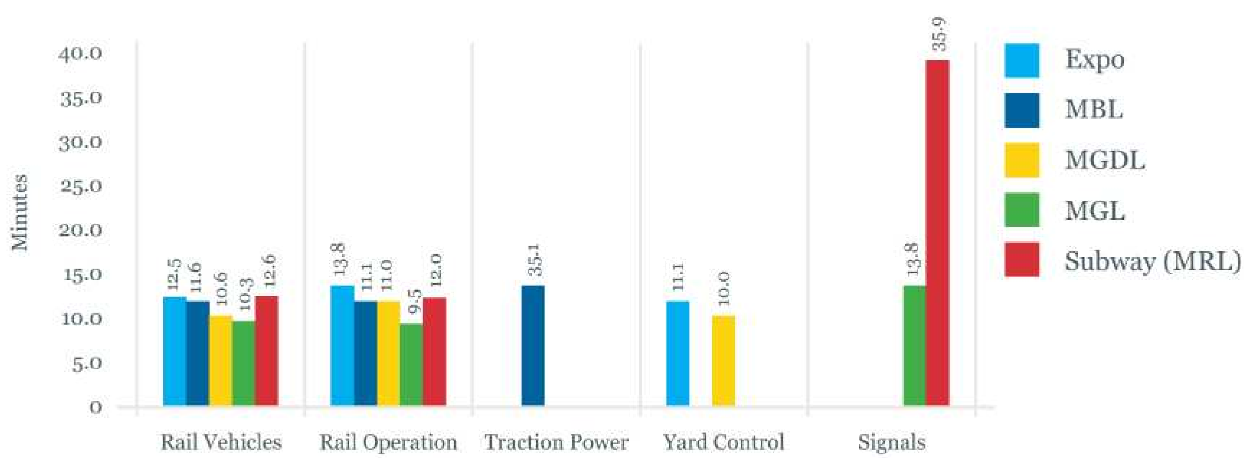
Max Delay by Incident Type	Expo	MBL	MGDL	MGL	Subtotal Light Rail	MRL
Rail Vehicles	2.953	5.295	3.424	2.806	**14.478**	1.682
Rail Operations	1.046	1.081	816	539	**3.482**	312
Traction Power		1.054			**1.054**	
Yard Control	278		215		**529**	
Signals				235	**235**	359
Grand Total	**4.277**	**7.430**	**4.491**	**3.580**	**19.778**	**2.353**

B8. As shown in Table 4 above, Traction power on the MBL caused nearly as much total maximum delay minutes as delays from rail operations incidents despite representing 67 fewer incidents.

B9. On MRL, signals caused more total delay minutes than rail operations incidents despite representing 16 fewer incidents, and the average maximum delay minutes were also highest for this category.

B10. The average maximum delay minutes were also highest for traction power and subway signal incidents. (see Figure 5.)

Figure 5: Average 'Maximum Delay' Minutes for Top Three Incidents Per Line



Recommendations Related to the Overall Review of the Top Three Causes of Delay by Line

While the overall review of incidents evaluated in this study is largely to set the stage for the analysis of each of these top causes of delay, the overall discussion also yields some recommendations.

6. Review the approach of mitigating delay time of Police/Health delay incidents (while not part of this analysis, these delay incidents warrant review based on their frequency and duration).

7. Partner with law enforcement agencies to review the process used for police/health incidents.

8. Identify root cause for the top three categories of delay for each line to allow Metro to develop mitigations that have the potential to significantly reduce total delay incidents.

9. Set priorities based on Metro's asset assessment as soon as it is completed to reduce delay incidents.

C. Rail Vehicle Delay Incidents: Top Cause of Delay on All Lines

Overall

Rail vehicle delay incidents caused by a fleet mechanical issue and evaluated by TWG as shown in the graph below are not the same as those tracked by maintenance. For example, the total vehicle incidents resulting in a delay, recorded for the MGDL, was 323 for 2016, based on the ROC incident logs provided to TWG. This figure included incidents of the P2550 and P3010 vehicles. However, the MGDL maintenance shop recorded 1,118 incidents for only the P2550 fleet in 2016. This would indicate that there are many more incidents for these vehicles than are recorded as resulting in a service delay. Through good maintenance, these incidents are caught before they become service delays. To be consistent with the data reviewed for all fleets, all incidents were based on the logs received from the ROC and the related work orders (WO) indicating how the original issue was addressed.

Based on the information from the ROC, a total of 1,422 rail vehicle incidents were recorded for 2016, 1,288 on the four light rail lines and 134 on the subway. (For subways, Metro Purple Line is incorporated into Metro Red Line for this report.) The MBL, which has the largest fleet, had the most rail vehicle incidents. (see figure 6.)

Figure 6: Rail Vehicle Incidents by Line

From the 1,422 incidents, 296 incident reports for light rail lines and 100 for the subway line were randomly sampled as a statistically significant representation of the data. Since all rail cars with a number higher than 1000 (new P3010 cars) are still under warranty, these vehicles were disregarded in the incidents report. Only causal cars of the P865/2020, P2000, and P2550 series were evaluated by TWG.

At Metro, the vehicle fleets are not restricted to one line. To be able to identify fleet issues leading to operating delays, the review in this section must be based on vehicle fleet and not the operating line. For example, the P2000 fleet operates on three lines, Green, Blue, and Expo lines. Some vehicles are even relocated between lines during the year. To evaluate the P2000 performance, the data from the ROC was filtered by the P2000 vehicle numbers and analyzed independently of where the incident happened.

The fact that a majority of the incidents were reported on the MBL should not be used to judge the quality of work performed at the MBL maintenance shop. In 2016, more vehicles operated on the MBL than any other line. The MBL also maintained the two oldest fleets: P865/2020 and P2000.

The total fleet size of LRVs excluding the new P3010 cars, which are still being delivered, is 171. Final delivery of the P3010 fleet is not before 2020.

Overall Findings for Light Rail Vehicles (which include P865/2020s, P2000s, and P2550s)

C1. Rail Vehicle Service Delay Incidents were a small subset of maintenance shop statistics on fleet incidents, indicating that the majority of issues do not result in delay.

C2. 27% of Rail Vehicle Incident reports often resulted in no problem being found during the maintenance crew's review of the work order. (see Figure 7 below.)

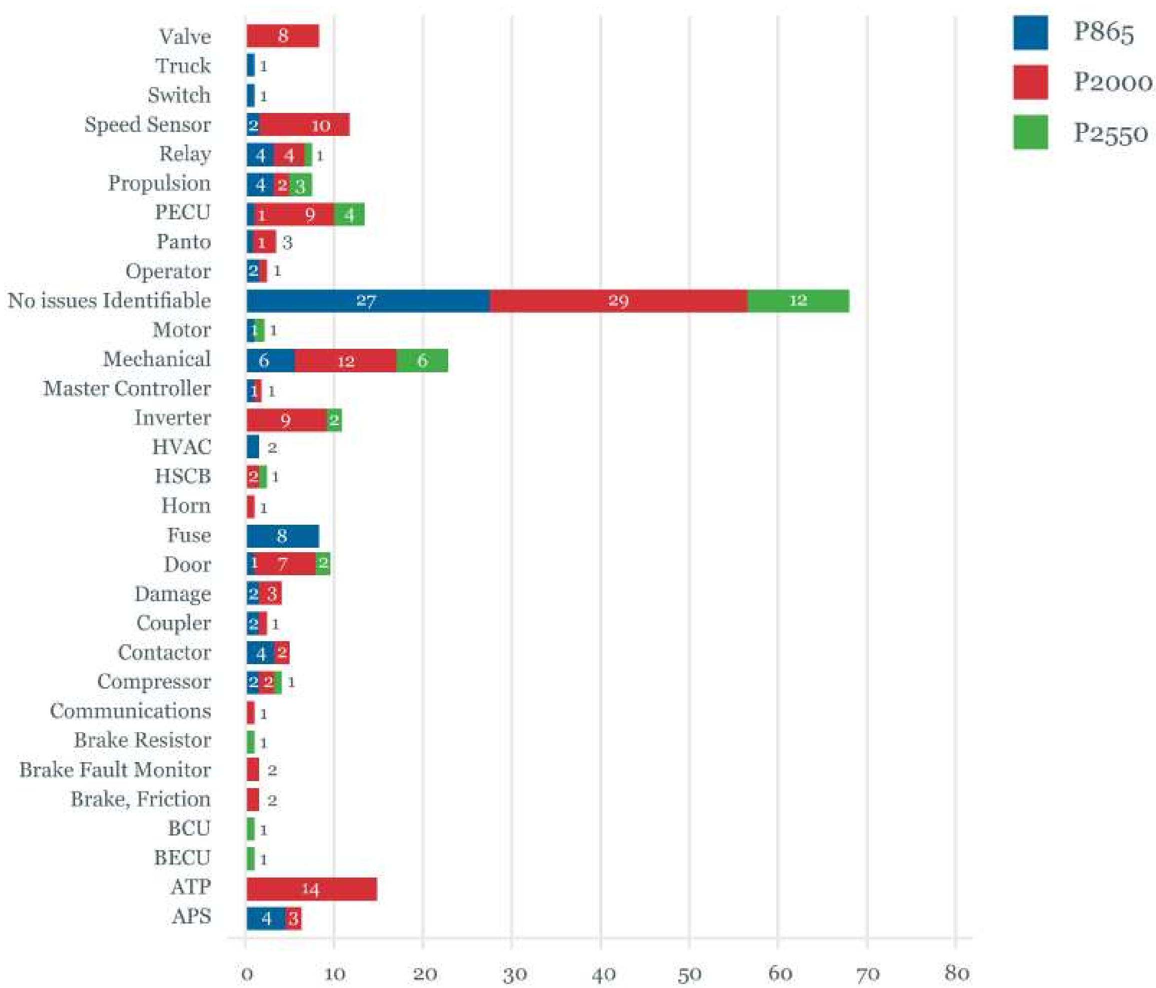
C3. Relative to their fleet size, most of the incidents causing service delays were caused by the P2000 vehicles.

C4. Midlife overhauls were not conducted on all fleets (under new leadership, this practice has changed; Metro now performs midlife overhauls, which are underway or planned for the other fleets).

C5. Incidents per car per fleet as reported by the ROC were:

- P2550 0.84
- P865/2020 1.08
- P2000 2.48

Figure 7: Causes of Rail Vehicle Incidents - Light Rail



Recommendations to Address Rail Vehicle Related Delays

10. Given the large number of incidents where no root cause was identifiable, establish a procedure to instruct vehicle maintenance personnel on providing consistent and complete detailed information related to vehicle failures in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of vehicle failure on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause.

11. Identify the funding and timeline for the new M3 system and move the project forward expeditiously. The new M3 module includes a more robust system for logging incident reports and will allow for more consistent and robust reporting of root causes of vehicle failures.

12. Establish a procedure for collecting the root cause of every vehicle failure even if it does not result in a service delay so that robust trends can be generated, tracked and mitigated.

13. Conduct periodic condition surveys on vehicles and components in advance of and complementary to the asset inventory that will be undertaken soon and refreshed every three years.

14. Establish a process and a criterion for replacement of existing vehicles and vehicle components that include useful life, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource to this end when it is finished, this system of prioritization should be formalized and implemented in current vehicle procedures.

P865/2020; MBL and Expo

- Vehicles: total 69 cars or 40% of all LRVs; Serial numbers 100 to 168.
- Currently, 49 cars operate on the MBL (72% of the service) and 20 cars on the Expo line. Since the Expo line has a varying amount of P3010 vehicles in operation, a percentage of P865 service on the Expo line cannot be given.
- Several of the P865 vehicles operated on both the MBL and Expo line.
- These vehicles are the oldest LRVs in service (P865 cars are 27-years old and P2020 cars are 23-years old).
- The propulsion system is a 40-year old, thyristor controlled DC chopper control technology that is over 50 years old and not used any more.

Finding for P865/2020

C6. The P865/2020 fleets never went through a midlife overhaul. With an adequate midlife overhaul, subsystems with a relatively high percentage of issues, such as control relays, contactors, and mechanical issues, could have been reduced. Improved reliability of these components also might have reduced some of the subsequent failures, such as the number of failed fuses (10.5%).

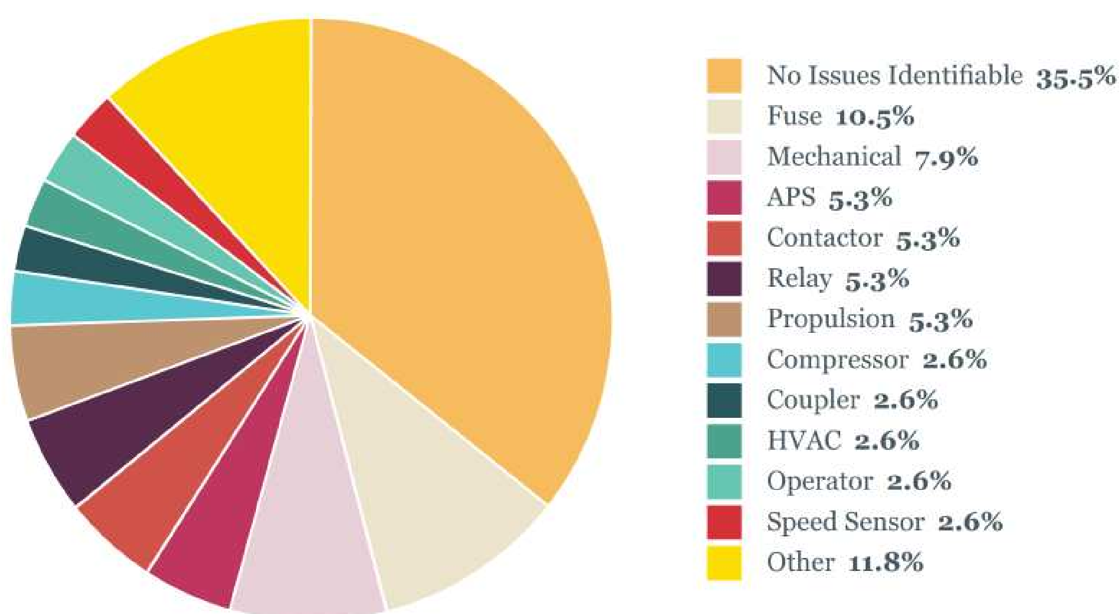
- The only subsystem replaced on some of the cars is the motor alternator (MA) set, which was responsible for 5.3% of the delay incidents in 2016. It is being replaced by a static Auxiliary Power Supply (APS).

- This fleet has been maintained since 1989 at the MBL shop, but recently Metro has been assigning some vehicles to the Expo shop, which may unnecessarily stretch resources. The knowledge for maintaining the 50-year old chopper design is concentrated in the MBL shop and all spare parts are at the MBL shop. It creates a logistics problem if a fleet needs to be maintained at different locations.

Findings on Subsystem Causes of P865/2020 Incidents

The causes of incidents leading to service disruptions have been categorized into the 13 areas shown in the following chart:

Figure 8: Causes of Rail Vehicle Incidents - Light Rail (P865 & P2020)



C7. 11.8% of the incidents categorized as "Other" were single incidents caused by the following subsystems:

- Automatic Train Protection (ATP)
- Brake Electric Control Unit (BECU)
- Friction brakes
- Propulsion Electric Control Unit (PECU)
- Doors
- Master controller
- Pantograph (Panto)
- Control switch
- Truck

C8. 10.5% of the incidents were caused by fuse failures. These fuses protect the high voltage chopper circuit. The fuse is never the root cause of this incident. Pantograph bouncing, PECU (control electronics) or contactor malfunctions are the most likely causes for fuse failures. The average maximum delay was 10.5 minutes.

C9. 7.9% of the incidents were caused by mechanical failures.

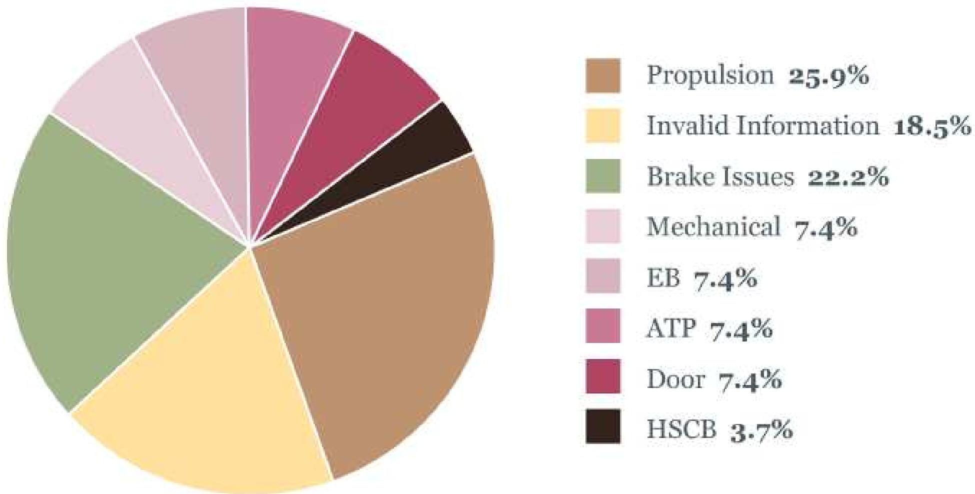
C10. 5.3% of the incidents were caused by Auxiliary Power Supply (APS) failures. APS incidents are caused by either a faulty MA set (which is being replaced) or the new static APS. No issues with the new APS were reported.

C11. No cause was identifiable for 35.5% of incidents. In such cases, the "Cause" cited was, for example, "no movement" and the WO showed "no issue found" or "pre-excitation unit changed," which could not be the cause for the vehicle not moving, since this device is used to initiate dynamic braking only. The cause, in this case, would have been no "dynamic brakes." Another example is the cause "door not closing" with the WO showing "no issue found." In this case, a passenger might have kept the door open.

- Figure 9 below classifies "No Issue Identifiable" incidents by the "Cause" of the delay as reported to the ROC.

- The average maximum delay of these "unidentifiable" incidents was 10.8 minutes.

Figure 9: No Issues Identifiable (P865 & P2020)



Findings on Specific P865/P2020 Vehicle Analysis

Over the whole 69 P865/P2020 fleet, the ROC reported 1.08 incidents per car during 2016.

C12. Cars with the most incident reports are from the first series of P865 cars (age 27 years).

- Car #130; four issues: The average maximum delay was 10.5 minutes.
  Incidents reported were failed ATP, PECU, Propulsion, and No Issues Identifiable.

- Car #142; four issues: The average maximum delay was 9.75 minutes.
  Incidents reported were failed BECU, Relay, and two instances of "No Issues" found.

C13. The cars with the most incidents from the second series of P2020 are:

- Car #163; three issues: The average maximum delay was seven minutes.
  Incidents reported were failed Contactor and Relay, Propulsion, and No Issues Identifiable.

- Car #165; two issues: The average maximum delay was 15 minutes. The cause of one incident was a failed MA set and the second incident was unidentifiable.

- The following list shows the 69 P865/P2020 car numbers and the corresponding number of incidents which led to a service delay:

Table 5: Number of Incidents Per P865/P2020 Car

Car #	Incidents	Car #	Incidents	Car #	Incidents
130	4	106	1	168	1
142	4	109	1	103	0
110	3	112	1	107	0
125	3	113	1	108	0
140	3	114	1	111	0
163	3	116	1	115	0
166	3	118	1	117	0
105	2	120	1	119	0
124	2	121	1	128	0
131	2	122	1	129	0
132	2	123	1	133	0
137	2	126	1	134	0
138	2	127	1	136	0
141	2	135	1	143	0
147	2	139	1	144	0
150	2	145	1	148	0
153	2	146	1	149	0
159	2	154	1	151	0
165	2	157	1	152	0
100	1	158	1	155	0
101	1	160	1	156	0
102	1	162	1	161	0
104	1	164	1	167	0

Findings on the Impact on Capital Programs/Investment

The analysis considered the impact of capital investment on each fleet.

C14. The P865/2020 fleets never went through a midlife overhaul. In 2005 when the P2550 vehicles were ordered, the P865 vehicles were already 15-years old. At that time, Metro determined that buying new vehicles would be more cost effective than investing in 15-year old ones. The intention was to order more P2550 vehicles and then replace the P865s, rather than overhauling them. Unfortunately, the P2550 order did not result in option cars. A new light rail specification was issued. This and, to some extent, the success of the light rail system in Los Angeles made it impossible to retire or sell the P865 as planned.

C15. These cars have been kept in service by "as needed" maintenance and investments for more than 10 additional years. Only the arrival of the new generation of LRVs (P3010) will allow Metro to retire the vehicles of the P865 fleet but still keep the slightly younger P2020 fleet, which are identical to the P865.

C16. Since 1989, these cars have been maintained out of the MBL shop, but recently some have been assigned to the Expo shop, requiring inefficient dispersion of knowledge and parts especially given the planned reduction in fleet size.

C17. When it became obvious that the P865 fleet was still needed, Metro started to invest in some component upgrades, such as replacing capacitors which were well past the expected service life of 15 years, replacing contactors, and upgrading the propulsion control power supply among other as needed components. Major subsystems, such as traction motors, gears, and brakes were maintained preventively as required by the manuals. On some cars, the MA set as the auxiliary power supply was replaced, or is being replaced, by a static Insulated Gate Bipolar Transistor (IGBT) APS.

Recommendations for Addressing All Findings on the P865/2020 Fleets

15. Continue funding for daily maintenance and up-keep of the P865/2020 fleets although no major capital investment is recommended at this time.

16. Identify the P865 cars in the worst condition for decommissioning and use them as spare part suppliers to support more reliable cars. This is only for the transitional period until the P3010 vehicles are delivered and the P2000s are overhauled. By doing this, spare parts will become available to keep the remainder of the fleet running for a while at reasonable costs. Since these vehicles are well known to Metro, problems could be resolved quickly by having these replacement parts available.

17. Keep enough P865 cars as floats to improve the availability of P2000 vehicles for refurbishment. The P2000 fleet has a higher incident rate than the P865 (2.5 incidents per car compared to 1 incident per car). Therefore, the priority should be to make enough P2000 cars available for refurbishment.

18. Review the decommissioning process of the P865 fleet given the lower incident rate for the P865 fleet. P865 cars with low or no incidents should be kept in service during the P2000 overhaul to expedite the overhaul, replacing some P2000 services with P865 cars to increase the vehicle availability during the overhaul.

19. Maintain the remaining P865 cars only out of the MBL maintenance shop, which has the best expertise, logistics and parts inventory to maintain the P865 fleet.

20. Continue with the P865 component upgrades to keep a reduced fleet with increased reliability in service until they are replaced by the P3010. Areas of upgrades still useful are contactors, relay panel and electronic control unit (ECU) power supply.

21. Evaluate overhaul needs of select main components. Depending on how long Metro intends to keep cars of the P865/2020 fleet, some of the main components, such as gears and traction motors, of selected well-performing cars might have to be overhauled.

22. Continue the refurbishment program begun by Metro to reduce fuse failures, such as upgrades to the chopper control unit, contactor and relay replacements, in place as needed for some of the P865 cars, which might remain in service for a few more years.

P2000; MBL, Expo & MGL

- P2000 vehicles total 52 cars or 31% of all LRVs, serial numbers 201 to 250 and 301 & 302.
- 29 cars (55%) run on the MGL; automatic train operation; cars 201 to 228 and 243.
- 19 cars (37%) run on the MBL.
- Four cars (8%) run on the Expo line.
- Several of the P2000 vehicles are known to have operated on both the MBL and the Expo lines.
- These vehicles are the second oldest LRVs in service with Metro. The average years in operation is 15 years.
- The propulsion system is an obsolete Gate Turn-Off Thyristor (GTO) inverter drive.

The vehicles are just starting to go through a midlife overhaul, replacing the propulsion system with modern IGBT 3 phase drives. Also, the Auxiliary Power Supply (APS), Low Voltage Power Supply (LVPS), and Automatic Train Control/Automatic Train Protection (ATC/ATP) will be replaced.

Subsystem Analysis

The difference between operation on the MGL and other lines is that on the MGL, the P2000 cars runs mostly in Automatic Train Operation (ATO). Therefore, the incident distribution between the two different services can be compared. The fleet is split into 55% of the cars for MGL and 45% on other, manually operated lines, or roughly half the fleet per lines.

Table 6: Incident Distribution

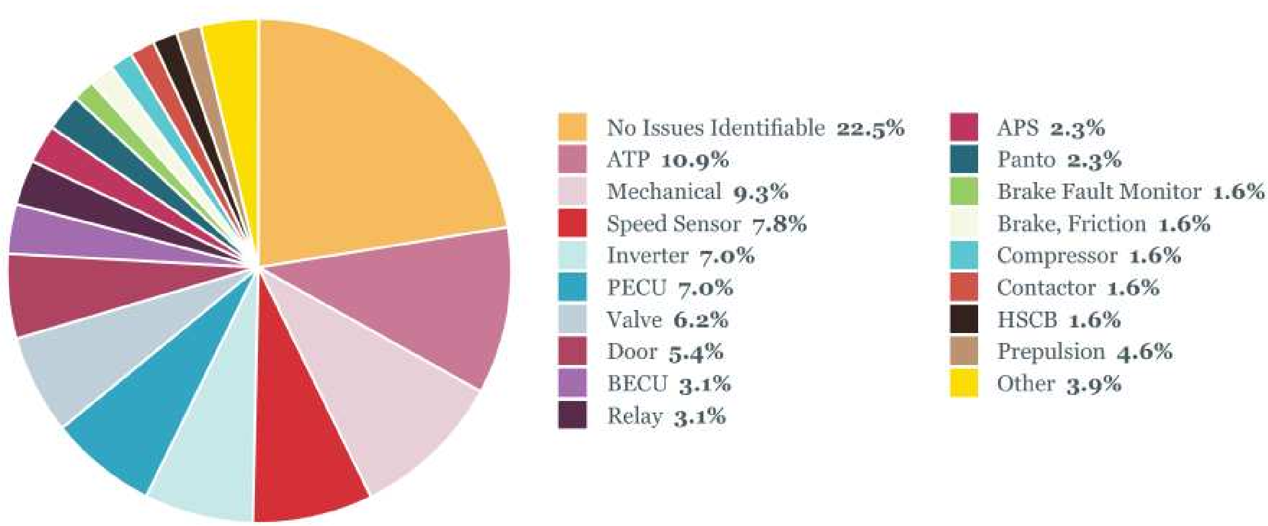
	MGL	MBL & Expo
Incidents leading to a delay	63	65
ATP/ATO Incidents	9 (64%)	5 (36%)
No Issue Identifiable	16 (53%)	14 (47%)

As shown in the above table, the statistics indicate that the P2000 car incidents do not vary much between the MGL operated in ATO and the lines operated manually. The major incident reported, "no issues identifiable," are about the same for both services. Therefore, it can be concluded that the ATO operation, which reduces the effect of human interference in the vehicle control to some extent, does not result in an improved service reliability.

Findings on Subsystem Causes of P2000; MBL, Expo & MGL Incidents

The causes of incidents leading to service disruptions have been categorized into 19 areas shown in the following chart:

Figure 10: Causes of Rail Vehicle Incidents - Light Rail (P2000)



C18. 14% of the incidents were propulsion related (Inverter 7% and PECU 7%) and resulted in an average maximum delay of 10.1 minutes per car.

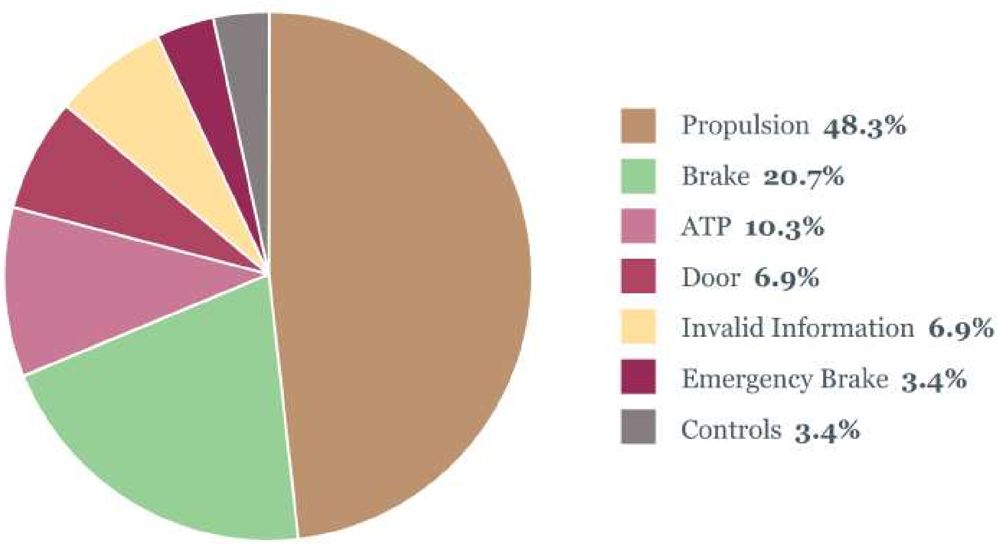
C19. 10.9% of the incidents were ATP/ATO related issues and generated an average maximum delay was 10.2 minutes per car.

C20. 9.3% of the incidents were mechanical issues, mostly related to the doors being misaligned, getting off rollers, or simply jammed, broken mirror, or a propulsion fault due to the air channels being clogged up.

C21. The cause for 22.5% of the incidents could not be identified from the incident reports and the work orders because there was inconclusive or contradictory information. This is 13% less than for the P865/2020 fleet. This could indicate that the P2000 fleet issues are easier to identify and investigate than for the P865/2020 fleet.

- The chart below categorizes "No Issue Identifiable" incidents by the cause of the delay reported to the ROC:

Figure 11: No Issues Identifiable (P2000)



- The chart above shows that 48.3% of no issue identifiable incidents were reported as propulsion issues. This indicates that the propulsion system diagnostics are more complicated than on the P865 and P2550 cars.

- The average maximum delay of these incidents was: 9.6 minutes per car.

Findings on Specific Vehicle Analysis

Over the entire 52 P2000 fleet, the ROC reported 2.48 incidents per car for the review period. This was more than twice as many as for the P865/2020 fleet.

C22. Car #222 (MGL) had the most incidents reported. This car had seven reports that included problems relating to APS, ATP, Compressor, PECU, Relay, and two instances of No Issues Identifiable. This should be the first car to run through the refurbishing process. On average, each incident caused an 8.6 minute delay.

C23. Six cars had five incidents each (MGL cars #205, 208. 212, 229 and on the MBL/Expo cars #242 and 247). On average, each incident on these cars caused a 10 minute delay.

C24. Six other cars had four incidents each (two for MGL and three for MBL/Expo).

C25. Eleven cars had three incidents each. The MBL/Expo lines had more of these cars than the MGL.

C26. The following table shows the 52 P2000 car numbers and the corresponding number of incidents which led to a service delay:

Table 7: Number of Incidents Per P2000 Car

Car #	Incidents	Car #	Incidents	Car #	Incidents
222	7	239	3	217	1
205	5	240	3	221	1
208	5	244	3	223	1
212	5	249	3	225	1
229	5	209	2	228	1
242	5	211	2	246	1
247	5	213	2	250	1
207	4	215	2	206	0
214	4	218	2	220	0
237	4	219	2	224	0
238	4	227	2	232	0
248	4	234	2	241	0
301	4	235	2		
203	3	243	2		
210	3	245	2		

Car #	Incidents	Car #	Incidents	Car #	Incidents
226	3	302	2		
230	3	201	1		
231	3	202	1		
233	3	204	1		
236	3	216	1		

Finding on the Impact on Capital Programs/Investment

The analysis considered the impact of capital investment on the P2000 fleet.

C27. The P2000 fleet is scheduled for a major overhaul. Considering the high incident rate per car and the relatively young age of these vehicle, this is the correct approach.

Recommendations to Address Findings on the P2000 Fleet

23. Plan the midlife overhaul to first upgrade the worst vehicles, such as cars #220, 205, 208, 212, 229, 242 and 247.

24. Analyze the float vehicle needs for the P2000 vehicle midlife overhaul and ensure that the overhaul contractor has enough cars to expedite the overhaul. On the MBL, P865 vehicles can replace P2000 vehicles, therefore if there is a shortage of vehicles for service, the number of P865 vehicles being decommissioned could be reduced temporarily, since statistics show in general that P865 vehicles are more reliable than P2000 vehicles. This will expedite the overhaul process by being able to provide enough vehicles to the overhaul contractor.

25. Consider converting some P2000 cars running on the MBL/Expo lines back to the MGL operation. The critical float will be the P2000 MGL cars with their line specific ATO/ATP equipment. These cars cannot be substituted with P865 cars. Converting some P2000 vehicles currently running on the MBL/Expo lines back to the MGL operation if the ATO/ATP packages removed earlier are still available would reduce the risk of service disruptions on the MGL during the overhaul.

26. Improve the diagnostic capabilities of the propulsion system.

P2550 MGDL

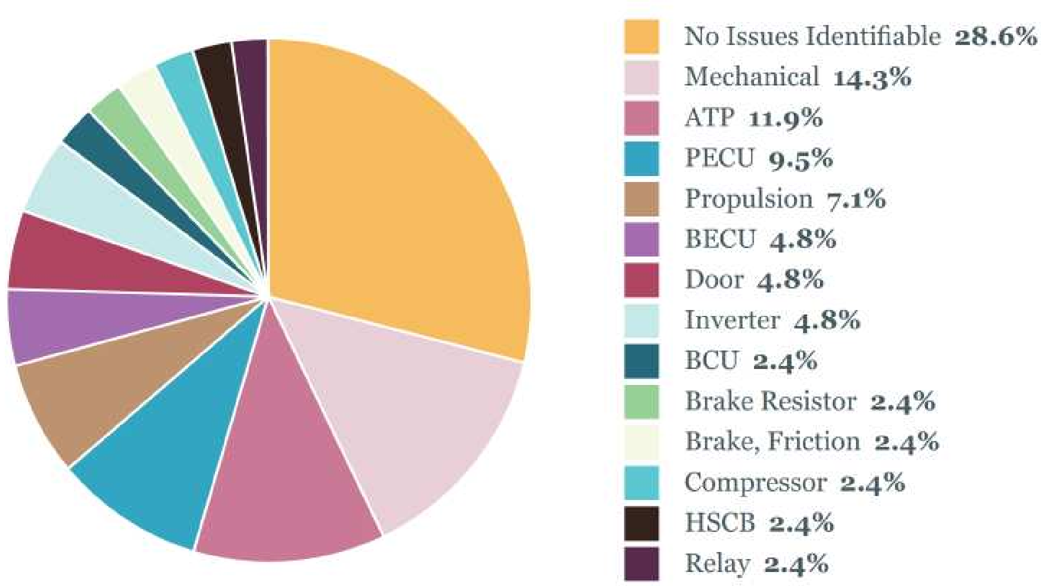
- P2550 vehicles total 50 cars or 29% of all 171 LRVs, serial numbers 701 to 750.
- All cars operate on the MGDL.
- These vehicles have been in service for about 10 years.
- The propulsion system is a modular 3 phase IGBT design.
- The condition of the vehicles is currently being assessed in anticipation of a midlife overhaul within the next five years.

Only recently did Metro management change their approach towards midlife overhauls of their fleets. Previously it was thought that ordering new cars instead of overhauling or upgrading existing ones was more economical. This change in approach came too late for the P865 fleet and just in time for the P2000 fleet. For the P2550 fleet, the midlife overhaul is now being planned proactively. Metro already has started a program to assess the condition of the P2550 vehicles after only 10 years in service and has established a comprehensive overhaul program.

Findings on Subsystem Causes of P2550 MGDL Delay Incidents

The causes of incidents leading to service disruptions of the P2550 vehicles have been categorized into fourteen areas shown in the following chart:

Figure 12: Causes of Rail Vehicle Incidents - Light Rail (P2550)



C28. 16.6% of the incidents were propulsion related (categorized as 7.1% propulsion and 9.5% PECU), caused by either inverter, sensors or electronic (PECU) failures. The average maximum delay for propulsion related incidents was 8 minutes.

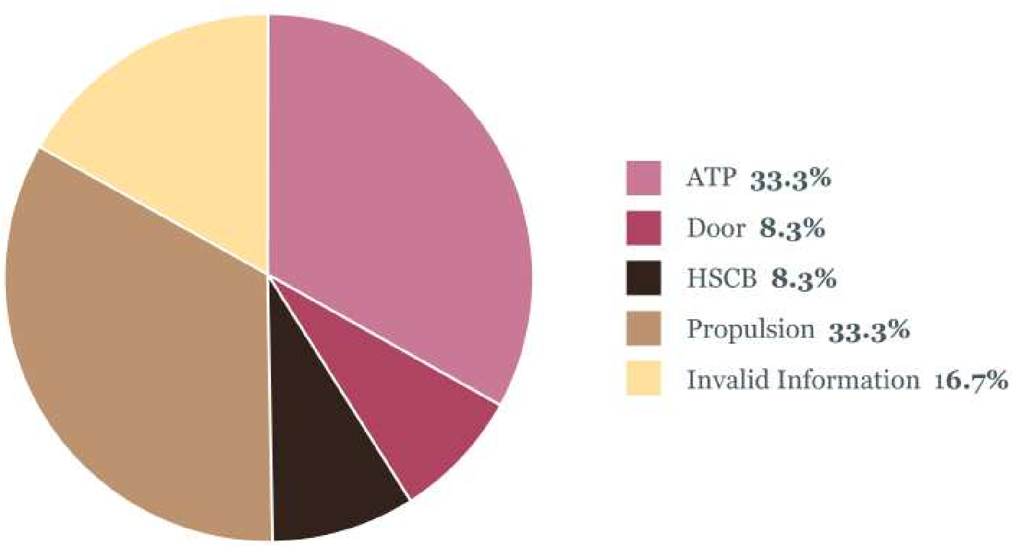
C29. 14.3% of the incidents were mechanical in nature, such as misaligned speed sensors, clogged air ducts, misaligned doors, and misaligned hinges. The average maximum delay of these incidents was 9.3 minutes per incident.

C30. 11.9% were categorized as ATP issues, suggesting that the Ansaldo Signaling and Transportation Systems (ASTS) and Hanning & Kahl (H&K) interface, which caused significant problems during the commissioning, might still have some issues. The average maximum delay caused by ATP issues was 12.4 minutes per incident.

C31. The cause for 28.6% of the incidents could not be identified from the incident reports and work orders because of inconclusive or contradictory information. This is comparable to the P2000 fleet.

- The chart below categorizes "No Issue Identifiable" incidents by the cause of the delay reported to the ROC:

Figure 13: No Issues Identifiable (P2550)



- The average maximum delay of these "unidentifiable" incidents was 11.4 minutes.

Findings of Specific Vehicle Analysis

For the 50 car P2550 fleet, the ROC reported 0.84 incidents per car during 2016. This makes the P2550 the most reliable LRV. This is within expectations on cars with only 10 years or less of service.

C32. Car 739 is the only car which shows an excessive number of incidents that caused a delay. This car had seven incidents that resulted in an average maximum delay of 8.6 minutes per incident. The causal subsystems were mostly related to brakes and ATP.

C33. The following table shows the 50 P2550 car numbers and the corresponding number of incidents leading to a service delay:

Table 8: Number of Incidents Per 2550 Car

Car #	Incidents	Car #	Incidents	Car #	Incidents
739	7	726	1	720	0
705	2	728	1	721	0
710	2	730	1	722	0
714	2	731	1	723	0
717	2	733	1	724	0
734	2	736	1	725	0
743	2	738	1	727	0
745	2	740	1	729	0
701	1	741	1	732	0
702	1	744	1	735	0
704	1	749	1	737	0
706	1	703	0	742	0
708	1	707	0	746	0
713	1	709	0	747	0
715	1	711	0	748	0
718	1	712	0	750	0
719	1	716	0		

Findings on the Impact on Capital Programs/Investment

The analysis considered the impact of capital investment on each fleet.

C34. The P2550 fleet is the youngest of all Metro fleets other than the P3010 vehicles, which are still being delivered. P2550 vehicles had the lowest incidence of service delays per car (0.84 during 2016). The P2550 cars have a train operator display (TOD) and an elaborate diagnostic system, which reduces incident-causing delays. This demonstrates the value of investing in diagnostics to improve vehicle availability.

C35. Metro keeps a list of all incidents experienced by these vehicles, even if they do not cause a service delay. The component health statistics and the vehicle inspections, currently performed by Metro, facilitate maintaining a reliable overhaul process.

C36. It seems that Metro is providing the needed funds to finance a useful midlife overhaul for the P2550 fleet.

Recommendations for All Findings on the P2550 Fleet

27. Use information from the TODs on the P2550 vehicles for improved incident reporting. The P2550 cars are the first Metro vehicles that have a sophisticated TOD and diagnostics.

28. Modify the incident reports for P2550 vehicles to include the information provided by the TOD at the time of the incident, in addition to the Operator reports.

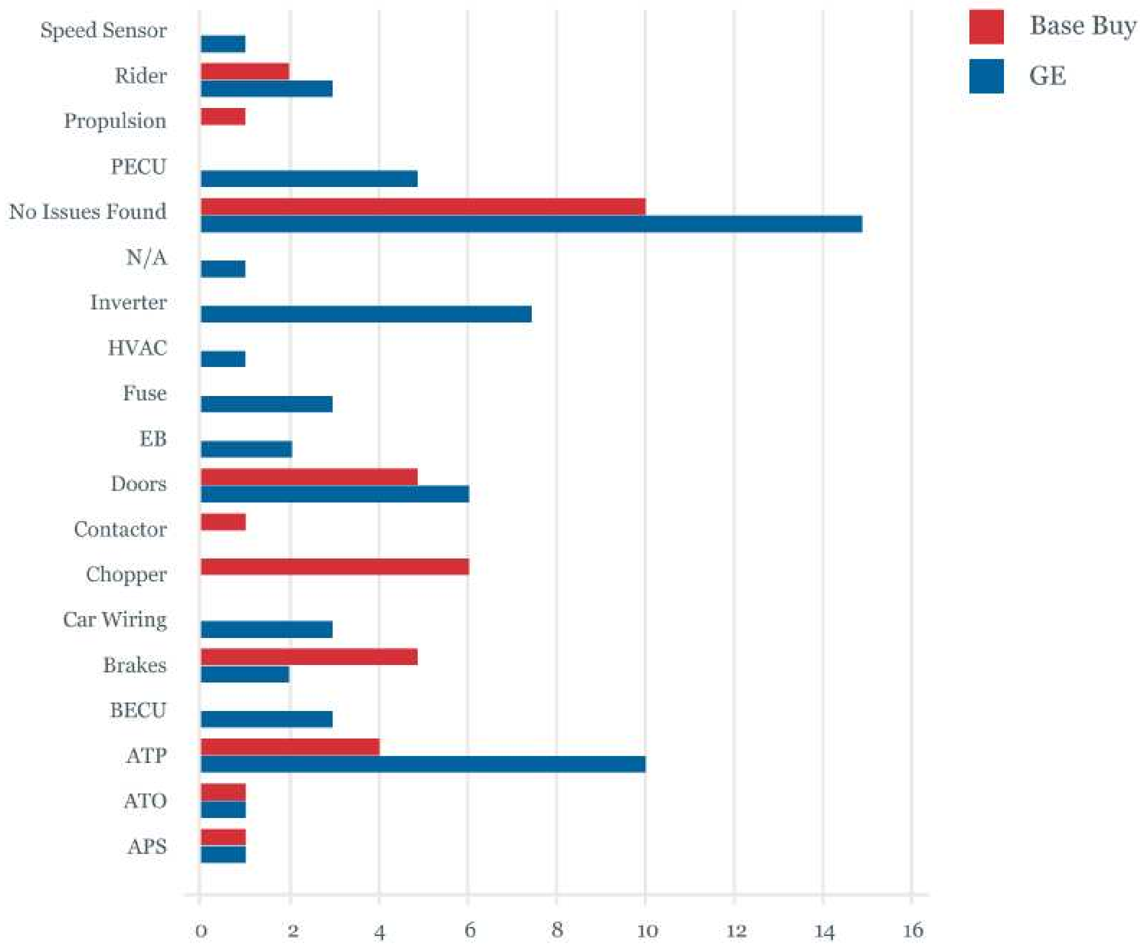
29. Accurately report the time of the incidents as shown on the TOD, not by the system time at the ROC.

30. Use the time of the incident displayed on the TOD in evaluating the delay incident to improve accuracy and turnaround time of the affected vehicle.

Review of Subway Events

The subway fleet consists of 30 Base Buy cars and 74 newer A650 General Electric (GE) cars. Review of sample incident reports for 2016 revealed that the Base Buy cars had a higher incident rate per vehicle than the GE cars. GE cars had more total incidents since they consist of 71% of the total subway fleet. Most of the vehicle components for the GE and Base Buy fleets are identical, other than the propulsion system and vehicle controls. Figure 14 below shows the number of rail vehicle incidents by causes.

Figure 14: Causes of Rail Vehicle Incidents - Subway



Incidents per car per fleet as reported by the ROC:

1. Base Buy 1.2
2. GE 0.82

Based on these figures, the A605 GE fleet of subway cars is the most reliable vehicle fleet Metro operates.

Base Buy Cars

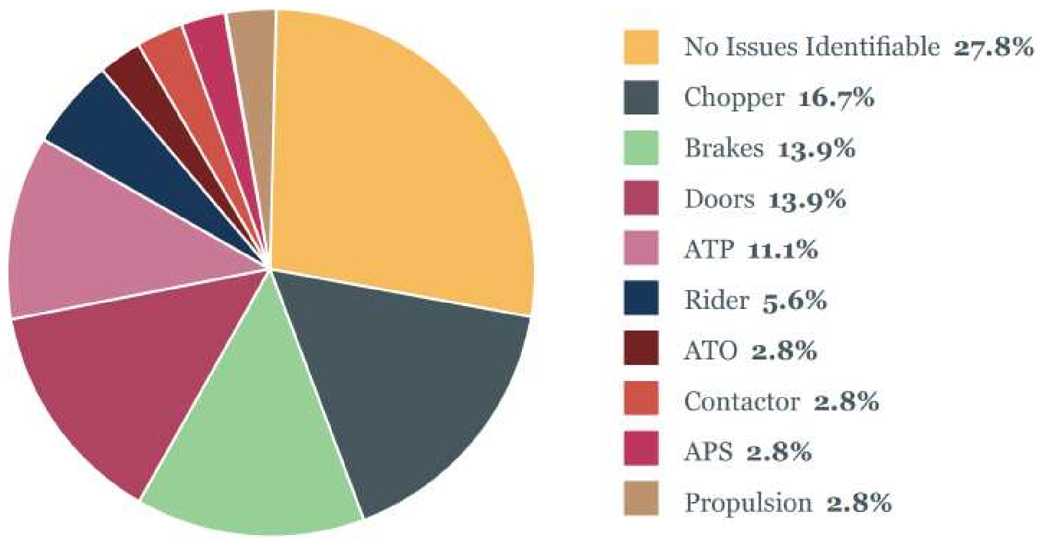
- Base Buy vehicles total 30 cars or 29% of all subway cars, serial numbers: 501 to 530.
- Base Buy and GE cars operate in mixed fleets and on all subway lines (Red and Purple)
- The Base Buy cars are the oldest Metro subway cars, in service for 24 years.
- As with the P865 fleet, these cars never went through a midlife overhaul.
- Some propulsion spare parts from similar cars, decommissioned by the Metropolitan Atlanta Rapid Transit Authority (MARTA), were acquired to improve maintainability.

- The propulsion system technology is more than 40-years old. It is a forced commutated thyristor controlled DC chopper design based on analog controls; no microprocessor is used.

Findings on Subsystem Causes of Base Buy Subway Car Delay Incidents

The causes of incidents leading to service disruptions have been categorized into ten areas shown on the following chart:

Figure 15: Causes of Rail Vehicle Incidents - Subway (Base Buy)



C37. 19.5% of the incidents were caused by the Chopper and other propulsion related issues. The average maximum delay was 19.4 minutes per incident.

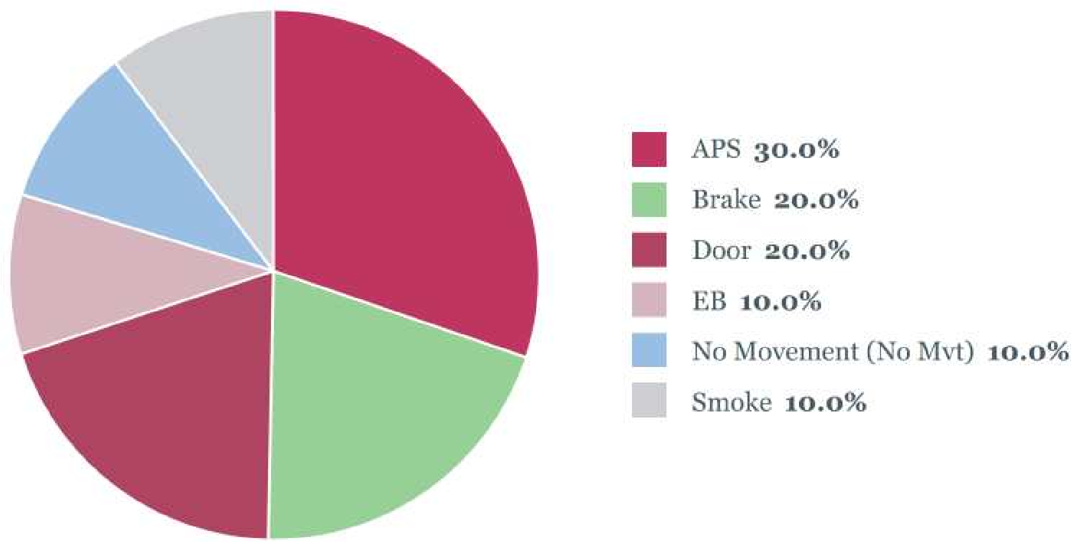
C38. 13.9% of the incidents were caused by the brake system. The average maximum delay was 8.4 minutes per incident. The much lower percentage of brake incidents on the GE vehicle suggests that the issues might be an interface issue with propulsion/vehicle controls since the GE vehicles use the same brake components.

C39. 13.9% of the incidents were caused by the door system. This is similar to the GE vehicles, which have the same doors. The average maximum delay was 8.2 minutes per incident.

C40. The cause for 27.8% of the incidents could not be identified from the incident reports and work orders because of contradictory information or because no issues were found.

- The chart below categorizes "No Issue Identifiable" incidents by the cause of the delay reported to the ROC:

Figure 16: No Issues Identifiable (Base Buy)



- The average maximum delay of these incidents was 10.8 minutes. APS, brakes, and doors caused 70% of the incidents where no issues were identifiable as shown in the above chart.

Findings of Specific Vehicle Analysis

For the entire Base Buy fleet, the ROC reported 1.2 incidents per car during 2016.

C41. Car #512 had the worst reliability record.

C42. This car had seven reported incidents. The average maximum delay was 17.4 minutes per incident. Incidents reported were mostly for brake issues, two ATO/ATP, and one door issue.

C43. Cars #505, 521, 523 and 527 had 3 issues each. The average maximum delay was seven minutes per incident. Incidents reported were mostly door issues and three propulsion issues.

C44. The following table shows the 30 Base Buy car numbers and the corresponding number of incidents which led to a service delay:

Table 9: Number of Incidents Per Base Buy Car

Car #	Incidents	Car #	Incidents	Car #	Incidents
512	7	525	2	508	0
505	3	509	1	513	0
521	3	510	1	515	0
523	3	514	1	518	0
527	3	516	1	519	0
503	2	526	1	520	0
506	2	501	1	522	0
511	2	502	1	528	0
517	2	504	1	529	0
524	2	507	1	530	0

Findings on the Impact on Capital Programs/Investment

The analysis considered the impact of capital investment on the Base Buy subway fleet.

C45. Similar to the P865 cars, the Base Buy cars have an obsolete propulsion and control system. The Base Buy cars never went through a refurbishment process, although capital funding was available a few years ago. Consequently, the Base Buy cars have an obsolescence problem, but not as severe as the P865 cars.

- Most of the control and chopper components are very old but still available, because no microprocessors are used.
- Also, the analog control boards are of a classic design, which can be maintained with regular tools and control knowledge.

C46. Base Buy cars are maintainable for a few more years, although this might not be cost effective. Metro intends to keep these vehicles in service until the new HR400 subway cars are delivered. With the correct funding in place, this approach is feasible.

Recommendations for Base Buy Cars

31. Keep the Base Buy subway cars running by continuing to ensure enough funding for Rail Fleet Services to maintain this fleet.

32. Ensure that the knowledge of the chopper controls, a technology that is 50 years old and no longer used, is not lost before the new cars arrive.

33. As the new HR4000 vehicles arrive, take the Base Buy cars out of service as early as possible to reduce maintenance costs. The cars in the worst condition should be replaced first.

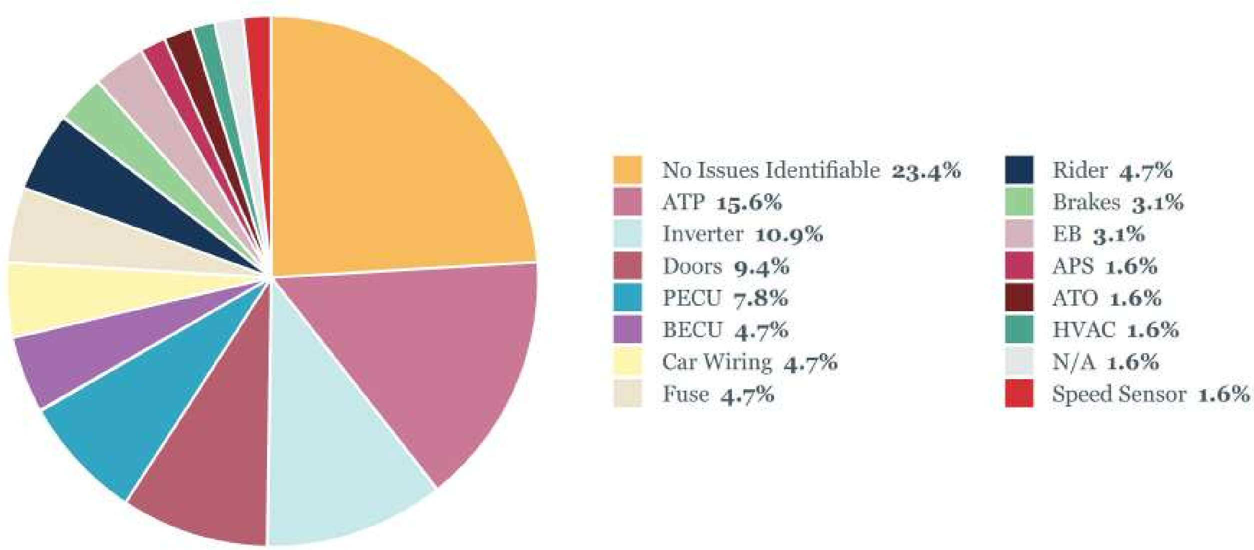
A650 GE Fleet

- GE vehicles total 74 cars or 71% of all subway cars, serial numbers 531 to 604.
- The GE fleet is about 18 years old.
- Base Buy cars and GE cars operate in mixed fleets and on all subway lines.
- The GE cars are mostly the same subway cars as the Base Buy cars, but have newer propulsion equipment, based on a GTO 3 Phase (ph) drive system.
- The GE fleet just started a midlife overhaul program.

Findings Based on GE Fleet Subsystem Analysis

The causes of incidents leading to service disruptions have been categorized into 16 areas shown in Figure 17 below.

Figure 17: Causes of Rail Vehicle Incidents - Subway (GE)



C47. 18.7% of the incidents were caused by the propulsion system, mainly the inverter modules and the controls PECU. The average maximum delay was 9.25 minutes per incident.

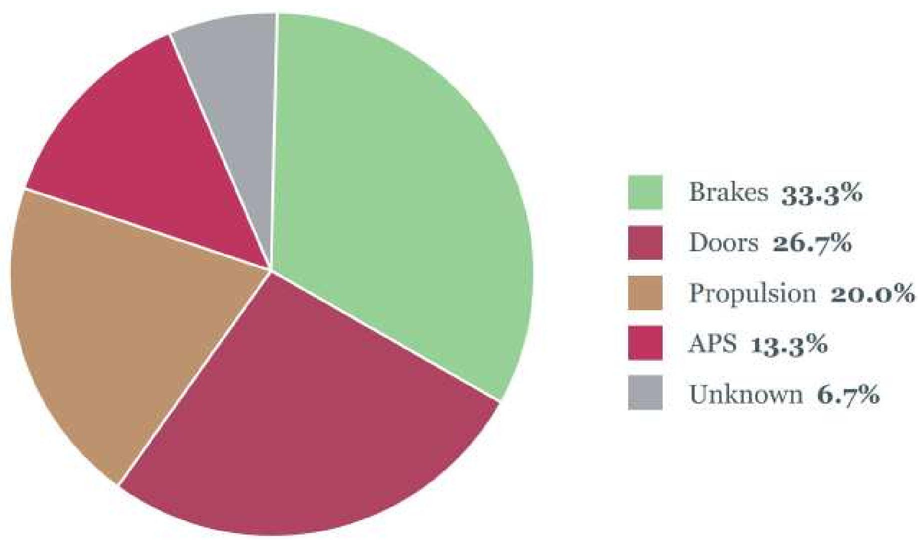
C48. 15.6% of incidents were due to equipment failures of the ATO/ATP system. The average maximum delay was 9.6 minutes per incident.

C49. 9.4% of the incidents were caused by the doors, which are the same as for the Base Buy cars. The average maximum delay was 12 minutes per incident.

C50. The cause for 23.4% of the incidents on the GE series could not be identified from the incident reports and work orders because of contradictory information or because no issues were found.

- The chart below categorizes "No Issue Identifiable" incidents by the cause of the delay reported to the ROC:

Figure 18: No Issues Identifiable - Subway (GE)



- The average maximum delay for incidents with no issue identifiable was 12.5 minutes per incident. Brakes, doors, and propulsion were reported in 80% of the incidents as the "cause" where no issues were identifiable.

Findings on Specific Vehicle Analysis

For the GE fleet, the ROC reported 0.82 incidents per car for 2016.

C51. Car #595 had significantly more incidents reported than any other cars. This car had 6 reported incidents that included problems relating to ATP, BECU, PECU, and three instances where no issues could be identified. Through closer review of work orders, the cases where "no issues found" were actually due to brakes and propulsion issues (two instances).

C52. The following table shows the GE car numbers and the corresponding number of incidents which led to a service delay:

Table 10: Number of Incidents Per GE Car

Car #	Incidents	Car #	Incidents	Car #	Incidents
595	6	563	1	559	0
539	3	566	1	560	0
540	3	567	1	561	0
557	3	575	1	562	0
565	3	577	1	564	0
576	3	580	1	568	0
537	2	582	1	569	0
542	2	587	1	570	0
543	2	592	1	572	0
550	2	593	1	573	0
555	2	594	1	574	0
571	2	596	1	578	0
585	2	598	1	579	0
588	2	599	1	581	0
531	1	604	1	583	0
533	1	532	0	584	0
536	1	534	0	586	0
538	1	535	0	589	0
545	1	541	0	590	0
546	1	544	0	591	0
551	1	547	0	597	0
553	1	548	0	600	0
556	1	549	0	601	0
		552	0	602	0
		554	0	603	0
		558	0		

Findings on Impact on Capital Programs/Investment

The analysis considered the impact of capital investment on the GE subway fleet.

C53. Metro just began the midlife overhaul for the A650 GE fleet. The obsolete GTO inverter is being replaced with a state of the art IGBT inverter. Other equipment is also being replaced, such as the APS and the Heating, Ventilation and Air Conditioning (HVAC) units. In addition, other major components, such as the doors, are being refurbished.

C54. The GE and the P2000 fleets are the first fleets to undergo a major midlife overhaul.

C55. The GE fleet will remain in service even after the new HR4000 vehicles are delivered.

Recommendation for GE Cars

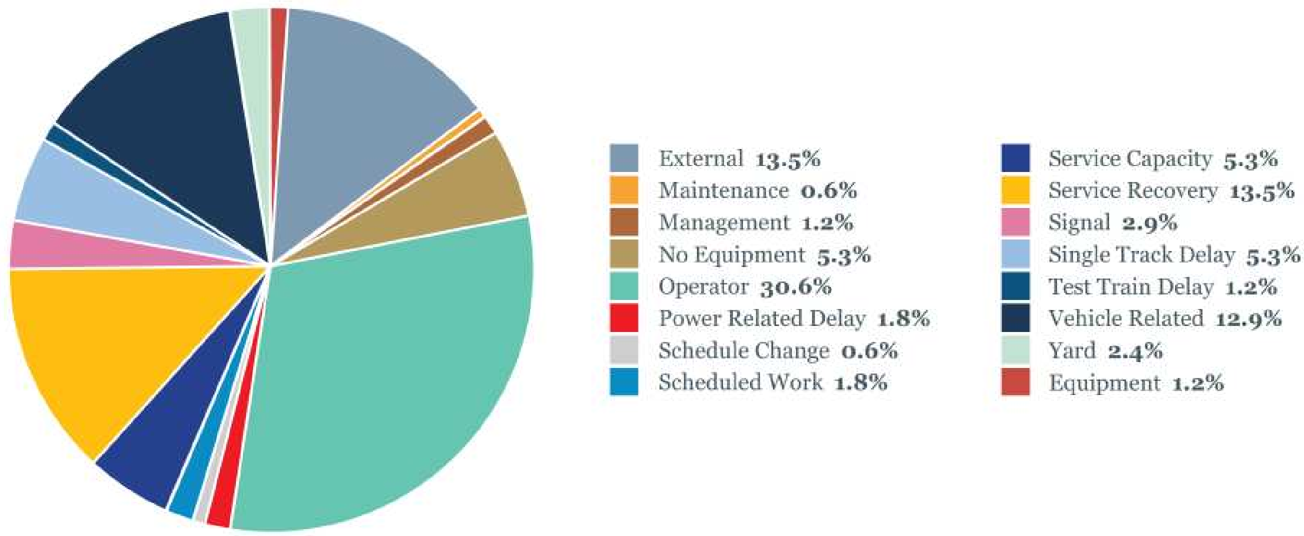
34. Perform the midlife overhaul on GE subway vehicles as planned.

D. Rail Operations Service Delay Incidents: Second Most Frequent Cause of Delay on All Lines

The 2016 the data provided to TWG reported 2,144 delay incidents (excluding police/health delay incidents) on all five lines of the LA Metro Rail. (Metro Purple Line is incorporated into Metro Red Line for this report.) These incident reports indicated that Rail Operations accounted for 330 incident delays (304 Light Rail; 26 Subway), which was the second leading incident type on all five lines. A review of the causes of the Rail Operation delay incidents follows with a focus on ways to mitigate those causes to reduce these delay impacts.

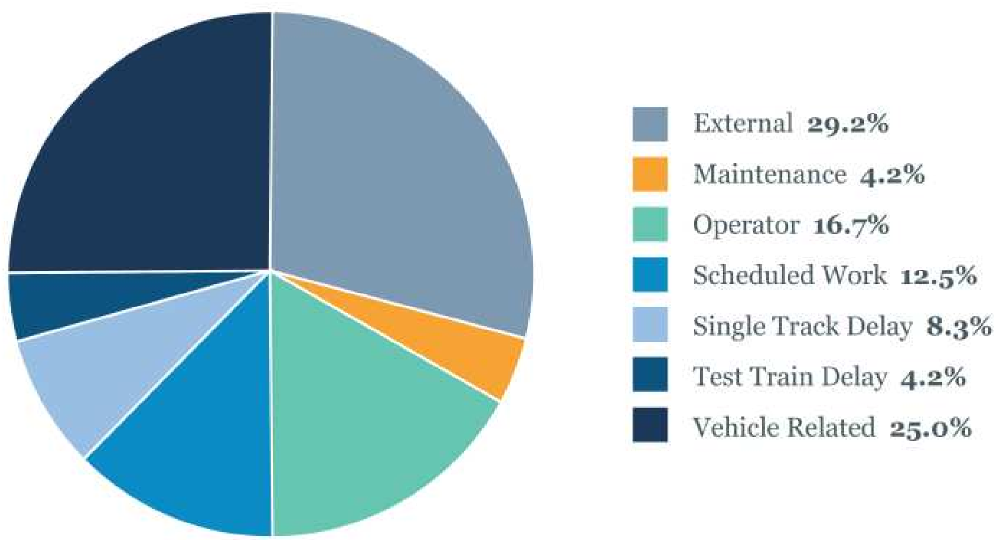
A sampling of 170 of the Light Rail Operations incidents were examined to further assess the types and related causes of incidents. These incidents were categorized into 16 primary causes of Light Rail Operations delay incidents. (see Figure 19.)

Figure 19: Causes of Rail Operations Incidents (Light Rail)



Similarly, the 26 delay incidents attributable to rail operations on the MRL were categorized into seven primary causes. (see Figure 20 below.)

Figure 20: Causes of Rail Operations Incidents (Subway)



Our analysis found that the 330 rail delay incidents resulted in a total of 3,794 maximum delay minutes or an average of 11.5 minutes per incident. The average maximum delay minutes per line ranged from 9.5 to 13.8 minutes as shown in the table below:

Table 11: Total 'Maximum Delay' Minutes and Average Delay Minutes for Rail Operations Delays

Line	No. of Incidents	Total Max Delay Min	Average Max Delay Min
Expo	76	1046	13.8
MBL	97	1081	11.1
MGDL	74	816	11.0
MGL	57	539	9.5
MRL	26	312	12.0
Grand Total	**330**	**3794**	**11.5**

Findings Related to Rail Operations Service Delay Incidents

D1. Service incident delays attributed to Rail Operations represents approximately 15% of the total 2,144 Metro Rail service delays.

D2. Operator caused incidents were the largest light rail category, accounting for 30.6% of the 170 incidents reviewed; this category included operators not being available because of absence, late arrival, restroom breaks, and operator error.

D3. On the MRL, operator caused incidents accounted for 16.7% of the 26 Operator related incidents. (see Figure 20 above.)

D4. Extrapolating to the total 330 Rail Operations related incidents for all lines, TWG estimates that 97 of the total incidents were attributed to Operators. However, this represents only 4.5% of the 2,144 total delay incidents reported in 2016.

D5. The causes of the remaining service delay incidents designated as Rail Operations cannot be controlled within that Division; these included externally caused delays, service recovery delays, vehicle caused delays, and other causes of delay.

Findings for Operator Caused Delays

D6. Of the Operator caused incidents, most (42.2%) were attributed to no operator available at the time of scheduled departure. Maintaining consistent operator availability to meet scheduled pullouts is a challenge throughout the industry. The incident reports indicated that some operators were either late or not available for their scheduled pullout resulting in the trip being either dropped or delayed with a replacement operator. This constrains Metro's ability to effectively maintain schedule requirements and service recovery efficiencies. Metro staff indicated that Extraboard staff are used to mitigate such impacts.

- Operator Extraboard staff was approximately 20% to 30% of the total scheduled operators. The Extraboard Operators are assigned by line but can operate on other rail lines as currently trained and qualified to do so. Although Metro does adequately budget for Extraboard Operators to address operator scheduled and unscheduled absences, the high frequency of Metro delays can exhaust available operator resources to support service recovery capabilities. Rail Operations' Operator Extraboard staffing levels may not be sufficient as a mitigation resource to address the scope and impact of Metro service incident delays.

D7. Slightly more than a quarter of the operator caused delays (26.9%) were related to restroom breaks (as identified by the code 10-100) at the end station terminal. In these cases, the lack of train layover time resulted in the train leaving later than the scheduled departure. Metro staff indicated that extra operators are built into the schedule and assigned to end station terminals to assist in operating the train to the vehicle turnback tracks and back into the station to facilitate the turnback operations. The reasons for the late train departures from the station terminals may involve no layover time due to in-service delays from a previous incident, schedule constraints, or no operator available to assist in moving the train to the opposite platform for the code 10-100 operator.

D8. Operator error was a factor in nearly one quarter of the operator related delays. These incidents involved operators who may not have applied vehicle troubleshooting measures effectively, were inadvertently locked out of the vehicle compartment, selected the wrong route, or didn't follow procedures resulting in a service delay. Operators involved in such incidents are provided reinstruction.

Recommendations to Mitigate Operator Caused Delays

35. Assess current mitigation measures to address operator absenteeism and late reports, and initiate management enhancements as appropriate.

36. Re-assess the level, allocation, and scheduling of Rail Operations Extraboard Operators as an opportunity to mitigate the impact of all service incident related delays resulting from service

recovery, operator late or no show, station terminal and yard operator related delays, "gap trains" staffing (extra trains added to the schedule to supplement service capacity as needed), etc.

37. Reinforce desired practices to mitigate future "Operator Error" service impact events including additional focus on operator vehicle troubleshooting tactics. Given that vehicle defects represent the most significant factor impacting Metro Rail service delays, assess operator awareness of common vehicle troubleshooting methods to expedite the safe movement of the vehicle and reduce service delays resulting from vehicle defects.

38. Consider the development of an Operations pocket size vehicle defect troubleshooting guide that reinforces what operators are trained to perform and summarizes the desired tactics to follow when confronted with vehicle related defects. Common vehicle troubleshooting methods and other lessons learned from operator errors that resulted in service delays should continue to be reinforced in current operator training programs.

39. Continue to hone service recovery contingency plans, which are key to minimizing the impact of all Rail Operations incidents.

Findings for Externally Caused Rail Operations Delay Incidents

D9. This category of delay, which includes such things as police action, service capacity, and grade crossing vehicular traffic impacts, was the second largest cause of Light Rail Operations Delay Incidents (13.5%) and the largest cause of MRL Rail Operations Delay Incidents (29.2%).

D10. While these incidents are characterized as Rail Operations incidents, they cannot be controlled within that division and should not be categorized as such.

Recommendation for Rail Operations Related Delays

40. Assess the designation of Rail Operations incidents and allocate accordingly to reflect only those accountable to that Division.

Findings for Service Recovery Caused Delays

D11. Service Recovery delays, which accounted for 13.5% of Light Rail Operations delays, reflected managing the impact of service incidents primarily caused by other factors, such as vehicle or infrastructure equipment defects, overcrowding, and external factors such as police action. Rail Operations reviews service delays on an ongoing basis to identify opportunities to reduce future occurrences and minimize the impact of those that do occur. Due to the high-level occurrence of service incidents and subsequent delays, Rail Operations has developed an effective toolbox of service restoration options to initiate as appropriate. Metro is always trying to minimize the delay and recover service as quickly as possible by adding a train from the yard or a gap train (or making up service recovery time to the terminal or "bumping the line," sending the next train out early) to stay as close as possible to the train schedule. Unique to Metro is that gap trains are built into the schedule, moved onto tail tracks in the morning, and are ready for service with Extraboard Operators on standby in the yard.

D12. It was not clear as to the adequacy of the Rail Operations schedule layover/recovery time at station terminals as ongoing service delays often impact on time schedule departures. Having insufficient layover time at terminal stations can also result in increased service delays from Operators requiring a restroom break (10-100).

Recommendations to Mitigate Service Recovery Caused Delays

41. Continue to assess service contingency plans and related staff training to implement the service restoration contingency provisions. Document current effective service restoration practices and reinforce staff awareness through training. The initiation of effective service recovery contingency plans such as these are key to minimizing the impact of all Rail Operations incidents and should be formalized to support their timely and consistent application.

42. Assess running time schedule needs by Line to confirm the adequacy of layover time at station terminals.

Findings for Vehicle Caused Delays

D13. Vehicle related delays caused a significant percentage of Rail Operations Delay Incidents, including 12.9% of the light rail incidents and 25% of the subway incidents.

D14. Some vehicle related delays were probably due to operator error, but many were not; the available information was not sufficient to determine the root cause. To the extent that these vehicle related delays reflect operator error in troubleshooting the problem, they are appropriately assigned to Rail Operations. But if they are in fact vehicle failures, the mischaracterization of these incidents has two negative effects: first, it assigns accountability to rail operations which is not accountable for vehicle failures; and second, it does not ensure that vehicle maintenance is apprised of the problem for appropriate correction and tracking.

Recommendation for Vehicle Caused Delays

43. Utilize the recommendations (numbers 1-4 and 7) relative to determining root cause to better instruct operators in troubleshooting and to identify the cause of the vehicle related incident. Allocate cause accordingly so that rail vehicle incidents are not characterized as rail operations. Vehicle related delays attributed to Operator error while troubleshooting vehicle defects should continue to be allocated to Rail Operations so that appropriate mitigations can be undertaken.

Finding for the Remaining Causes of Rail Operations Incidents

D15. Similar to vehicle-caused delays, the remaining causes of Rail Operations Delay Incidents reflected categories that involved limited control by Rail Operations, such as no equipment, single track operations, scheduled maintenance/capital work, and test train. These are not primarily attributed to Rail Operations' scope of responsibilities.

Recommendation for Remaining Causes of Rail Operations Incidents

44. Utilize recommendations (numbers 1-4 and 7) relative to determining root cause to better identify the cause of the incident. Allocate accordingly so that incidents not caused by the operator are appropriately characterized and not attributed to rail operations so that appropriate mitigations can be undertaken.

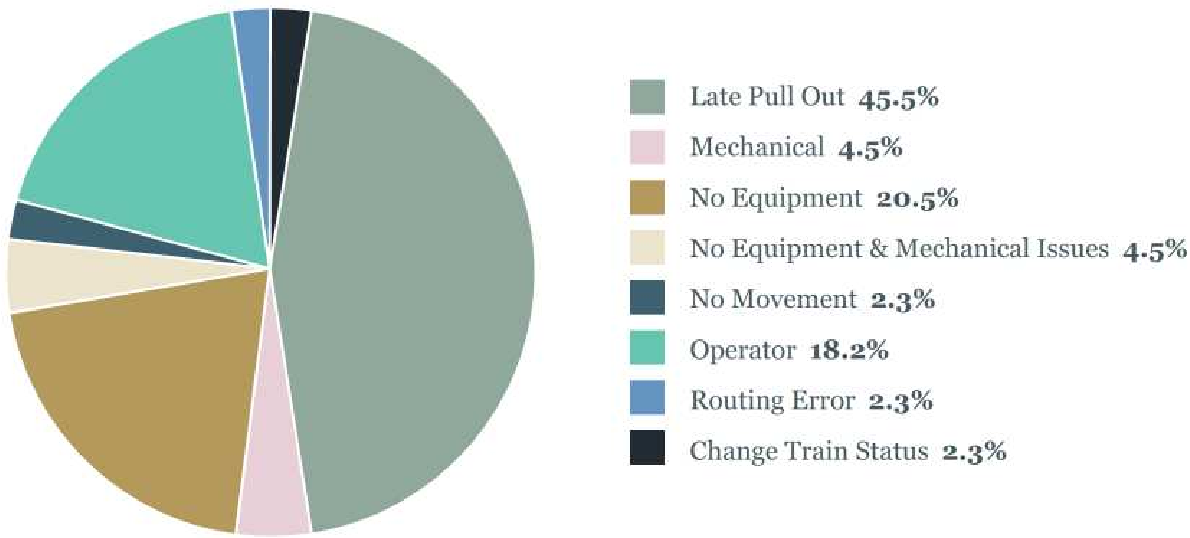
E. Yard Control Service Delay Incidents: Third Highest Cause of Delay on the Expo and Metro Gold Lines (MGDL)

Yard Control incidents were the third highest cause of delay, with 50 incidents on the Expo and MGDL; 22 incidents each for Expo and MGDL were randomly sampled as a statistically significant representation of the data.

Findings for Yard Control Related Delays

These incidents were categorized into 8 primary causes of Light Rail Operations delay incidents. (see Figure 21.)

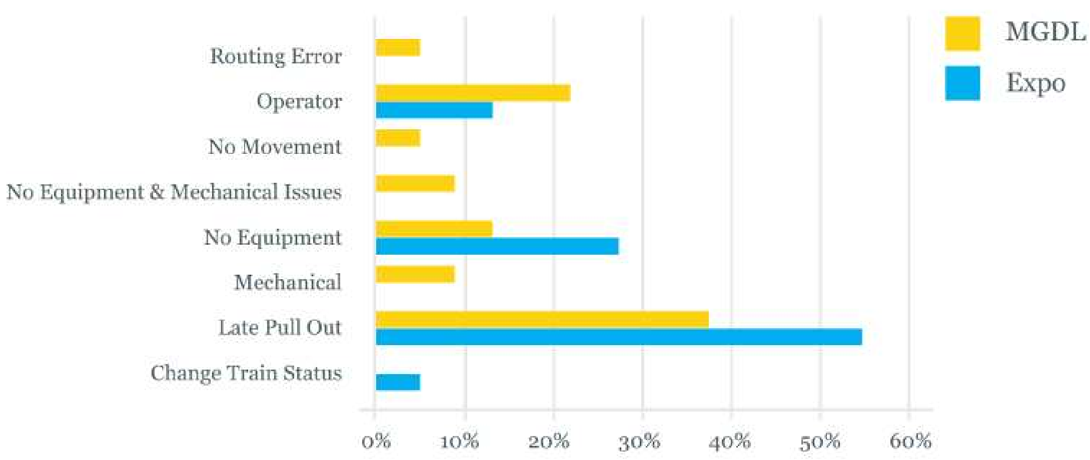
Figure 21: Causes of Yard Control Incidents (Light Rail)



E1. As shown in the above chart, the top three incidents due to Yard Control were late pull out (45.5%), no equipment (20.5%), and operator (18.2%) (mostly operator not available).

E2. The analysis in Figure 22 shows that Yard Control related service delays were largely not specific to the yards.

Figure 22: Causes of Yard Control Incidents by Line



Recommendations to Mitigate Yard Control Related Delays

45. Limit the designation of Yard Control incidents to those actually attributed to yard issues.

46. Review Yard vehicle availability constraints and evaluate options designed to further support the consistent achievement of 100% equipment schedule availability.

F. Signal Service Delay Incidents: Third Highest Cause of Delay on the Metro Green Line (MGL) and the Metro Red Line (MRL)

This part of the review and analysis of service delays focused on delays to train service that were caused by failures in the existing signal installations, which were the third highest frequency cause of delay on MGL and MRL from the data provided.

In a prior study on LA Metro's Safety Culture and Rail Operations Review completed in 2016, the OIG tasked TWG with the review of signal records to determine whether signal equipment downtime is promptly recorded and corrected.

The main relevant findings from the previous study include the following:

- MBL had the highest failure rate per track mile due to having the oldest equipment and an operating environment that includes grade crossings.
- The time to repair 39% of the signal failures was more than two hours.
- The largest three contributors to signal failures were grade crossing equipment (29.8%), track circuit equipment (25.6%) and signal equipment (18.1%).
- The impact of signal failures on train operation was not clearly and consistently reflected in the Main Line Incident Status Log Reports. The majority of the Main Line Incident Status Log Reports (169 out of 215) did not discuss the impact on train service or any train delays resulting from the maintenance failures. Further, 15 maintenance incidents were missing from the Main Line Incident Status Log Reports.
- There was a high failure rate of maintenance equipment at the MGL Marine Interlocking (57% of the signal failures on MGL occurred at this interlocking).

TWG made many recommendations related to these findings, which are currently being addressed by Metro. In view of the relevancy of the prior study to the current task of assessing the impact of signal failures on train service, TWG will leverage the findings and recommendations from the 2016 report in this analysis.

Findings on Frequency of Signal Incidents

With respect to the current study, TWG analyzed incident reports and work orders by line for delays to train service attributed to signal failures during 2016. Overall, 72 signal delay incidents affected the five Metro lines. Based on the methodology employed for this delay analysis, the top three broad causes of delay on each line system were analyzed in depth. As such, signal failures were identified as the third major cause of delays on MGL and MRL with 17 and 10 incidents respectively. Therefore, this report focused on the signal incidents that affected service on these two lines.

F1. In this analysis, MGL and MRL signal incidents comprise only 27 signal incidents in total, a surprisingly small number. In view of the finding in the 2016 study that signal failures are not consistently reflected in incident reports and do not report the impact on train service, it appears that the signal failure data identified by Metro in 2016 may not reflect the full extent of signal failure issues. This is evident from the low number of identified signal incidents (72 for an entire year for all lines) compared to the data analyzed in the prior study (215 for two months). If we extrapolate the number of total signal failures for 2016 based on the signal failure data provided for two months in 2015, the result would be about 1,290 incidents.

F2. While the 2016 data may not have identified a significant delay impact, without a full assessment and analysis of all signal failures on a line, it is difficult to provide an objective analysis of the root causes for signal failures, and to also assess the current process for allocating capital funds to progress the state of good repair for signal installations.

F3. Further, even if signal failures do not cause service delays, it is likely that a signal failure will impact normal train operation and may require a train to operate in a degraded mode of operation pursuant to operating rules and procedures. Such degraded mode of operation should be reflected in the incident report. Any time a train loses signal protection and operates under rules and procedures, a record should be made because it is related to safety.

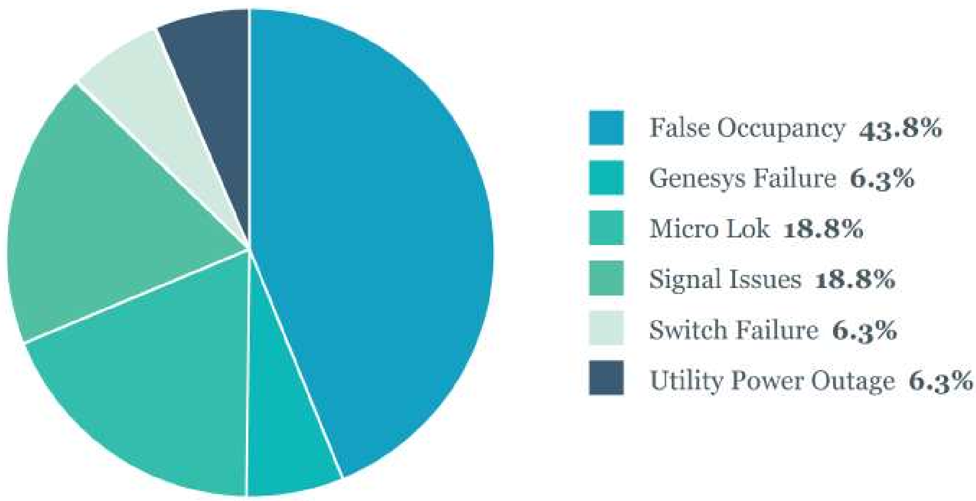
F4. According to interviews with Metro staff, as part of its Enterprise Asset Management program, the agency is moving toward a system that is expected to centralize diverse databases so that all information about signal failures would be available in one place and allow for more thorough root cause identification, tracking, and mitigation. While this would be ideal, steps can be taken in the interim to improve the existing data.

It should be noted that under this task, TWG did not perform any physical inspection of signal installations, and did not review any existing design or installation drawings. TWG relied entirely on the information reflected in the incident reports, associated work orders, and interviews with Metro personnel.

Findings on Signal Incidents

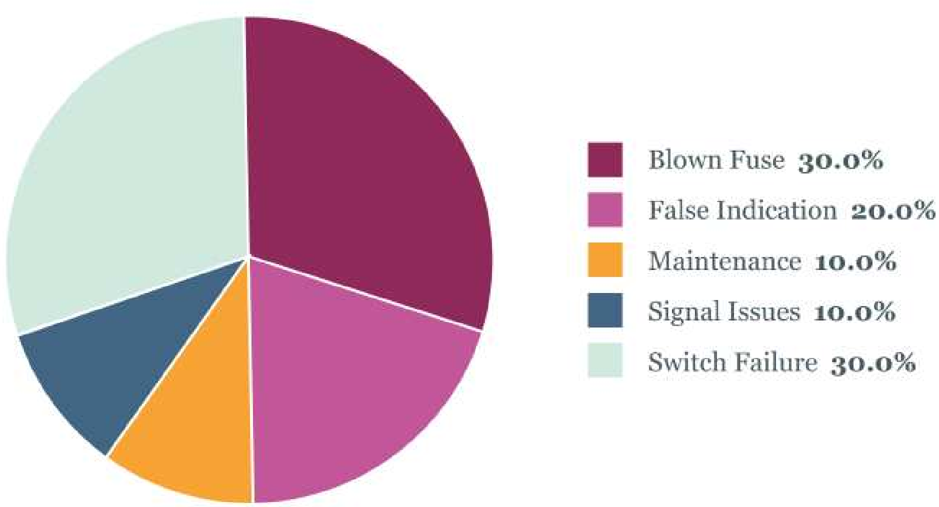
Six causal categories were identified for Signal delays on MGL. As shown in the chart below, false occupancy, Micro Lok (an interlocking control system, manufactured by Ansaldo), and Signal issues accounted for 81.4% of all signal incidents on the MGL, although many of these did not identify root cause.

Figure 23: Causes of Signal Incidents - Light Rail (MGL)



Five causal categories were identified for signal delays on MRL. As shown on the chart below, blown fuse, switch failure and false occupancy accounted for 80% of these MRL signal delay incidents, although no systemic failure could be identified based on the low incidence of these delays and the information provided on the work orders.

Figure 24: Causes of Signal Incidents - Subway Line (MRL)



MGL Findings

A review of the causes of signal delay incidents on MGL found:

F5. The low number of identified signal incidents (72 for all lines for an entire year) does not include the estimated hundreds of additional signal failures that did not cause delay. This makes it difficult to provide an objective analysis of the root causes and to assess the current process for allocating capital funds to progress the state of good repair for signal installations.

F6. Signal failures that do not cause service delays but likely impact normal train operation and may require a train to operate in a degraded mode of operation are not captured in incident reports.

F7. On the MGL, 7 out of the 16 incidents (44%) were attributed to "False Occupancy," which caused 2 cancelled trips and 27 late trips. A "False Occupancy" occurs when a track circuit falsely indicates the presence of a train within its boundaries.

F8. The magnitude of the delays on the MGL ranged from 5 to 30 minutes. Our analysis of these delays showed the following:

- Signal issues resulted in the longest delays, ranging from 8 to 30 minutes.
- Failed circuit or connection issues under false occupancy were the most common cause for delays. These delays lasted between 5 and 20 minutes.

F9. Review of reports and associated work orders did not reveal a systemic issue or a pattern of failures that is out of industry norm.

F10. The signal system on the MGL, which was completed in April 1995 and is controlled by an advanced cab-signaling system provided by Ansaldo, is not beyond its useful life and should be in a state of good repair.

MRL Findings

A review of the causes of signal delay incidents on MRL found:

F11. On the MRL, 10 incidents caused 11 cancelled trips and 20 late trips during 2016.

F12. The magnitude of the delays on the MRL ranged from 5 to 220 minutes.

- The longest delay of 220 minutes was due to false indication related to the supervisory control and data acquisition (SCADA) system.

- Two-thirds of the blown fuses occurred at the North Hollywood Station and took between 8 and 12 minutes to replace.

- Repair and replacement of switches took 8-20 minutes.

F13. The incident reports and associated work orders on MRL did not reveal a systemic pattern of failure.

F14. The first phase of the MRL opened in January 1993. Its cab-signaling based on audio frequency track circuits is not beyond its useful life and should be in a state of good repair.

Findings Related to Work Orders and Capital Investment

F15. Work orders for signal incidents often lack details and specificity related to the cause of failure and the repair action taken. It is difficult to analyze root causes for various failures without details and specificity.

- For example, in WO #6027766 the failure is identified as "MICRO-LOK FAILURE" that was repaired, without indicating the details of this failure. Similarly, WO #5936399 reflects that the failure was "LOSS OF CAB SIGNALING" without indicating what caused this failure.

F16. Currently, Metro does not perform structured periodic condition surveys for the purpose of prioritizing existing signal installations to receive capital funds for the state of good repair.

F17. Currently, according to interviews, service delays caused by signal equipment failures are not linked to the level of funding needed for a state of good repair.

F18. As such, Metro does not currently have a criterion for allocating capital funds to various assets based on condition survey, impact of failures on train service, and obsolescence of equipment.

F19. TWG did not find any evidence that the capital and maintenance programs for signals adequately and timely addressed critical needs identified through incidents that cause delays to train service.

Recommendations to Mitigate Signal Incidents

47. Establish a procedure to instruct signal maintenance personnel on providing consistent and complete detailed information on the cause of signal failures and the repair action taken in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of signal failures on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause. This will better allow trends to be identified and mitigated.

48. Identify the funding and timeline for the new M3 system and move the project forward expeditiously. The requirements for the design of the new M3 module includes a more robust system for logging incident reports that can be expected to allow for more consistent and robust reporting of root causes of signal failures.

49. Perform more investigations and analysis to determine the root causes for high frequency failures even if they do not result in service delays.

50. Establish a procedure for operating personnel to reflect the impact of any signal failure on normal operation even if it does not result in a service delay. This is necessary to ensure that operating personnel comply with operating rules and procedures.

51. Conduct periodic condition surveys on signal installations in advance of, and complementary to, the asset inventory that will be undertaken soon and refreshed every three years.

52. Establish a process and a criterion for replacement of existing signal installations that includes useful life of installation, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource to this end when it is finished, this system of prioritization should be formalized and implemented in current signal procedures.

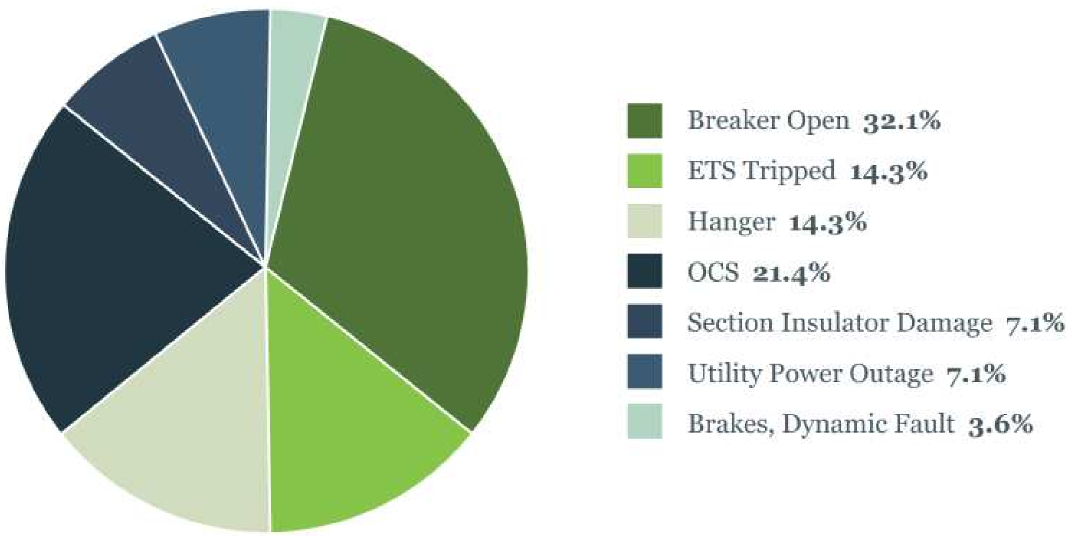
G. Traction Power Service Delay Incidents: Third Highest Cause of Delay on the Metro Blue Line (MBL)

This part of the review and analysis is focused on delays to train service that were caused by failures in the existing traction power installations. TWG analyzed incident reports and work orders for delays attributed to traction power failures during 2016. The reports and work orders are grouped by line. Overall, 92 traction power delay incidents affected the five Metro lines. Based on the methodology employed for this delay analysis, the top three broad causes of delay on each line were analyzed in depth. As such, traction power failures were identified as the third major cause of delays on MBL with 30 incidents. Therefore, this report focused on the traction power incidents that affected service on MBL during 2016. (It should be noted that TWG did not perform any physical inspection of traction power installations, and did not review any existing design or installation drawings.) TWG relied entirely on the information reflected in the incident reports, associated work orders, and interviews with Metro personnel.

Findings on Traction Power Related Delays

Twenty-eight incident reports were randomly sampled as a statistically significant representation of the traction power delays on the MBL. Seven causal categories were identified for these traction power delays as shown in the chart below.

Figure 25: Causes of Traction Power Incidents - Light Rail (MBL)



A review of these causes of traction power delay incidents found:

G1. Traction power failures on the MBL resulted in 358 cancelled trips and 113 late trips in 2016.

G2. 12 out of 28 (43%) incidents were related to failures or interference with the catenary infrastructure (21.4% Overhead Contact System (OCS) failure, 7.1% section insulator damage, and 14.3% hanger interference and broken wires). The catenary failures resulted in 191 cancelled trips and 48 late trips.

G3. 9 out of 28 (32.1%) incidents were related to open breakers due to hardware failures or undetermined causes. The breaker failures resulted in 115 cancelled trips and 24 late trips.

G4. 4 out of 28 (14%) incidents were due to tripping of the Emergency Trip System (ETS). The ETS failures resulted in 23 cancelled trips and 20 late trips.

G5. 6 out of 28 (21%) incidents occurred at San Pedro Traction Power Substation (TPSS).

G6. The magnitude of the delays ranged from 7 to 197 minutes.

- The largest contributor to traction power incidents with significant impact on train service was the failures or interference with the catenary infrastructure. The longest delay was a result of a broken contact wire with OCS down. Traction power was repaired and service was restored after 197 minutes. Other OCS repairs took between 10 and 20 minutes.

- The second largest contributor to traction power incidents with significant impact on train service was related to failures in the TPSS equipment. This could have been caused by design or installation issues or related to state of good repair, but there was insufficient information to determine this. (It should be noted that MBL is the oldest line in the LA Metro Rail Network.)

G7. Similar to signal failures, a number of work orders for traction power lacked the details of the specific cause of failure and the repair action taken. Detailed failure information is required for proper analysis of failures and determination of root causes. Consequently, there is no process in place that links service delays caused by traction power equipment failures to the level of funding needed for state of good repair.

G8. There are currently no periodic condition surveys for the purpose of identifying traction power elements that need capital funds for the state of good repair so it is not clear how priorities for capital expenditures are established.

G9. As such, TWG did not find any evidence that the capital and maintenance programs for traction power were adequately and timely addressing critical needs that were identified through incidents that caused delays to train service.

Recommendations to Mitigate Traction Power Related Delays

53. Perform more investigations and analysis to determine the root causes for traction power failures, including a review of the catenary design, installation standards, and operating condition of TPSS equipment.

54. Establish a procedure to instruct traction power maintenance personnel on providing complete detailed information related to traction power failures in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of traction power failures on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause.

55. Investigate the high level of failures that occurred at San Pedro Traction Power Substation.

56. Conduct periodic condition surveys on traction power equipment in advance of, and complementary to, the asset inventory that will be undertaken soon and refreshed every three years.

57. Establish a process and a criterion for replacement of existing traction power equipment that includes useful life of installation, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource when it is finished, this system of prioritization should be formalized and implemented in current signal procedures.

Next Steps

As Metro advances its initiatives related to its Enterprise Asset Management Plan, its ability to mine its data for root cause, track trends, identify mitigations and prioritize investments will become increasingly effective. Expediting those steps currently underway promises to yield immediate and long-term benefits. In the interim, this report provides steps that Metro can take to be able to better identify, track, and reduce incidents occurring now.

Section III

Mitigating Delay Incidents Through State of Good Repair Investment

Interviews with Metro staff described an agency in the midst of implementing important improvements to their State of Good Repair program. Metro is implementing asset condition surveys across all assets, which will allow better investment priorities to be set to address safety and reliability needs. Metro is also redesigning its M3 maintenance system, which promises to combine diverse service disruption incident databases and provide a platform for tracking root cause of incidents, and is taking other steps to implement a robust Enterprise Asset Management System. In the interim, maintenance activities address most incidents that occur during daily service; and capital investments are based on the priorities of the agency, departments, and expertise of the asset managers. While this analysis did not find any systemic failures, opportunities for improvement have been noted, particularly in this interim period before these ongoing improvements are fully implemented.

The $4.8 billion dedicated to state of good repair over ten years as described in the Short Range Transportation Plan demonstrates Metro's focus on SGR. However, this amount comes to about $480 million per year, which needs to cover many assets. In addition to addressing new rolling stock for bus and rail, it also must address the needs of an aging infrastructure. These competing needs are clearly reflected in the FY 2018 Adopted Budget. The FY 2018 Adopted Capital Program budget of $2.09 billion includes $1.7 billion for expansions and $394 million for Operating Capital, which covers safety and security projects, bus and rail state of good repair, capital infrastructure and other related investment categories. The total budgeted specifically for Rail State of Good Repair is $224 million. Of this total, $145 million (65%) is for vehicle investments that address the types of issues identified in TWG's analysis of vehicle related service disruption incidents. These include:

MBL P865/2020 Mid-life Overhaul	$2,601,000
MGDL P2550 Vehicle Component Overhaul	$2,563,000
MGDL P2550 Mid-life Overhaul	$ 615,000
MRL Heavy Rail Mid-life Overhaul	$9,912,000
MRL Heavy Rail Procurement	$5,793,000
Subway Railcar Component Replacement	$3,043,000
Multiple Lines P2000 Light Rail Mid-life Overhaul	$13,406,000
Multiple Lines Light Rail Fleet Replacement	$102,080,000
Multiple Lines P2000 Component Replacement	$2,984,000
Professional Service to Support P3010 Buy	$2,014,000
TOTAL	**$145,011,000**

Vehicle Related Service Delay Incidents. These investments are consistent with needs to address the findings of TWG's review of vehicle related service disruption incidents, the most frequent cause of delay across all Metro lines. TWG's review of the P865/2020 fleets identified issues associated with a fleet that never went through a midlife overhaul. In 2005 when the P2550 vehicles were ordered, the P865 vehicles were already 15-years old. Rather than overhauling the P865s, the intention was to replace them with the P2550 vehicles. The P2550 order did not result \in option cars; instead a new light rail specification was issued. When it became obvious that the P865 fleet was still needed, Metro started to invest in some component upgrades, such as replacing capacitors which were well past the expected service life of 15 years, replacing contactors, and upgrading the propulsion control power supply as well as other critical components. This necessary investment is included in the FY 2018 SGR budget.

TWG's review also confirmed that a major overhaul was the correct approach for the P2000 series fleet considering the high service disruption incident rate per car and the relatively young age of these vehicles. It is appropriate for Metro to provide the needed funds to finance a useful midlife overhaul for the P2550 fleet.

Similar to the P865 cars, the Base Buy subway cars have obsolete propulsion and control systems that have never gone through a refurbishment process. Metro intends to keep these vehicles in service until the new HR4000 subway cars are delivered. The funding in the SGR budget makes this approach feasible. Metro just began the major midlife overhaul for the A650 GE fleet, replacing the obsolete GTO inverter and other equipment. The GE fleet will remain in service even after the new HR4000 vehicles are delivered beginning 2021. In April 2017, Metro contracted to purchase 64 HR4000 subway cars for $178 million.

In addition to vehicle investments, the FY 2018 Rail SGR budget includes about $80 million for all remaining rail SGR needs system-wide. Whether this level of investment is sufficient for the other top causes of service delay is not clear as discussed below relative to each of the top causes of delay incidents.

Rail Operations and Yard Related Service Delay Incidents. The service disruptions attributable to Rail Operations, the second most frequent cause of delay across all lines, do not involve infrastructure and do not require capital investments. Similarly, Yard Control, the third largest cause of service disruption on MGDL and Expo Line, were not specifically caused by yard related infrastructure issues. They were more often associated with lack of equipment, and do not require capital investments beyond the rail car purchases and upgrades discussed above.

Signal Related Service Delay Incidents. For Signal service disruption incidents, the third most frequent cause of delay on MGL and MRL, the low number of identified signal incidents does not include the estimated hundreds of additional signal failures that did not cause delay and were not reflected in the incident log reports maintained by the ROC. This makes it difficult to provide an objective analysis of the root causes and to assess the current process for allocating capital funds to progress the state of good repair for signal installations.

The signal system on the Metro Green Line, which was completed in April 1995 and is controlled by an advanced cab-signaling system provided by Ansaldo, is not beyond its useful life and should be in a state of good repair. That being said, the FY 2018 Budget does not include a budget for MGL Signal System Rehabilitation Phase II.

MRL was completed in January 1993. Its cab-signaling based on audio frequency track circuits is not beyond its useful life and should also be in a state of good repair. While the Adopted Capital Program budget did not contain any investments for MRL signal work, based on the data available, TWG cannot evaluate this decision.

While signal issues were not identified as among the top causes of delay for MBL, the FY 2018 program includes $19.8 million for MBL Signal System Rehabilitation and Operations Improvement, which includes funding for MBL Overhead Catenary System Rehabilitation.

Also, there are a number of diverse signal technologies in use on the various light rail and heavy rail lines. Metro should consider the development of a strategic plan for signal modernization that will minimize these differences. This should result in operational and maintenance benefits, including achieving interoperability between light rail lines. The current funding approach is on a per line basis, which will maintain the differences between the lines.

Traction Power Related Delay Incidents. Disruptions related to Traction Power were the third highest cause of delay on MBL. A number of work orders lacked the details of the specific cause of failure and the repair action taken. Detailed failure information is required for proper analysis of failures and determination of root causes. Consequently, there is no process in place that links service delays caused by traction power equipment failures to the level of funding needed for state of good repair. Although the FY 2018 Capital Program includes $600,000 for MBL Emergency Trip System Replacement as well as $785,000 for MGL's Emergency Trip System, TWG cannot evaluate the adequacy of this funding.

There are currently no periodic condition surveys for the purpose of identifying asset components that need capital funds to maintain state of good repair so priorities for capital expenditures are established primarily based on priorities of the agency, departments, and expertise of the asset managers. As such, Metro does not currently have a criterion for allocating capital funds to various assets based on condition surveys, impact of failures on train service, and obsolescence of equipment.

Metro will need to reevaluate whether its investment strategy is sufficient once the asset condition inventories currently underway are completed and priorities for investments to achieve a state of good repair are set. Metro will then be positioned to establish a process and a criterion for replacement of existing assets that includes useful life of the asset, failure rate, impact on service delays, obsolescence, service needs, and available funding. While the Metro asset condition inventory will provide an important resource to this end when it is finished, this system of prioritization should be formalized and implemented in current procedures for all asset classes.

While expansion of the system is critical, it cannot take place at the expense of maintaining the existing system. Setting this balance, however, requires a firmer understanding of the condition of the core infrastructure. Expediting the work currently underway will position Metro to better make these tradeoffs.

Appendices

Appendix A

Abbreviations

APS	Auxiliary Power Supply
ASTS	Ansaldo Signaling and Transportation Systems
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BCU	Brake Control Unit
BECU	Brake Electric Control Unit
DC	Direct Current
EB	Emergency Brake
ECU	Electronic Control Unit
ETS	Emergency Trip System
Expo	Metro Expo Line
GE	General Electric
GTO	Gate Turn-Off Thyristor
H&K	Hanning and Kahl
HSCB	High Speed Circuit Breaker
HVAC	Heating, Ventilation and Air Conditioning
IGBT	Insulated Gate Bipolar Transistor
IT/ITS	Information Technology/Information Technology Services
LRV	Light Rail Vehicle
LVPS	Low Voltage Power Supply
M3	Maintenance and Material Management System
MA	Motor Alternator
MARTA	Metropolitan Atlanta Rapid Transit Authority
MBL	Metro Blue Line
Metro	Los Angeles County Metropolitan Transportation Authority
MGDL	Metro Gold Line
MGL	Metro Green Line
MOW	Maintenance of Way
MRL	Metro Red Line
OCS	Overhead Contact System

OIG .... Office of the Inspector General
Panto .... Pantograph
PECU .... Propulsion Electric Control Unit
Ph .... Phase
ROC .... Rail Operations Center
SCADA ..... Supervisory Control and Data Acquisition
SGR .... State of Good Repair
TOD .... Train Operator Display
TPSS .... Traction Power Substation
TWG .... The Wathen Group
WO .... Work Order

Appendix B

Schedule of Recommendations and Metro's Proposed Actions to Implement LA Metro Service Disruption Review - Report

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
1	Instruct operators to report all alert indications shown on the console. This is especially important given the amount of information that is available on the console of the new trains. In addition, operators should assess whether passenger behavior caused an indication as opposed to a problem with the equipment.	A1 A2 A3 A4	Root Cause	System-wide				
2	Establish a dedicated, 24/7 "super-tech" maintenance team full time in the ROC to provide expert support to the ROC for equipment, systems and infrastructure faults.	A5	Root Cause	System-wide				
3	Ensure the Rail Vehicle Department records root cause for rail vehicle delay incidents, which are the highest number of incidents across all five rail lines. Instruct the ROC to record "Rail Vehicle Event" for subsequent update by the Rail Vehicle Department.	A6 A7 A8	Root Cause	System-wide				
4	Maximize the redesign of the M3 software program logging module. All departments should work with the design expert to create a drop-down listing that would capture the most meaningful root cause categories for their area of responsibility. Ideally, the ITS department should also bring all fault reports into one environment, so that internal department reports of failures can be tracked along with those recorded through the ROC. This redesign of the M3 module should allow for automated tracking of delays and their root causes, reporting delay trends, identifying mitigations and tracking their impact.	A9	Root Cause	System-wide				
5	Include Train Operator Display (TOD) information, such as time of the incident, in the reporting of incidents.	A4	Root Cause	System-wide				
6	Review approach to Police/Health delay incidents (while not part of this analysis, these delay incidents warrant review based on their frequency and duration).	B1	Police/ Health	System-wide				
7	Partner with law enforcement agencies to review process used for police/health incidents.		Police/ Health	System-wide				

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
8	Identify root cause for the top three categories of delay for each line to allow Metro to develop mitigations that have the potential to significantly reduce total delay incidents.	B2-B10	Top 3 causes by line overall	System-wide				
9	Set priorities based on Metro's asset assessment as soon as it is completed to reduce delay incidents.	B2-B10	Top 3 causes by line overall	System-wide				
10	Given the large number of incidents where no root cause was identifiable, establish a procedure to instruct vehicle maintenance personnel on providing consistent and complete detailed information related to vehicle failures in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of vehicle failure on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause.	C2	Rail Vehicle	System-wide				
11	Identify the funding and timeline for the new M3 system and move the project forward expeditiously.	C1-C5	Rail Vehicle	System-wide				
12	Establish a procedure for collecting the root cause of every vehicle failure even if it does not result in a service delay so that robust trends can be generated, tracked and mitigated.	C1	Rail Vehicle	System-wide				
13	Conduct periodic condition surveys on vehicles and components in advance of and complementary to the asset inventory that will be undertaken soon and refreshed every three years.	C1-C5	Rail Vehicle	System-wide				
14	Establish a process and a criterion for replacement of existing vehicles and vehicle components that include useful life, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource to this end when it is finished, this system of prioritization should be formalized and implemented in current vehicle procedures.	C1-C5	Rail Vehicle	System-wide				
15	Continue funding for daily maintenance and up-keep of the P865/2020 fleets although no major capital investment is recommended at this time.	C15-C18	Light Rail Vehicle	MBL, Expo Line				
16	Identify the P865 cars in the worst condition for decommissioning and use them as spare part suppliers to support more reliable cars.	C12-C14	Light Rail Vehicle	MBL, Expo Line				
17	Keep enough P865 cars as floats to improve the availability of P2000 vehicles, which have a higher incident rate, for refurbishment.	C5	Light Rail Vehicle	MBL, Expo Line				

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
18	Review the decommissioning process of the P865 fleet given the lower incident rate for the P865 fleet. P865 cars with low to no incidents should be kept in service during the P2000 overhaul to expedite the overhaul, replacing some P2000 services with P865 cars to increase the vehicle availability during the overhaul.	C5 C14	Light Rail Vehicle	MBL, Expo Line				
19	Maintain the remaining P865 cars only out of the MBL maintenance shop, which has the best expertise, logistics and parts inventory to maintain the P865 fleet.	C6 C17	Light Rail Vehicle	MBL, Expo Line				
20	Continue with the P865 component upgrades to keep a reduced fleet with increased reliability in service until replaced by the P3010. Areas of upgrades still useful are contactors, relay panel and ECU power supply.	C7-C11 C15 C16 C18	Light Rail Vehicle	MBL, Expo Line				
21	Evaluate overhaul needs of select main components. Depending on how long Metro intends to keep cars of the P865/2020 fleet, some of the main components, such as gears and traction motors, of selected well-performing cars might have to be overhauled.	C7-C11 C15 C16 C18	Light Rail Vehicle	MBL, Expo Line				
22	Continue the refurbishment program to reduce fuse failures, such as upgrades to the chopper control unity, contactor and relay replacements, in place as needed for some of the P865 cars.	C16 C18	Light Rail Vehicle	MBL, Expo Line				
23	Plan the midlife overhaul to first upgrade the worst vehicles, such as cars #220, 205, 208. 212, 229, 242 & 247.	C23-C28	Light Rail Vehicle	MGL, MBL, Expo Line				
24	Analyze the float vehicle needs for the P2000 vehicle midlife overhaul and ensure that the overhaul contractor has enough cars to expedite the overhaul. On the MBL, P865 vehicles being decommissioned could be reduced temporarily to provide enough vehicles to the overhaul contractor.	C5 C14 C28	Light Rail Vehicle	MGL, MBL, Expo Line				
25	Consider converting some P2000 cars running on the MBL/Expo lines back to the MGL operation if the ATO/ATP packages removed earlier are still available. The critical float will be the P2000 MGL cars with their line specific ATO/ATP equipment.	C5 C14 C28	Light Rail Vehicle	MGL, MBL, Expo Line				
26	Improve the diagnostic capabilities of the propulsion system.	C19	Light Rail Vehicle	MGL, MBL, Expo Line				
27	Use information from TODs on the P2550 vehicles for improved incident reporting. The P2550 cars are the first Metro vehicles that have a sophisticated TOD and diagnostics.	C35	Light Rail Vehicle	MGDL				

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
28	Modify the incident reports for P2550 vehicles to include the information provided by the TOD at the time of the incident, in addition to the Operator reports.	C35-C36	Light Rail Vehicle	MGDL				
29	Accurately report the time of the incidents as shown on the TOD, not by the system time at the ROC.	C35-C36	Light Rail Vehicle	MGDL				
30	Use the time of the incident displayed on the TOD in evaluating the delay incident to improve accuracy and turnaround time of the affected vehicle.	C35-C36	Light Rail Vehicle	MGDL				
31	Keep the Base Buy subway cars running by planning enough funding for Rail Fleet Services to maintain this fleet.	C46-C47	Subway Vehicle	Subway				
32	Ensure that the knowledge of the chopper controls is not lost before the new cars arrive.	C38 C46	Subway Vehicle	Subway				
33	As the new HR4000 vehicles arrive, take the Base Buy cars out of service as early as possible to reduce maintenance costs. The cars in the worst condition should be replaced first.	C42-C45 C47	Subway Vehicle	Subway				
34	Perform the midlife overhaul on GE subway vehicles as planned.	C53-C55	Subway Vehicle	Subway				
35	Assess current mitigation measures to address operator absenteeism and late reports, and initiate management enhancements as appropriate.	D3 D7 D8	Rail Ops					
36	Re-assess the level, allocation, and scheduling of Rail Operations Extraboard Operators as an opportunity to mitigate the impact of all service incident related delays resulting from service recovery, operator late or no show, station terminal and yard operator related delays, "gap trains" staffing (extra trains added to the schedule to supplement service capacity as needed), etc.	D7 D8	Rail Ops					
37	Reinforce desired practices to mitigate future "Operator Error" service impact events including additional focus on operator vehicle troubleshooting tactics. Given that vehicle defects represent the most significant factor impacting Metro Rail service delays, assess operator awareness of common vehicle troubleshooting methods to expedite the safe movement of the vehicle and reduce service delays resulting from vehicle defects.	D9	Rail Ops					

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
38	Consider the development of an Operations pocket size vehicle defect troubleshooting guide that reinforces what operators are trained to perform and summarizes the desired tactics to follow when confronted with vehicle related defects. Common vehicle troubleshooting methods and other lessons learned from operator errors that resulted in service delays should continue to be reinforced in current operator training programs.	D9	Rail Ops					
39	Continue to hone service recovery contingency plans, which are key to minimizing the impact of all Rail Operations incidents.	D7 D8	Rail Ops					
40	Assess the designation of Rail Operations incidents and allocate accordingly to reflect only those accountable to that Division.	D10 D11	Rail Ops					
41	Continue to assess service contingency plans and related staff training to implement the service restoration contingency provisions. Document current effective service restoration practices and reinforce staff awareness through training.	D12	Rail Ops					
42	Assess running time schedule needs by Line to confirm the adequacy of layover time at station terminals.	D13	Rail Ops					
43	Utilize the recommendations (numbers 1-4 and 7) relative to determining root cause for vehicle caused operations delays to better instruct operators in troubleshooting and to identify the cause of the vehicle related incident. Allocate cause accordingly.	D14 D15	Rail Ops					
44	Utilize the recommendations (numbers 1-4 and 7) relative to determining root cause to better identify the cause of the incident. Allocate accordingly so that incidents not caused by the operator are appropriately characterized and mitigated.	D16	Rail Ops					
45	Limit the designation of Yard Control incidents to those actually attributed to yard issues.	E1 E2	Yard Control	Yards				
46	Review Yard vehicle availability constraints and evaluate options designed to further support the consistent achievement of 100% equipment schedule availability.	E1	Yard Control	Yards				
47	Establish a procedure to instruct signal maintenance personnel on providing consistent and complete detailed information on the cause of signal failures and the repair action taken in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of signal failures on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause.	F1 F2 F3 F15	Signals	MGL, MRL				

Rec. #	Recommendation Description	Related Finding #	Delay Category	Line	Assigned Staff in Charge	Agree or Disagree	Proposed Action	Est. Date of Completion
48	Identify the funding and timeline for the new M3 system and move the project forward expeditiously.	F4	Signals	MGL, MRL				
49	Perform more investigations and analysis to determine the root causes for high frequency signal failures even if they do not result in service delays.	F15 F16	Signals	MGL, MRL				
50	Establish a procedure for operating personnel to reflect the impact of any signal failure on normal operation even if it does not result in a service delay.	F1-F3 F5 F6 F13	Signals	MGL, MRL				
51	Conduct periodic condition surveys on signal installations in advance of, and complementary to, the asset inventory that will be undertaken soon and refreshed every three years.	F4 F16	Signals	MGL, MRL				
52	Establish a process and a criterion for replacement of existing signal installations that includes useful life of installation, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource to this end when it is finished, this system of prioritization should be formalized and implemented in current signal procedures.	F17 F18	Signals	MGL, MRL				
53	Perform more investigations and analysis to determine the root causes for traction power failures, including a review of the catenary design, installation standards, and operating condition of TPSS equipment.	G7	Traction Power	MBL				
54	Establish a procedure to instruct traction power maintenance personnel on providing complete detailed information related to traction power failures in the WO reports. While awaiting a new log-in system with a consistent and nested drop down of primary causes of traction power failures on incident reports, redesign work order forms along these lines, with a consistent section and checklist for identifying root cause.	G7	Traction Power	MBL				
55	Investigate the high level of failures that occurred at San Pedro Traction Power Substation.	G5	Traction Power	MBL				
56	Conduct periodic condition surveys on traction power equipment in advance of, and complementary to, the asset inventory that will be undertaken soon and refreshed every three years.	G8	Traction Power	MBL				
57	Establish a process and a criterion for replacement of existing traction power equipment that includes useful life of installation, failure rate, obsolescence, service needs, and available funding. While the Metro asset inventory will provide an important resource when it is finished, this system of prioritization should be formalized and implemented in current signal procedures.	G7-G9	Traction Power	MBL				

Appendix C

List of Interview Participants

Metro Participants in Interview Groups	The Wathen Group Interviewers	Date	Time
1. Control Center		6/8/17	3:00 - 4:00 PM (PDT)
Bernard Jackson, Sr. EO, Rail Ops Robert Castanon, Service Ops Superintendent	Nabil Ghaly Linda Kleinbaum Deborah Wathen Finn Werner Uttinger		6:00 - 7:00 PM (EDT)
2. Rail Vehicles		6/9/17	11:30 AM - 12:30 PM (PDT)
Bob Spadafora, Senior, EO, Rail Fleet Services Michael Ornelas, Sr. Director Rail Vehicle Maintenance Richard Lozano, Senior Director, Rail Vehicles Acquisition & Maintenance	Werner Uttinger Linda Kleinbaum Nabil Ghaly		2:30 - 3:30 PM (EDT)
3. Rail Operations/Yards		6/9/17	2:30 - 3:30 PM (PDT)
Bernard Jackson, Sr. EO, Rail Ops John Sanchez, Director of Transportation Operations Patty Alexander, Services Operations	Jim Brown Linda Kleinbaum Nabil Ghaly		5:30 - 6:30 PM (EDT)
4. Signals/Traction Power		6/21/17	2:00 - 3:00 PM (PDT)
Erroll Taylor, Senior EO, Maintenance & Engineering Marshall Epler, DEO, Systems Engineering Remi Omotayo, DEO, Wayside Systems Engineering & Maintenance Leonid Bukhin, DEO, Corporate Safety	Nabil Ghaly Linda Kleinbaum		5:00 - 6:00 PM (EDT)
5. Capital Programs/Asset Management Plan/SOGR		6/12/17	10:00 - 11:00 AM (PDT)
Greg Kildare, Chief Risk, Safety & Asset Management Officer Denise Longley	Linda Kleinbaum Werner Uttinger		1:00 - 2:00 PM (EDT)
6. OMB Finance Department		6/16/17	9:30 AM (PDT)
Quintin Sumabat, DEO, Finance Chris Gallanes, DEO, Finance	Deborah Wathen Finn Nabil Ghaly Werner Uttinger James Brown Linda Kleinbaum		12:30 PM (EDT)
7. M3 Logging Module		6/19/17	3:00 PM (PDT)
Patrick Astredo, DEO, Enterprise Information Management (out sick) Regina Lim, Supvg Engineer Cathy Fong	Deborah Wathen Finn Nabil Ghaly Werner Uttinger James Brown Linda Kleinbaum		6:00 PM (EDT)
8. Vehicle Engineering and Acquisition		6/22/17	1:30 PM (PDT)
Jesus Montes, Director, Rail Vehicle Acquisition & Maintenance Stephanie Kaping, Sr. Administrative Analyst	Linda Kleinbaum Werner Uttinger		4:30 PM (EDT)
9. Chief Operating Officer's Department		6/23/17	4:00 PM (PDT)
Diane Coral-Lopez, Executive Officer - Central Oversight & Analysis	Linda Kleinbaum		7:00 PM (EDT)

Appendix D

List of Tables

Appendix E

List of Figures