San Francisco
County Transportation
Authority

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# Memorandum

**AGENDA ITEM 10**

**DATE:** February 21, 2020

**TO:** Transportation Authority Board

**FROM:** Eric Cordoba– Deputy Director for Capital Projects

**SUBJECT:** 2/25/20 Board Meeting: Independent Management and Oversight Report on the San Francisco Municipal Transportation Agency's Siemens Light Rail Vehicle Procurement

## RECOMMENDATION ☒ Information ☐ Action

This is an information item.

## SUMMARY

On April 23, 2019 the Board continued consideration of the San Francisco Municipal Transportation Agency's (SFMTA's) request for $62.7 million in Prop K funds for the Siemens Light Rail Vehicle Procurement in light of safety and reliability issues with the vehicle's doors, brakes, and shear pins, among others. The Board directed staff to conduct independent oversight to identify the root cause of problems, effective fixes, as well as determine whether the cost of the solutions are covered under warranty or at the SFMTA's expense. We secured the services of T.Y. Lin International to conduct an in-depth review of the issues raised. At the February 25 Board meeting, Robert Sergeant, Director of Rail and Transit for T.Y. Lin will present their findings and recommendations, which are summarized in the slide deck and detailed in the final report (Attachments 1 and 2). Overall, the findings note that good progress is being made with repairs completed, increased availability of vehicles, and significantly improved reliability. There are a number of recommendations reflecting lessons learned and the need for continued oversight through attainment of the Mean Distance Between Failures (MDBF) reliability requirement and Phase 1 warranty repairs. We are working on a revised Prop K allocation request that incorporates the recommendations included in this report.

☐ Fund Allocation

☐ Fund Programming

☐ Policy/Legislation

☐ Plan/Study

☒ Capital Project Oversight/Delivery

☐ Budget/Finance

☐ Contract/Agreement

☐ Other

## DISCUSSION

**Background.**

In 2014, the SFMTA contracted with Siemens Industry Inc. for the procurement of fourth-generation light rail vehicles (LRV4). This included a Phase 1 order of 24 LRVs (subsequently expanded to 68) for fleet expansion, a Phase 2 order of 151 vehicles to replace the existing Breda fleet which is reaching the end of its useful life, and options for an additional 41 LRVs for a total potential order of up to 260 light rail vehicles with a not to exceed price of $1,192,651,577. The Transportation Authority has thus far contributed $131 million in Prop K funds for this procurement. As of December 2019, 65 LRV4s are commissioned and available for service. The remaining three LRVs in the Phase 1 procurement have been assembled but not commissioned.

The T.Y. Lin International staff reviewed a substantial amount of available background material including contract documents, root cause analyses, testing and commissioning plans and reports and documentation regarding repair progress. They conducted a multi-day investigation of the current state of repairs during September 2019 in conjunction with SFMTA. T.Y. Lin staff also participated in weekly commissioning team meetings and met with operators and union representatives to gain insight on their perspective.

**Findings and Recommendations.**

T.Y. Lin provides an oversight report describing the status and recommendations for a range of LRV issues (Attachment 1). They concluded that many issues have been resolved (including all safety issues), and those that remain are performance-related and being addressed, but warrant continued oversight and monitoring.

Issues that have been resolved and are under warranty include:

| Issues | Repair Solutions |
|---|---|
| **Door Safeguards** | Additional sensitive edges added to doors. |
| **Pantographs** | Electrical shunts added and nuts/bolts replaced |
| **Aux. Power Supply** | Brackets modified |
| **Hydraulic Power Unit** | Motor-driver boards, wiring and control valves have been re-engineered |

In Attachment 2: Program Management Oversight Presentation on SFMTA LRV Procurement, slide 5 provides a summary of issues In-Progress, cost/responsibility (e.g. warranty repair or SFMTA cost), and the anticipated timeline for completion.

| Issues | Repair Solution | Cost/Responsibility | Timeline |
|---|---|---|---|
| **Wheel Flats** | Phase 1 LRV4s being retrofitted with additional set of track brakes | $1.75 M at SFMTA cost | March 2020 |
| **Couplers** | Temporary fix (shear pin replacements) in place<br><br>Second round of investigation and testing is underway. | Warranty repair | Testing and analysis to be completed in February, with repairs starting in June |
| **Cameras** | SFMTA evaluating camera and monitor size and type | $1.6M at SFMTA cost for upgrade (estimate) | Timing for upgrade to be determined |
| **Seating** | Revised seating style and height have been identified | $20.2 M at SFMTA cost for upgrade (estimate) | To be determined (Mod 7) |
| **CCTV** | Modify software to improve integration | Warranty repair | To be determined |
| **Door Adjustment** | Adjustments have been made and testing is in progress | Warranty repair | To be determined |
| **Brake Control Unit** | Analysis of brake lock-ups is on-going | Warranty repair | To be determined |

Attachment 2 - Slide 6 contains a similar table focused on reliability issues. Of particular note, the MDBF has improved from 4,000 miles in July to about 17,000 miles in January, but is still below the 25,000 miles (average for 6 months) contract goal. SFMTA staff projects Siemens (the LRV manufacturer) will achieve this goal in June 2020.

| **Issue** | **Repair Solution** | **Cost/ Responsibility** | **Timeline** |
| --- | --- | --- | --- |
| **LRV Availability** | 65 of 68 LRV4s commissioned. Daily availability of LRV4s in January was 43. Improving due to warranty repairs | Siemens | Commissioning of final 3 LRV4s scheduled for Spring/Summer |
| **Mean Distance Between Failure (MDBF)** | Improved from 4,000 miles in July to approximately 17,000 miles in January | Siemens | SFMTA projects 25,000 miles to be achieved in June 2020 |
| **Spare Parts** | Improved estimates of spare parts inventory need<br>SFMTA and Siemens to prepare Spare Parts Plan | SFMTA/Siemens | September |

Based on their review, T.Y. Lin's recommendations include:

- Ensure resolution of remaining Phase 1 repair strategies
- Take stock of lessons learned to apply to the Phase 2 procurement
- Conduct design reviews prior to issuing the Notice to Proceed for Phase 2
- Clarify the MDBF contractual requirements and consequences of not meeting contract specification (SFCTA funding condition)
- Revise spare parts requirements

- Continue SFCTA monitoring and oversight through Phase 1 LRV attainment of MDBF and delivery of Phase 1 warranty repairs.

*The recommendations are summarized on Attachment 2 - slide 8 and found on page 27 of the report.*

## FINANCIAL IMPACT

None. This is an information item.

## CAC POSITION

None. This is an information item. The CAC will be briefed on this item at its February 26 meeting in advance of considering acting on the updated Prop K allocation request for the LRV procurement.

## SUPPLEMENTAL MATERIALS

- Attachment 1 – Program Management Oversight Report for SFMTA Light Rail Vehicles Procurement
- Attachment 2 - Presentation slides

Attachment 1

# PROGRAM MANAGEMENT OVERSIGHT REPORT

# FOR

# SFMTA LIGHT RAIL VEHICLE PROCUREMENT

Prepared for:

San Francisco County Transportation Authority

San Francisco County Transportation Authority
1455 Market Street, 22nd Floor
San Francisco, CA 94103

Prepared by:

T·Y·LIN INTERNATIONAL
engineers | planners | scientists

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February 20, 2020

## Section 1. Executive Summary

The San Francisco Municipal Transportation Agency (SFMTA or MUNI) contracted with Siemens Industry Inc for the procurement of Light Rail Vehicles (LRV4) in 2014. This included a Phase 1 order of 24 LRVs that has been expanded to 68, including 4 additional cars procured separately for the opening of the Chase Center, a Phase 2 order of an additional 151 vehicles to replace the existing Breda fleet and options for an additional 45 LRVs for a total potential order of up to 264 light rail vehicles with a not to exceed price of $1,192,651,577. A portion of the budget for this procurement is coming from the San Francisco County Transportation Authority (SFCTA). This report represents a portion of SFCTA's fiscal oversight associated with the procurement funding. The focus of this oversight is safety and performance, as well as to clarify financial responsibility (change orders vs warranty items)

The initial LRV4 was delivered, tested, commissioned and placed into service in November 2017. As of December 2019, 65 LRV4s are commissioned and available for service. The remaining three LRVs in the phase 1 procurement have been assembled but not commissioned. Two vehicles are at the Muni Maintenance facility and one remains at Siemens plant in Sacramento. Since the initial roll out of the Siemens LRV4s a number of safety and operational issues have developed. This report summarizes the major items, describing the issue, root cause (if known), proposed solution and the status of repairs and modifications through January 2020.

Many of the identified issues are covered under the contractual warranty and have been successfully addressed. They include:

- Auxiliary Power Supply (APS), where a water intrusion issue was corrected under warranty
- Pantographs, where electrical faulting that impacted service in the tunnel was corrected under warranty
- Doors, which have failed by not retracting at times when something is in the way, have been corrected under warranty.
- Hydraulic Power Units (HPU), which control the braking, have been retrofitted with updated driver boards and wiring revisions under warranty.

The remaining major warranty repair item is the coupler between trains where the shear pins failed due to metal fatigue much earlier than allowed. A warranty fix was put in place during Spring 2019, but a new failure occurred in December. A temporary measure is in place and Siemens and the coupler supplier are initiating additional testing to validate a proposed redesign. If the testing planned for early 2020 validates the redesign proposal, warranty repairs will commence in June 2020.

SFMTA has also initiated upgrades to improve operations and maintenance and address rider comfort. Since these are modifications to the contract requirements and specifications, SFMTA is responsible for any cost differences to implement the modifications.

- Additional track brakes are being installed ($1.75 million for phase 1) to reduce wheel flattening and the associate cost of wheel truing and reduced vehicle availability. The funding is within the existing budget due to reduced escalation costs
- Revised seat designs ($20.2 million for phase 1 and 2 LRV4s) to accommodate rider comfort with funding coming from the existing budget due to reduced escalation costs.
- Modifications to the exterior cameras and cab monitors to address operator visibility concerns at a cost to SFMTA to be determined

The overall success of the LRV4 procurement is measured by the Mean Distance Between Failures (MDBF). Contractually, Siemens is required to demonstrate the vehicles will achieve an overall MDBF of 25,000 miles. SFMTA is targeting this to be achieved by the middle of 2020. The MDBF started at about 6,000 miles in December 2018 dropping to 4,000 in June 2019 as a result of a series of component failures. As a result of the completed and on-going warranty repairs the MDBF improved to approximately 17,000 miles in January exceeding SFMTA's projection. The daily availability of LRV4s for revenue service has also been steadily rising at a rate that is matching or exceeding SFMTA's projections. This growth is shown graphically in Exhibit 23.

To put the MDBF into perspective other transit properties in the west have been surveyed about their MDBF requirements or achievement. The MDBF varies between 9,000 and 43,000 miles which may be a result of differing definitions of chargeable failure and actual operating environments. The contractual requirement of 25,000 miles is aggressive but is based strictly on mechanical failures that are under Siemens purview. If it is not achieved, SFMTA will have increased maintenance costs and reduced number of LRVs in revenue service, thus impacting riders. The contract with Siemens does not have specific damages for not achieving the MDBF requirement but SFMTA is holding up to $12.9 million in contract retention under the current $344 million phase 1 contract authorization through contract modification 6, until the LRV4s meet reliability (MDBF) requirement. This retention represents 3.75 percent of the phase 1 contract value.

Key issues that need to be resolved to allow achievement of the reliability goals will be track brakes (representing a potentially significant reduction in maintenance time) and the renewed failure of the couplers that have caused early metal fatigue and failure of the shear pins. The installation of additional track brakes is well underway and should be completed in March. The couplers and shear pin issue is being analyze and temporary warranty fixes are in place allowing two-car trains to operate a final solution has not been validated and early estimates to start repairs are June 2020.

The availability of spare parts has become a growing issue. The number and type of spare parts required in the contract was developed by SFMTA and included in the procurement documents. This part listing, however, was fairly general and was developed without experience with the Siemens vehicles. The requirement should be revisited based on the current experience of SFMTA. The intent is to develop a more specific spare parts plan, listing what is needed to avoid ordering too many spare parts or large assemblies when only specific parts may be needed on a routine basis.

The contract with Siemens calls for them to make warranty repairs at their expense including providing parts. Parts for warranty repairs are to be available at a Siemens' facility in San Francisco. In practice however it appears that warranty repair parts were taken from the assembly line in Sacramento if not otherwise available. This worked well during the early stages of assembly when parts were available but as the assembly process came to an end parts were not readily available. Siemens then utilized a practice of borrowing parts from an LRV that has not been commissioned to make warranty repairs. This practice is common in the transit industry where parts are taken from a vehicle under repair to keep other vehicles in service, it is however not common for parts to be taken from vehicles that are essentially complete and awaiting final commissioning. We are recommending this practice be changed for subsequent phases of work and dedicated warranty parts be warehoused in San Francisco.

SFMTA is eager to continue the fleet replacement program with the issuance of a Notice to Proceed (NTP) for the Phase 2 LRVs in March or April. Care should be taken that the NTP addresses all the retrofits made to the Phase 1 LRVs and incorporates planned upgrades and lessons learned from the Phase 1 procurement. Most important is the resolution of the coupler problem and assuring commercial terms are modified for Phase 2 to better assure vehicle performance and availability.

These issues are summarized in the following table.

| Issue | Repair Solution | Cost/Responsibility | Timeline |
|---|---|---|---|
| 1-LRV Availability | 65 of 68 LRV4s commissioned. Daily availability of LRV4s in January was 43 | Siemens | Commissioning of final 3 LRV4s scheduled for Spring/Summer |
| 2-Mean Distance Between Failure (MDBF) | The aggressive 25,000 mile requirement has not been met but is increasing from 4,000 miles in July to 17,000 miles in January | Siemens | SFMTA projects 25,000 miles to be achieved in June 2020 |
| 3-Wheel Flats | Phase 1 LRV4s being retrofitted with additional set of track brakes | $1.75 M at SFMTA cost | March 2020 |
| 4-Door Safeguards | Additional sensitive edges added to doors. | Warranty repair | Complete |
| 5-Couplers | Second round of investigation and testing is underway. Temporary fix (shear pin replacements) in place | Warranty repair | Testing and analysis to be completed in February, with repairs starting in June |
| 6-Pantographs | Electrical shunts added and nuts/bolts replaced | Warranty repair | Complete |
| 7- Aux. Power Supply | Brackets modified | Warranty repair | Complete |
| 8-Cameras | SFMTA evaluating camera and monitor size and type | $1.6M at SFMTA cost for upgrade (estimate) | Study underway. Timing for upgrade to be determined |
| 9-Spare Parts | Improved estimates of spare parts inventory. SFMTA and Siemens to prepare updated spare parts plan | SFMTA/Siemens | September |
| 10-Hydraulic Power Unit | Motor-driver boards, wiring and control valves have been reengineered | Warranty repair | Complete |
| 11-Seating | Revised seating style and height have been identified and change orders have and are being issued | $20.2 M at SFMTA cost for upgrade (estimate) | To be determined |

## Section 1. Introduction

SFCTA retained T. Y. Lin International in August 2019 to conduct program management oversight for the San Francisco Municipal Transportation Agency's (SFMTA's) Siemens Light Rail Vehicle (LRV) repairs. The oversight was intended to consider potential causes and mitigations to the range of issues including coupler shear pin failures, door opening and closing issues, and wheel flats identified during the Summer of 2019.

The T.Y. Lin International staff reviewed a substantial amount of available background material including contract documents, root cause analyses, testing and commissioning plans and reports and documentation regarding repair progress. They conducted a multi-day investigation of the current state of repairs during September 2019 in conjunction with SFMTA. A report was issued in October summarizing the issues being addressed by SFMTA and Siemens, the root cause analysis that had been previously performed for the failures and the status of repairs/modifications. Root cause analysis is an integral part of the quality process. It is a structured approach to identify the cause for a failure by looking at a range of potential causes, evaluating if they are causes or symptoms. Only when the primary cause is determined are potential fixes evaluated and implemented. The process then evaluates and monitors the fix to validate the recommended modification truly addresses the failure.

This report updates and expands on the October report giving the status of what issues have been addressed, the status of repairs at the end of January 2020 and whether the issue and repair are considered a warranty item with Siemens responsible for the cost or if the repair is considered a change or upgrade to the contract requirements with SFMTA responsible for the cost. This report also addresses additional items including spare parts availability and planned upgrades to the seating and camera/monitors. The impact of the ongoing repairs is then presented in terms of vehicle availability and Mean Distance Between Failures. Finally, recommendations are made to modify the Phase 2 procurement to incorporate the lessons learned during the start-up of the Phase 1 program.

## Section 2. Auxiliary Power Supply

**Description**

The Auxiliary Power Supply (APS) line choke compartment is located on the roof of the car and is simply a covered box within which the APS unit resides [*Exhibit 1*]. The compartment is not intended to be waterproof but is drained so as to not hold rainwater.

During the rainy season, there were a number of failures attributed to water being captured in the compartment and not draining. Water is permitted by design to enter this compartment, however without adequate drainage localized arcing occurred in the APS unit.

This impacts auxiliary power which does not directly impact safety but causes LRVs to be taken out of service thus impacting service for riders, increasing maintenance costs and impacting the MDBF.

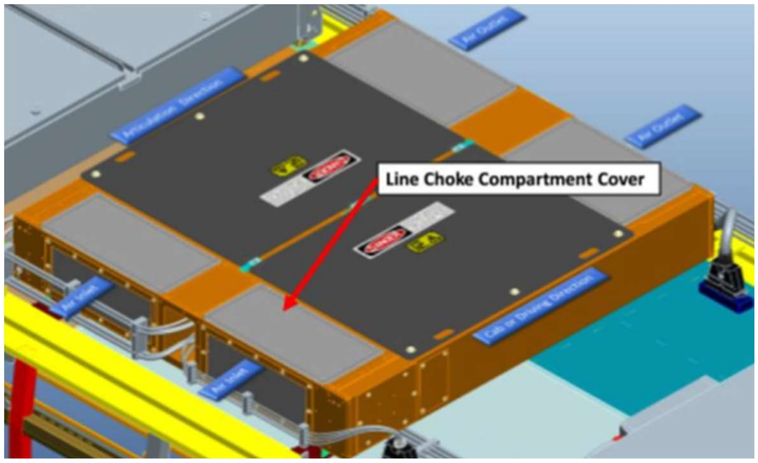



*Exhibit 1 - Schematic of Car Roof*

**Root Cause**
The root cause was determined to be the mounting of the APS unit. The APS unit brackets placed the bottom of the APS unit at approximately the same plane as the bottom of the compartment [*Exhibit 2*]. Therefore, water would accumulate in the compartment and not be able to get under/past the APS unit to the drain, splash into the APS and arcing would occur. The water volume, although minimal, was enough that during car movements the water would splash into the APS unit and the APS unit would fail. Note that the APS unit requires air circulation for cooling and is therefore not sealed from water.

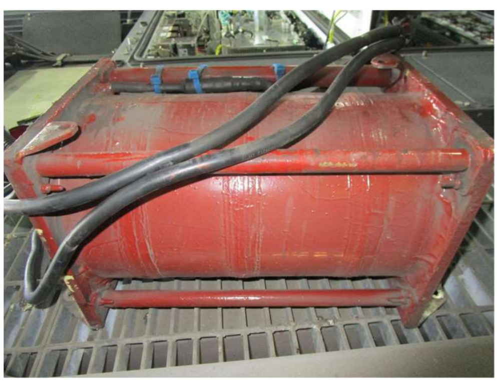


*Exhibit 2 - Old Design – Brackets at same plane as bottom of APS*

*Exhibit 3 – New Design – Brackets extend below bottom of APS for drainage clearance*

**Solution**
In order to provide clearance for water to be drained underneath the APS, the mounting ears that were integral to the APS frame were removed and new brackets were designed and attached to the APS frame that slightly raised the APS off the floor of the APS line choke compartment [*Exhibits 3 and 4*]. The compartment provides for the additional APS height and the cover and car clearance are not impacted.

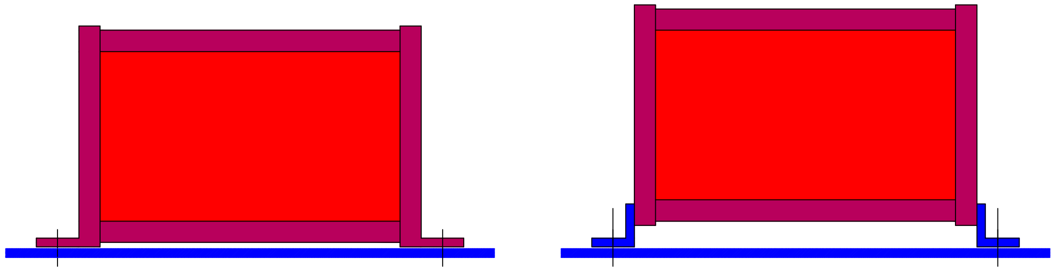


*Exhibit 4 – Old design on the left with ears integral to the frame. New design with mounting brackets separate from the frame raising the APS unit above the compartment floor for drainage clearance*

**Status**
Once the root cause had been identified, washers were placed between the APS mounting frame ears and the compartment floors as a temporary fix to provide clearance for drainage on 100% of the cars. The permanent solution, which has been installed on all phase 1 LRV4s, is the new raised mounting brackets.

New APS units with brackets were provided and installed by Siemens under warranty at no cost to SFMTA. Exhibit 5 shows Siemens installing a new APS unit on one of the LRV4s.

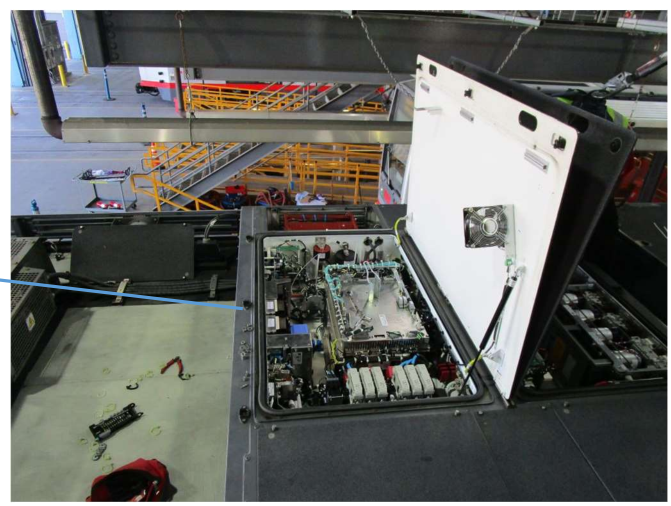



*Exhibit 5 – Installation of new APS unit in process*

# Section 3. Pantograph

**Description**
The pantograph is located on the top of the car and collects power from the catenary and transmits the energy to the car and the traction motors. The design of the pantograph is such that the entire assembly is energized. Insulators or isolators between the pantograph and car roof protect the car from being energized.

A pantograph has a graphite contact shoe or slide plate in the collector or pan head that contacts the catenary current wire. The graphite conducts the power and serves as a lubricant to the catenary. It is also brittle and is the wear piece on the pantograph.

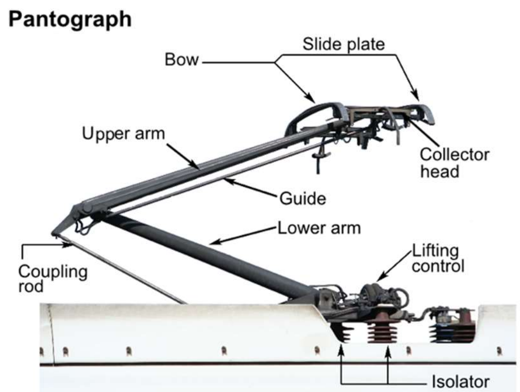



*Exhibit 6 – ICE Train Pantograph [note LRV4 cars use two double slide plates]*

The failure occurred when energy moved through the slide plate mounting bolts that were installed using Nylock nuts. The nylon on the nuts failed because they overheated from the current, which resulted in a slide plate partially separating from the pantograph frame. Because the car was in a tunnel and the pantograph collector head was only two feet above the car roof, the slide plate touched the roof of the car causing a fault.

This could impact safety and maintenance costs by potentially damaging the LRV and overhead catenary. When a failure occurs the LRV must be taken out of service thus impacting service to riders, increasing maintenance costs and impacting vehicle availability and MDBF.

**Root Cause**
There were two root causes for this fault. First, hardware such as the Nylock nuts should not have been used in this application because the pantograph is fully charged. Second, in this application, the current should not be going through hardware but through shunts. Shunts are devices such as cables that provide a low resistance path for electric current.

*Exhibit 7 – Nylock Nuts shown on left, Nordlock Washers shown on right*

**Solution**
Although there was only one such failure in the system, because of the severity of the failure and the potential to damage not only a car but also the catenary, all Nylock nuts on the pantographs were replaced with metal Nordlock washers and standard nuts. Also, eight (8) shunts were installed on each pair of collector heads to direct the path of the current from the graphite collectors and blocks through the shunts to the pantograph arms, thereby moving the current around the mounting hardware.

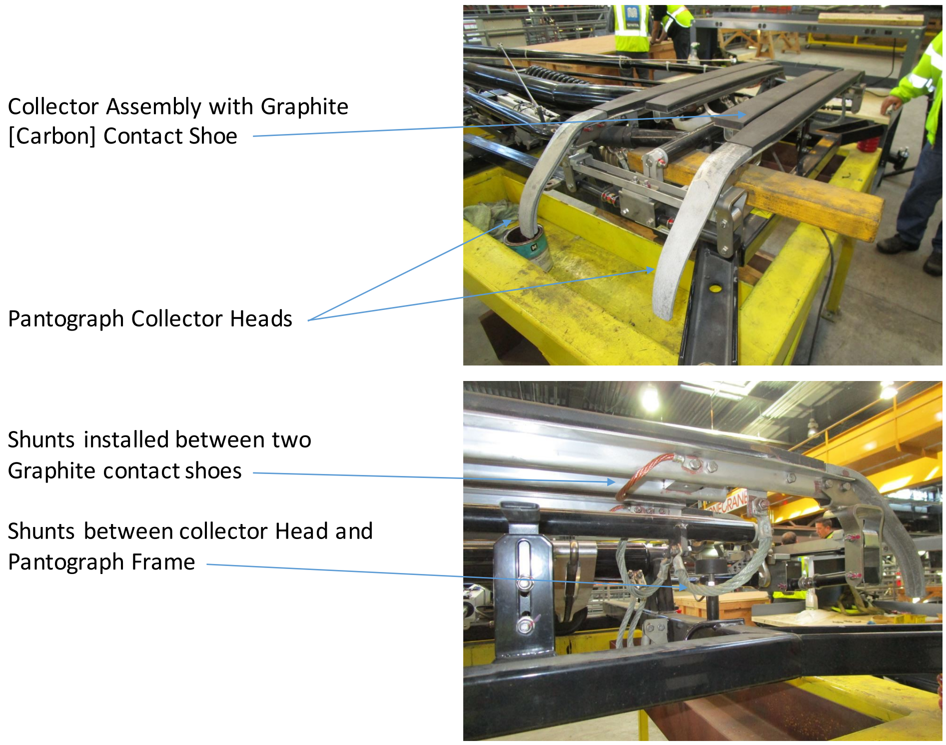



*Exhibit 8 – Collector Assembly with Shunts and Nordlock Washers installed*

**Status**
The solution has been tested and approved by the Safety and Security Subcommittee including CPUC. All pantographs have since been modified, as a Siemens warranty repair, and the issue is closed.

## Section 4. Door Sensitive Edges

**Description**
The passenger front and rear doors on the LRV4s are single leaf and plug type. They open by first moving straight out, away from the car body, and then slide open to the side of the door frame on the outside of the car body. They close in reverse to how they open.

In the original design there was one sensitive edge strip installed on the door frame that is attached to the car body [*Exhibit 11*]. The strip was the full height of the door. When touched by an object or person when the door is closing, the pressure on the strip signals to door to stop and reverse back to the open position.

Multiple events have been recorded where the end doors failed to retract when encountering something in the doorway. No pressure had apparently been detected by the sensitive edge strip to reverse the operation of the door. This can pose a safety issue and potential delays during service when an operator must manually clear an obstruction and close the affected door. During the repair period rear doors were locked closed thus delaying the boarding process and potentially impacting the ability to maintain schedules.

**Root Cause**
The door design with only one sensitive edge strip left a gap at the interlock point when the door closes where an object or hand could be pinched. [*Exhibits 9 & 11*].

*Exhibit 9 – Fingers shown on door pinch point*

**Solution**
It was determined that if additional sensitive edge strips were incorporated both in the gap where the pinch point existed and on the edge of the door [*Exhibits 10 & 12*], any object in the path of a closing door would be detected and reverse the door's operation.

The driver's control panel on the LRV4s shows the specific door that is being obstructed and the car's cameras allow the driver to see the obstruction. If the driver cannot see an obstruction via the cameras, as part of the existing procedure the driver will go to the door to see if an object is triggering the sensitive edge strips to reverse the door. If there is no obstruction and the door continues to reverse each time it closes, the driver will place the door out of service and continue on the route. The door would be checked at the end of the day during inspection at the MUNI Maintenance East facility (MME).

Note that sensitive edge strips by design have a flexible surface to allow any pressure on the surface to trigger contact between the conductive ribbons inside the strip. The strips that were specified for the LRV4s proved to be robust for the service during testing. Only one strip failed after it was purposely hit with a metal object.


*Exhibit 10 – Detail of Sensitive Edge Modification*

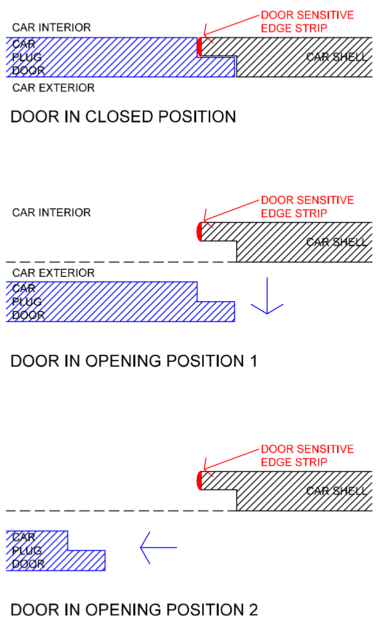



*Exhibit 11 – Sketch of Original Door Design*

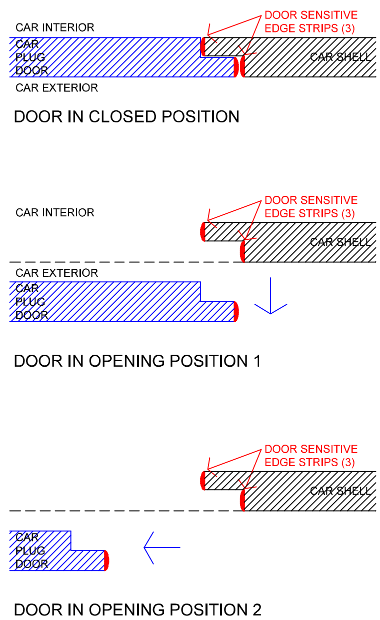



*Exhibit 12 – Sketch of Modified Door Design*

**Status**

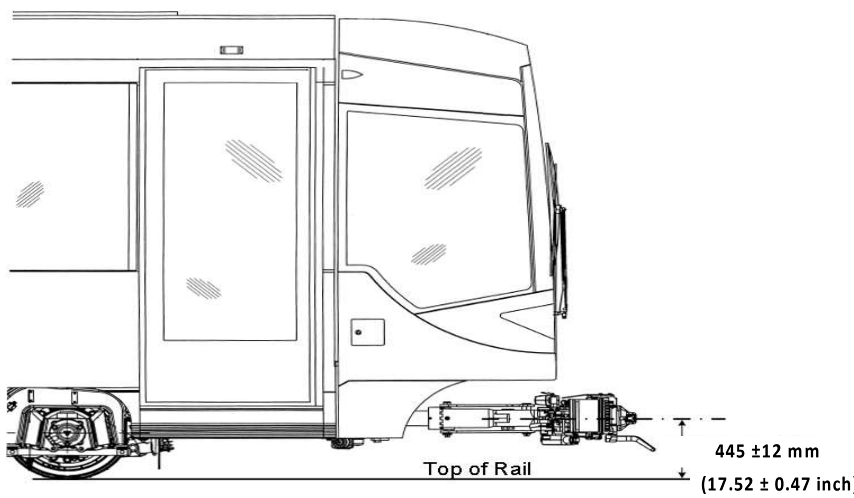
All cars have now been modified with the three-strip approach as a Siemens warranty item. The fix was monitored and approved by the SFMTA Safety and Security Committee. This committee has been directly involved with overseeing the vehicle commissioning process and includes representatives from multiple SFMTA departments. The California Public Utilities Commission (CPUC) also participates in these committee meetings where the fixes are reviewed and approved through the safety certification process. The issue is now closed.

# Section 5. Coupler

**Description**
The coupler assembly is designed such that the coupler face is always at the same height on the carshell. Coupler height adjustments are not required. When wheels are trued [cut] the coupler center will be lower than the required ~17.5 inches above Top of Rail. This is corrected when the wheels are reattached to the bogies and then to the carbody by means of a shimming system between the carbody and the bogie, not by adjusting the coupler. Shimming is done due to changes in wheel height to meet the required 17.5-inch clearance. Further adjustments over time due to wheel wear are accomplished with an adjusting screw (see exhibit 15). Note that this shimming also corrects the height of the car floor and steps so that the steps and door match the required heights at the platforms.

There are adjustment bolts for the coupler inclination. The coupler must be level to the track to perform properly. Exhibit 13 shows the maintenance instruction for adjusting the couplers.

2.5 Coupler Adjustments




| | | A-Cab | B-Cab |
|---|---|---|---|
| Note: | Use VOITH *User Manual- Scharfenberg Coupler 330.470_Draft.pdf.* | | |
| Action: | Perform section 5.12 Checking and adjusting the projection of the electric heads. | | |
| Result: | Electric heads are properly adjusted per section 5.12. | _____ | _____ |
| Action: | Perform section 5.13 Adjusting the inclination of the coupler (Vertical). | | |
| Result: | Coupler vertical adjustment performed per section 5.13 and graphic above. Height is 445 ± 12 mm (17.52 ± 0.47 inch) above top of rail. RAV | _____ | _____ |
| | Coupler vertical height is parallel to top of rail with the smallest inclination angle of -0.5 degrees and the largest inclination angle of 0 degrees. | _____ | _____ |
| Note: | Account for wheel wear when measuring vertical height. | | |
| Action: | Perform section 5.14 Centering of the coupler (Horizontal). Coupler horizontal adjustment performed per section 5.14. | _____ | _____ |

*Exhibit 13 – SII-MTA-1021A SMI-OSAT-SFMTA Mechanical Adjustment Rev 1_3, Pg. 9*

This is a safety issue that could in an extreme event could allow 2-car trains to separate, although should this rare event occur, other parts would immediately stop each car. During the interim fix only single car trains were operated thus reducing capacity for riders in addition to impacting maintenance cost and indirectly MDBF by reducing the number of miles traveled by each car.

When a two car consist was going through the Judah/La Playa/Ocean Beach turnaround in April 2019, the shear pin on the paired couplers broke. The shear pins (two per coupler) are designed to break when forces exceeding allowable limits occur, such as in a collision, and are intended to be a sacrificial element to both protect the rest of the car and allow the couplers to fold into the car thereby placing the anti-climbers, located on the face of the car above the couplers, in a position to stop the obstruction the car hit from climbing up and into the car driver/passenger compartment.

**Root Cause**

A root cause analysis of the failure was performed by Siemens and SFMTA when the issue surfaced. Several parts were damaged as a result of this incident, but because the cars had not hit any obstruction, the root cause could not be determined without further evaluation of all components within the assembly that were damaged as well as revisiting the assembly design and design parameters. Therefore, the shear pins, bearing housing, lateral stops, support springs, bearing brackets and other components were all inspected and tested including metallurgical testing of the shear pins. The track alignment design parameters were also all checked to determine if the coupler assembly design for maximum coupler horizontal swing angle had been exceeded. The testing and studies determined that all components performed as designed and that the maximum horizontal swing angle of the coupler could not be exceeded on the SFMTA track alignment including at all turnarounds. This indicated the shear pins should not have failed, due to sharp curves, within the SFMTA operating parameters.

The only unusual variable that appeared in the inspections is that the lateral stop bracket, which limits the coupler horizontal swing during maintenance had been damaged and partially detached [*Exh. 14*]

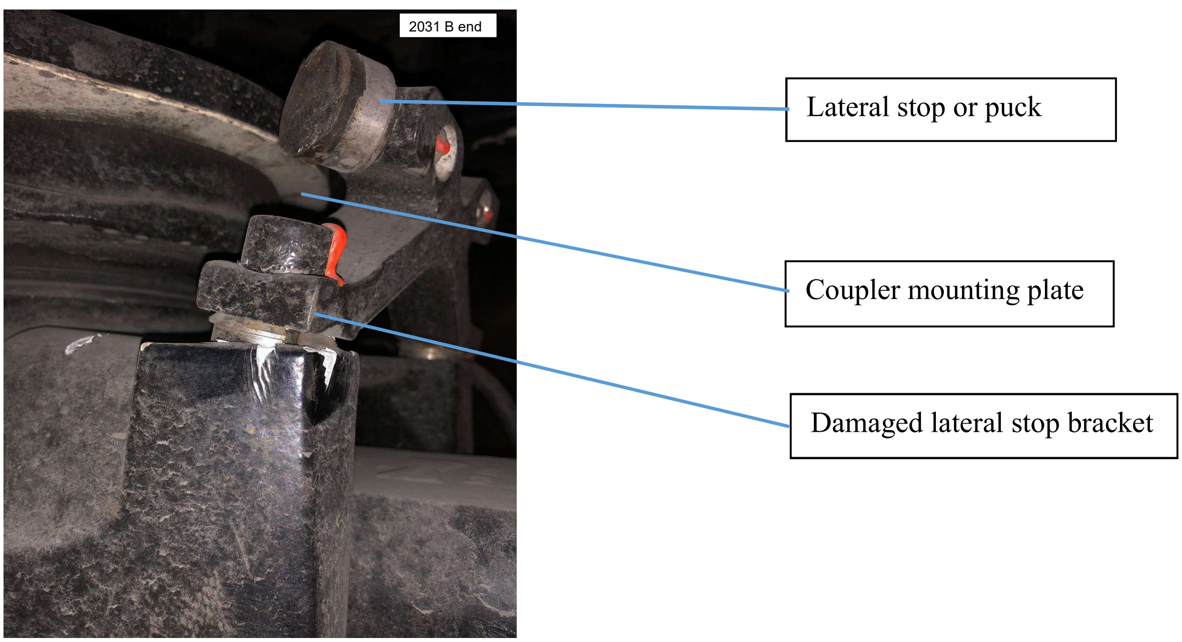



*Exhibit 14 – Lateral Stop and Upper Clam Shell Damage*

Exhibit 14 also shows that the rubber piece on the stop, which is called a puck, is larger than the lateral stop bracket and is at the height of the coupler mounting plate. Note also that the coupler mounting plate, which is part of the car not the coupler, extends beyond the coupler assembly, which mounts to the plate.

Testing revealed that when a coupler assembly with an undamaged lateral stop bracket is pushed to the maximum horizontal limit, the stop engages the clamshell and swings approximately 2 mm under the coupler mounting plate as designed. Testing also revealed that if the lateral stop bracket puck hit the coupler mounting plate, it would do so within the maximum horizontal swing limits of the coupler. Therefore, it was determined that the cause for the shear bolts to break was the coupler swing was impeded by the stop bracket puck hitting the coupler mounting plate.

Further investigation into the engineering of the stop bracket mounting determined that the mounting bolt for the lateral stop bracket and the adjusting bolts for the coupler inclination occupied the same hole. If the coupler adjustment bolt was over tightened, compressing the rubber vertical support, the bolt would push the mounting bolt for the stop bracket out. With only 2mm clearance available between the puck and the coupler mounting plate, this was determined to be the root cause for the failure of the coupler.

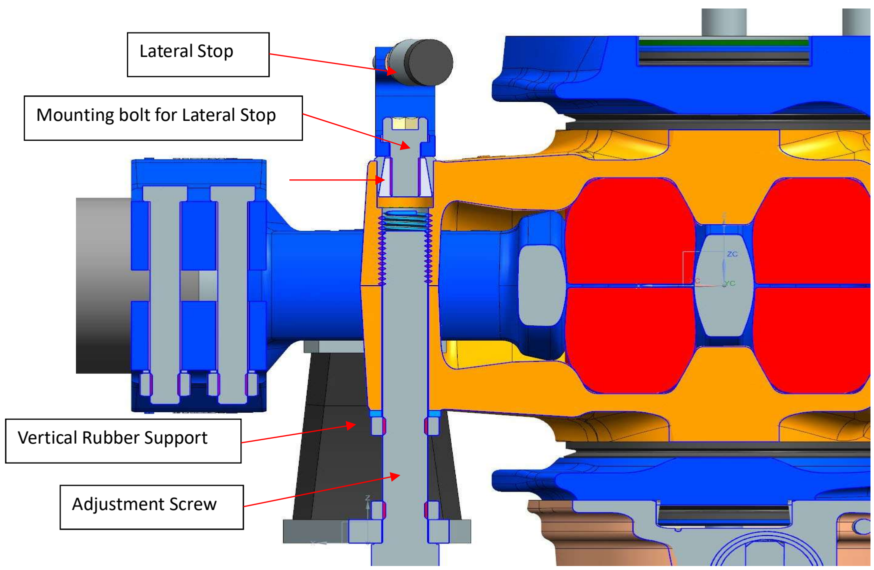



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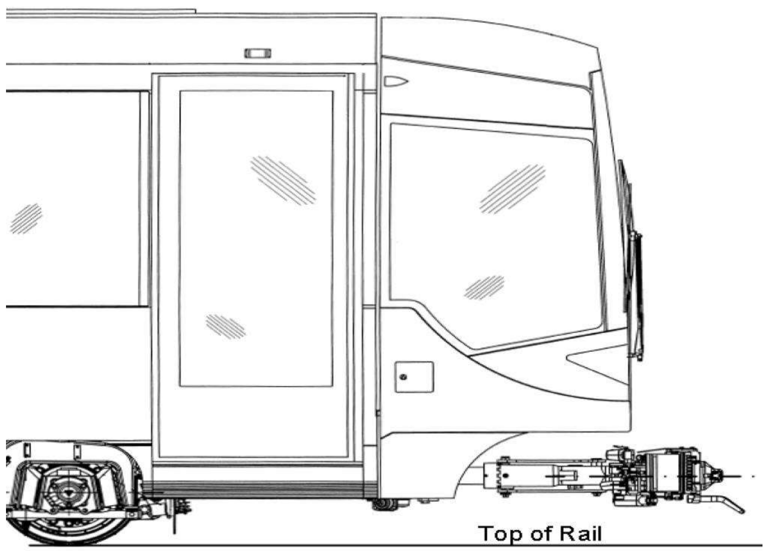
*Exhibit 15 – Cross Section through Coupler Bearing Housing*




| | | A-Cab | B-Cab |
|---|---|---|---|
| Note: | Use VOITH *User Manual- Scharfenberg Coupler 330.470V1.pdf.* | | |
| Action: | Perform section 5.12 Checking and adjusting the projection of the electric heads. | | |
| Result: | Electric heads are properly adjusted per section 5.12. | _____ | _____ |
| Action: | Perform section 5.13 Adjusting the inclination of the coupler (Vertical). | | |
| Result: | Coupler is parallel to the track with the smallest inclination angle of -0.5 degrees and the largest inclination angle of 0 degrees. | _____ | _____ |
| Action: | Perform section 5.14 Centering of the coupler (Horizontal). | | |
| Result: | Coupler horizontal adjustment performed per section 5.14. | _____ | _____ |

*Exhibit 16 - SII-MTA-1090A SMI-OSAT-SFMTA Mechanical Adjustment Rev 1_6, Pg 9*

**Solution**

First it was determined that the maintenance instruction suggested that the height on the coupler needed to be adjusted. The only method available to the maintenance worker to adjust the coupler height was the adjustment screw for coupler inclination. Unfortunately, the screw was being over tightened. This necessitated a revision to the maintenance instructions [*Exhibit 16*] where the instructions did not require the coupler height to be adjusted or provide a coupler height requirement and reference instructions to adjust the coupler height.

Second, the 2mm clearance between the lateral stop bracket puck and the coupler mounting plate was deemed insufficient. Therefore, because the stop bracket is only a bump stop to keep the coupler from damaging car underframe parts when a maintenance worker swings the coupler out of the way for servicing the car, a smaller diameter replacement puck that would not extend beyond the height of the lateral stop bracket would be adequate [*Exhibit 17*]. This would increase the clearance between the puck and the mounting plate to 7mm.

*Exhibit 17 – Lateral Stop Bracket Puck Extends 5MM above Bracket*

Third, in order to prevent the adjustment screw from being over tightened due to, for example, not coupler height but wear of the rubber support, a sleeve spacer was installed on the Adjustment Screw to prevent the Adjustment Screw from being tightened such that it engages and pushes the mounting bolt for the lateral stop out of the clamshell [*Exhibit 18*].

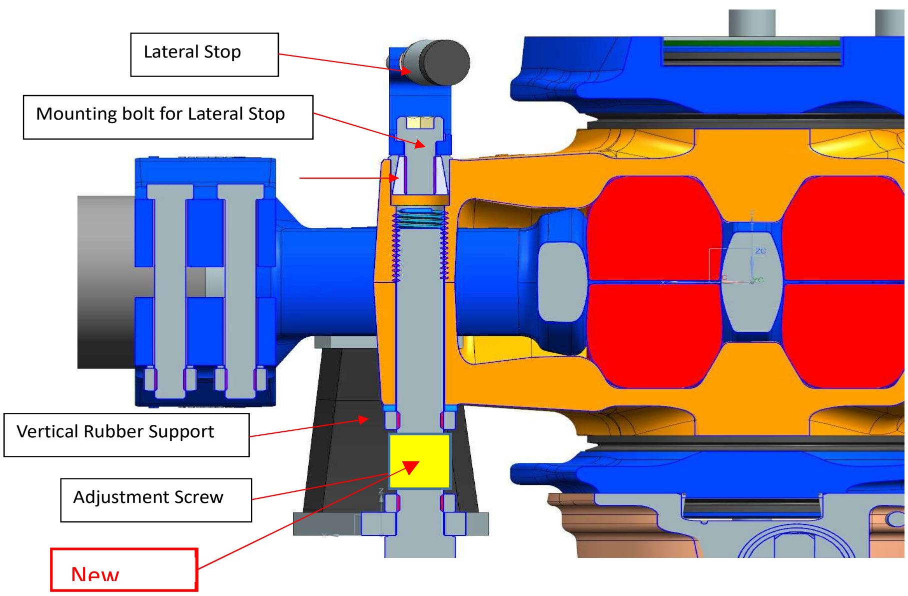



*Exhibit 18 – Cross Section through Coupler Bearing Housing with Proposed Sleeve*

**Status**

Although there was only one failure, a total of 31 of 116 couplers showed signs of contact at the lateral stop and damage to the upper clam shell. All coupler assemblies have now been inspected and damaged parts replaced. And all shear pins and support springs have been replaced. A new smaller puck design and sleeve was installed and tested on a LRV4 and a Field Modification Instruction

(FMI) was developed, and a field modification on all LRV4s was initiated This work was completed as a warranty repair by Siemens and was expected to fully address the coupler issue.

In December 2019 the coupler issue reoccurred. An operator noticed an unusual circumstance similar to being rear-ended. The passengers were off-loaded, and the two-car train was taken out of service and thoroughly inspected in the yard. Inspection revealed broken shear pins in both cars and Siemens was notified immediately. The Siemens' project team elevated the issue within their organization and to the CEO level of the coupler supplier, Voith Turbo Inc. One-car trains were then run until shear pins could be replaced.

Siemens and Voith have identified some potential causes of the new failure and potential design solutions to the unusual metal fatigue issue. They have fully instrumented LRV4s to validate their assumptions and tested the train on multiple locations within the SFMTA system. A formal report including recommended corrective actions is expected to be available by the end of February. Voith committed to recommending a corrective design ready for validation by March 12, 2020. Assuming successful validation materials they committed to having parts shipped and ready for installation on the entire LRV4 fleet by June 12, 2020.

Based on the current circumstances both a short term and long-term validation are being recommended. The long-term validation will include regular shear pin condition assessments over at least a 12-month period. During the interim Siemens has issued a letter to SFMTA indicating the new shear pins (same design as originally provided) can operate in coupled cars for at least 90 days. Siemens and Voith have agreed to provide all additional shear pins as required as a warranty item at no cost to SFMTA.

SFCTA staff and consultants will participate in reviews of the design alternatives, validation of data and proposed retrofits. Additionally, the SFMTA Safety Committee including a CPUC representative will need to approve the changes as part of an updated Safety Certification. Analysis and repairs are being completed as a warranty item with Siemens and its supplier responsible for all costs

## Section 6. Wheel Flat Spots

**Description**

Flat spotting of wheels occurs when the wheels lock or stop rotating and are dragged during braking until the car stops. This can be the result of either emergency braking or a slippery track. The friction between the rail and wheels while the wheels are locked creates localized heating, which changes the alloy structure of the wheels and results in premature wear. Flat spots can be removed by wheel truing. This places additional stress on the cutters of the wheel truing machine and the cutters typically need to be replaced after cutting a single flat spot wheel. Cutting carbide tips typically last through numerous cutting operations on non-flat spot wheels. Note that flat spots in extreme cases, left untreated can damage rails and cause a derailment.

The old Breda cars and the new Siemens LRV4 cars have similarly positioned braking controls although the effects of the controls are slightly different. The 'T' handle controller on both cars accelerates and stops the cars [*Exhibit 19*]. For an emergency stop the Breda 'T' handle is pulled straight back and twisted 90 degrees. The Siemens 'T' handle is just pulled straight back but not twisted.

*Exhibit 19 – LRV4 ‘T’ Handle in 90 Degree Off Position*


*Exhibit 20 – LRV4 Emergency Red Stop Button*

The emergency stop button (referred to as the “mushroom”) on both cars is in the same position and when hit, puts the car into emergency stop mode [*Exhibit 20*]

Wheel flats are not a safety issue, but increase maintenance costs and reduce vehicle availability. The braking system on the LRV4s includes three components: dynamic brakes, friction brakes and track brakes. The vehicles were thoroughly tested under varying load, alignment and weather conditions in San Francisco with the originally specified brake configuration prior to final safety certification and commissioning. The additional track brakes are not required to meet the contractual braking requirements but will reduce maintenance costs and improve vehicle availability.

**Root Cause**

The first difference between the two designs has to do with reaction time of the driver. It’s simply faster to hit the emergency stop button on the Breda car than pull back and twist the ‘T’ handle. In the LRV4 design the time to pull the ‘T’ handle back or hit the emergency stop button is understood to be the same.

The second difference between the two designs is the braking. In emergency braking on the Breda cars, the wheels do not lock up. In emergency braking on the LRV4 cars using the ‘T’ handle, the wheels also do not lock up. But, in emergency braking on the LRV4 cars using the emergency stop button, the wheels do lock up causing flat wheels.

Because of an incident several years ago in a Breda car that resulted in a fatality, the drivers have all been trained when in an emergency to always hit the emergency button. Unfortunately, in the SFMTA’s operating environment, with substantial in-street running, emergency stops are a regular, sometimes daily event. Hitting the stop button has become part of the driver’s muscle memory.

In order to not flat spot the wheels on the LRV4 cars, it has been suggested to retrain the drivers to use the ‘T’ stick in emergency situations. Because drivers may operate either the Breda cars or LRV4 cars, changing the muscle memory of the drivers for the LRV4 cars is not recommended. If an emergency situation were to present itself in a Breda car where the driver’s muscle memory is attuned to the LRV4 cars, another unfortunate incident may occur.

Simply, although the cost of flat spot wheels to SFMTA is substantial, another fatality would be unacceptable.

**Solution**
The LRV4 cars are equipped with both hydraulic friction brake systems on the wheels and with electro-magnetic track brakes on the center bogie. The track brakes engage the track to stop the car.


*Exhibit 21 – LRV4 Single Car at MME*

The combination of the wheel brakes and track brakes stops an LRV4 within the required distances and speeds without damage to the LRV or track structure. This requires that additional pressure be applied by the wheel’s brakes and therein we get wheel lock. It was determined that if less pressure were applied to the wheel’s brakes, such that they would not lock up, and more pressure were applied by track brakes, such that the car would still stop within the required distances, additional track brakes would need to be installed on the end bogies. This would not damage either the LRV or track structure.

An LRV4 car has been equipped with the additional track brakes and tested on the SFMTA alignment. There were 500 emergency stops using the emergency stop button performed during the test resulting in flat spot wheels in only two stops. This compares to almost 100% of the wheels being flat spotted with the present single bogie track brakes when the emergency stop button is applied.

The total time and labor to true a single car is approximately 2.5 days. Because many of the cars operate in two car consists, when an LRV4 emergency stop button is applied, all 24 wheels are impacted, doubling the maintenance effort and cost to get the cars back in service. Note that labor costs greatly outweigh the other costs. After wheels have been trued a number of times the wheels become too small and must be replaced entirely. This process can take up to a month to complete.

**Status**
Installation is in progress (51 vehicles have been completed) and will be completed in March 2020. Funding for this upgrade is SFMTA's responsibility and was included in contract modifications 5 and 6, which were approved by the SFMTA Board in October and November. Funding for the modification was obtained due to cost savings within the existing not-to-exceed budget. The funding availability resulted from a lower cost escalation rate than was assumed in the original contract.

The overall cost including proposed contract modification 7 (to the SFMTA Board in February/March) is estimated to be $4.7 million which includes $1.75 million for phase 1, which was approved in contract modifications 5 and 6. The cost justification appears clear. When a car flat spots the wheels, all 12 wheels need to be trued, the car needs to be shimmed and the coupler inclination adjusted. The wheel life is reduced and the cutters on the wheel lathe will need to be replaced after each set of flat spot wheels are trued. Because the wheel lathe is presently in constant use due to flat spot wheels, this also impacts the machine's maintenance requirements and life cycle.

## Section 7. Hydraulic Power Unit

**Description**
The Hydraulic Power Unit assembly supports the hydraulic friction brakes on the car wheels. HPU failures are a major service availability issue as they fail in a safe mode keeping the brakes applied. The criticality of correcting this issue was significant. The high failure rate also contributed to a reduction in MDBF and vehicle availability.

**Root Cause**
Three potential root causes were identified; the motor driver board, the wiring harness and the brake control valve. Further investigation led to determining all three were part of the cause with the motor driver board being the primary factor

**Solution**
Siemens reengineered the motor driver boards, wiring harness, control valve and issued a Field Modification Instruction.

**Status**
All LRV4s have been retrofitted with the new motor driver boards, wiring harnesses and control valves. All work is covered by the Siemens warranty.

## Section 8. Cameras and Monitors

**Description**

LRV4s are equipped with cameras mounted on the outside of the vehicles that transmit video to a monitor in the cab car along with a video recorder. This is different from the existing Breda fleet which utilizes outside mirrors. Both systems are used by transit properties across the country using both exclusive and non-exclusive right of way. The dynamic envelope of the LRV4s combined with the geometrics of the track and the proximity of physical obstructions adjacent to the trackway preclude retrofitting the LRV4s with outside mirrors. The cameras also provide views from the front and rear of the train, which will be more important as SFMTA introduces longer 3-car trains.

After the approval by the SFMTA Safety and Security Committee and the CPUC, SFMTA operators expressed concerns related to being able to see if pedestrians are too close to the cars or on the yellow safety markers adjacent to the car boarding position. Concern was also expressed regarding the size of the monitor in the cab and the quality of the image, particularly when the LRV travels between light and dark areas such as when an LRV enters or exits a tunnel. The current camera system was reviewed by operators, SFMTA Safety and Training, Training Department, and CPUC staff and determined to provide acceptable views for the length of a two-car consist. The system has now been approved by the SFMTA Safety and Security Committee and the CPUC. It is therefore not considered a safety issue at this time and does not impact vehicle availability or MDBF. A demonstration program later this year is proposed for three-car consists, which will be reviewed and approved by the SFMTA Safety Committee prior to being put into service.

SFMTA staff is concerned about the issues raised by the train operators and is considering potential modification to the cameras and monitors. Staff, including operators and union representatives, is working with Siemens to evaluate potential modifications including larger cameras to expand the views and larger or multiple monitors on each side of the cab.

**Status**

This is currently a work in progress. Staff has recently visited the Siemens plant in Sacramento where they were able to observe cameras and monitors on LRVs being used by other transit properties. They have also uncovered previously unknown issues, such as an operator not being able to see objects in a proposed monitor replacement due to the polarization on their sunglasses. Staff is working towards identifying appropriate modifications during the first half of 2020, to allow incorporation into the phase 2 vehicles and retrofit of the phase 1 vehicles. Alternative monitor concepts were viewed in the SFMTA yard by a committee of program management staff, operators and union representatives in late January. A concept was agreed to and Siemens is developing a prototype that can be mounted on an LRV4 for testing later this Spring.

It is anticipated that these potential changes from the contract specifications and safety certified conditions will be an upgrade with SFMTA bearing the cost responsibility.

## Section 9. Seats

**Description**

The LRV4s are equipped with flat seats as opposed to the current Breda seats that have individual indentations. The longitudinal flat seats allow riders to slide when the LRVs start-up or stop. The seat height is also higher than the Breda cars. MUNI riders have requested, as a matter of comfort, that all LRV4 seats be replaced with seats with design and height similar to those in the Breda vehicles. This is not considered a safety issue and does not directly impact vehicle availability or MDBF.

**Status**
This change is being considered and funding ($1.57 million) was provided in contract modification 6 to initiate the design process to add depressions to the seats and adjust height. An estimated additional $18.6 million is being contemplated in future contract modification 7 to cover the cost of revised seats for both the phase 2 vehicles and retrofit of phase 1 vehicles. It is anticipated that this potential change will be an upgrade with SFMTA bearing the cost responsibility.

## Section 10. Other Items

**Description**
During the course of our oversight, several other items have been identified that may impact the availability or reliability of the LRV4 fleet. These items have not risen to the same level as the previously discussed issues. These items are being addressed by SFMTA and Siemens on an on-going basis. The items are noted below along with their status and an informational item.

- CCTV Failure – The CCTV have intermittently failed to record data. This appears to be a software integration problem. Siemens is currently testing a software modification to resolve the issue of communication between the vehicle and the SFMTA specified camera system.
- Door Adjustments – Siemens has adjusted the doors on five test vehicles to reduce opening/closing issues. These are currently being tested and no issues have been observed. If the testing is completed without issues the remaining LRV4 fleet will have their doors adjusted and the SFMTA mechanics will be trained not to make additional adjustments as they are required to do on the existing Breda fleet.
- Brake Control Unit – Several LRV4s have experience brake locking that may be caused by the brake control unit. SFMTA and Siemens are currently evaluating these incidents to determine if they are unique events or a potential fleet failure issue. This analysis and any required repairs will be completed as warranty items by Siemens.

## Section 11. Mean Distance Between Failures

**Description**
The Mean Distance Between Failures (MDBF) is a means to evaluate the effectiveness of a transit property's maintenance practices over time. With new vehicles it can also be a means of tracking manufacturing quality.

The MDBF calculations depend on two factors, mileage traveled and recorded failures. Siemens is contractually required to provide an MDBF of 25,000 miles. And yet, the MDBF for the LRV4s at the start of service was approximately 5,000 miles. By January 2020 the MDBF had improved to approximately 17,000 miles [*Exhibit 22*]. By comparison, the current Breda fleet had an MDBF of 3,300 in FY 2003, which dropped to under 2,000 miles in FY 2005. Ultimately the MDBF increased to a high of 5,500 miles in FY 2006. The calculation of MDBF for the existing Breda fleet is based on a different assumption regarding chargeable failures. The Breda calculation includes many non-mechanical failures including (train control, operator caused, customer caused) that are beyond the control of Siemens and therefore not included in the LRV4 MDBF calculation requirements.

The MDBF trend for the LRV4s is calculated on a monthly basis by Siemens and reviewed by SFMTA staff and their Failure Management Board. This information is reviewed to identify trends and any particular causes for changes. For example, the MDBF was positive at the end of 2018, but in February of 2019 then took a negative hit for the APS faults. It was the rainy season and a number of APS units failed from excess water in the APS Line Choke Compartment. This also impacted availability and mileage as all car APS units needed to be modified with the temporary solution. Once corrected the trend was again positive. In May the MDBF took another negative hit for both the couplers and the doors. And even though there was only one recorded failure for each, the repairs were required on all cars, which impacted availability and mileage. The continued flat spotting of the wheels is not considered a failure, but it does impact MDBF in that it impacts the availability and mileage put on the LRV4 cars.

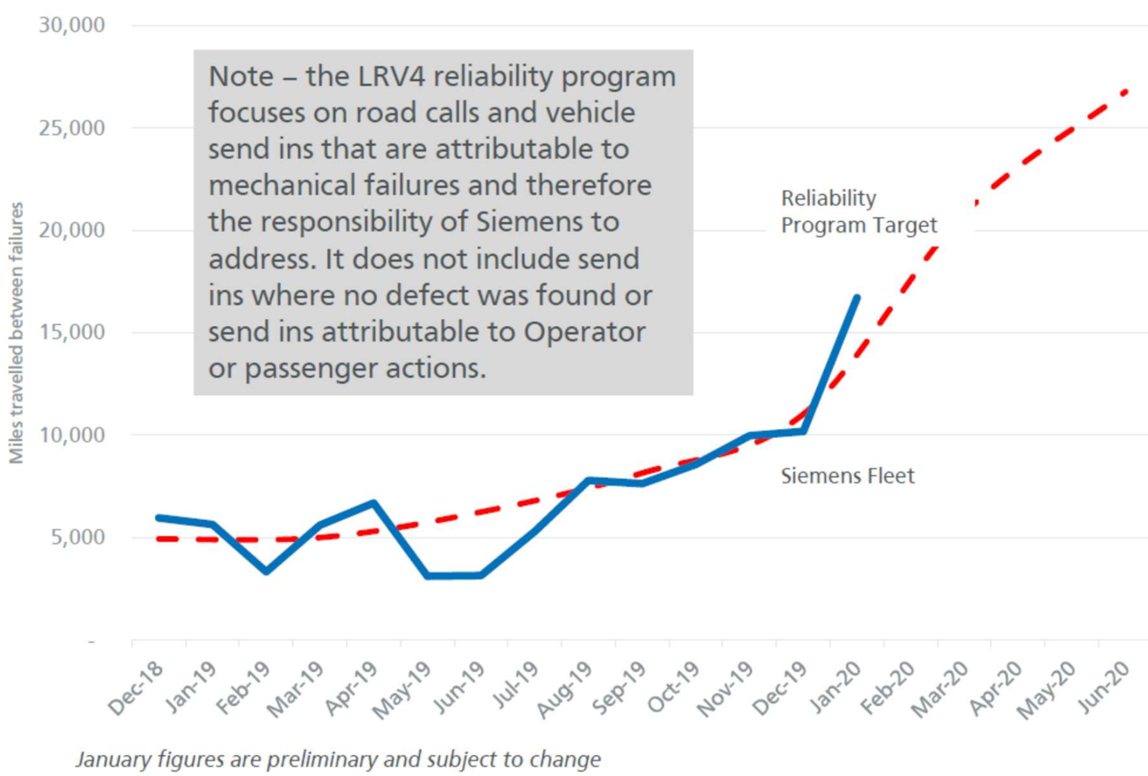



*Exhibit 22 - LRV4 Projected MDBTF*

The MDBF improvement also contributes to the increased availability of LRV4s for revenue service. Exhibit 23 shows the daily availability of LRV4s over time. This accounts for delivery of vehicles and availability due to planned and unplanned maintenance activities.

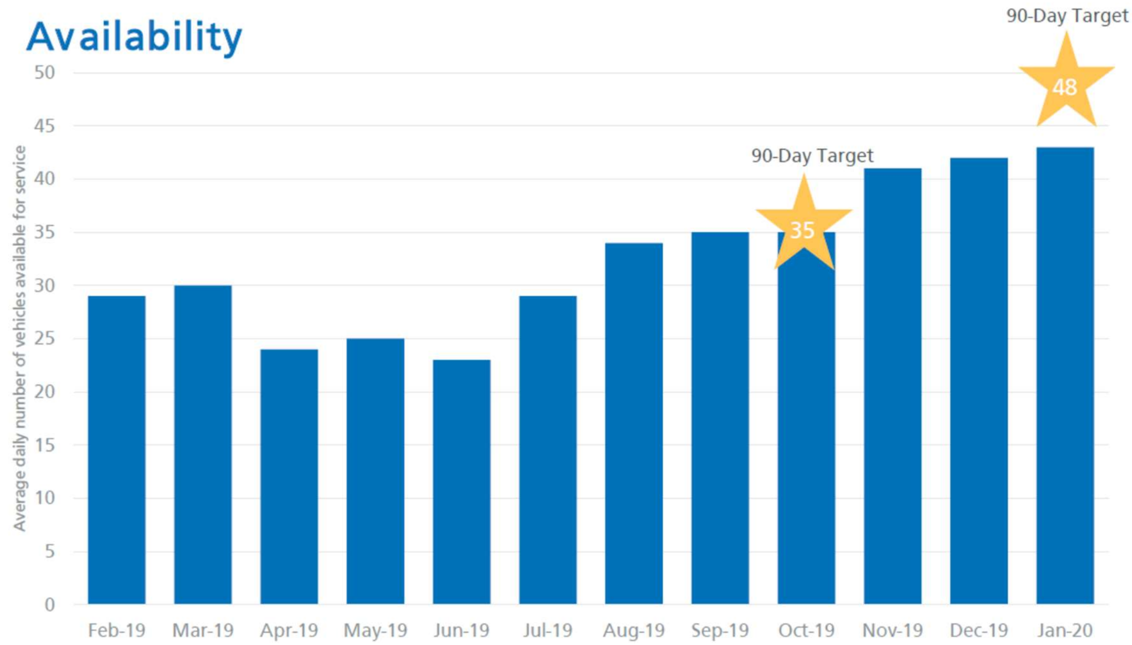



*Exhibit 23 – LRV4 Daily Availability*

The contract with Siemens specifies the allowable mean distance or times between failures by system type and then summarizes this by requiring Siemens to demonstrate the combination of all systems failure modes to result in Mean Distance Between Train Delays of 25,000 miles (contract volume 2, section 2.8.1)

This is clearly a contractual requirement, however, some people have expressed concerns that it may not be achievable. While each transit property collects data differently and operates under different operational conditions it is useful to see what other transit properties use to benchmark their systems.

The following table notes the MDBF, either actual or planned for various light rail systems.

| Transit Property | MDBF | Actual or Planned | Source |
|---|---|---|---|
| Sound Transit, Seattle WA | 20,000 | Planned | Design Criteria Manual, Rev 5, 2018 |
| TriMet, Portland OR | 12,000 | Actual | 2018 quarterly performance report |
| Santa Clara VTA | 25,000<br>43,951 | Planned<br>2019 Actual | FY 20/21 Adopted Biennial Budget |
| Los Angeles Metro | 20,000 | Operational Target | Personal communication |
| San Diego MTS | 9,239 | 2018 Actual | FY 2016-2018 Triennial Performance Audit of MTS |
| Houston Metro | 20,027 | FY 2018 Actual | 2018 Monthly performance report |

The above table represents a range of transit environments and importantly different definitions of chargeable incidents. The Siemens contract requirement of 25,000 miles is based strictly on mechanical failures and not other types of failures (train control system, operator caused, customer caused) that SFMTA includes in their own MDBF calculations for the existing Breda fleet.

The contract with Siemens identifies the MDBF requirement, as a means of determining expected quality. There, however, does not appear to be any time frame for achieving this. The monetary incentive for Siemens is the contract closeout when SFMTA releases the final contract payment including up to $12.9 million in contract retention. If the MDBF requirement is not met, SFMTA will be performing more frequent maintenance resulting in higher labor and parts costs than if the LRV4s met the 25,000-mile MDBF specification. Failing to meet the MDBF requirement may also reduce the vehicle availability potentially impacting ridership. SFMTA should consider tightening this requirement as they move forward with the phase 2 vehicle order to add specific time frames for achieving the requirement and penalty if it is not achieved. Penalties could include retaining a greater amount of phase 2 payments if not achieved by a certain time. Alternatively, SFCTA would withhold all or a portion of the phase 2 funding until the requirement is met.

## Section 12. Spare Parts

**Description**
The LRV4s have experienced a notable shortage of spare parts. During the initial phases of vehicle delivery, Siemens appeared to provide warranty parts taken directly from their assembly lines. This did not pose substantive problems until the production was reaching a close and parts from the assembly line were no longer readily available.

When parts were not readily available, Siemens utilized a common practice with transit agencies of borrowing parts from one or more vehicles that were not in service to keep more vehicles in service. This practice is similar to what is labeled "Hangar Queens" in the aircraft industry. This practice while common in the transit industry is typically found in mature fleets where parts may be borrowed from other vehicles under repair and not otherwise available for revenue service as opposed to new vehicles that are awaiting commissioning and final payment.

The contract includes a specific spare parts list. The list however was developed during the procurement period and according to SFMTA staff was very generalized since SFMTA had no experience with the Siemens vehicles and did not want to order parts that would not be needed for years causing storage problems at the Muni maintenance facility and adding to the overall program cost.

**Status**
Siemens has borrowed parts from an LRV4 that was essentially complete but had not been commissioned and was still under Siemens ownership. Over the past year as the LRV4s are being rolled out into revenue service, SFMTA is gaining a better understanding of what and how many spare parts are required to keep the entire fleet available for revenue service.

Our review of the contractual requirements suggests some refinements to the contractual approach may be appropriate to maintain an appropriately sized parts inventory and to obtain reasonably priced parts. Specifically:

1. The contract calls for large assemblies when specific parts may be more appropriate. Our experience is other transit properties have more extensive and specific spare parts

requirements in their procurement documents. Having SFMTA maintenance staff work with Siemens and their parts catalog, using the lessons learned from phase 1, to develop a more refined list of needed parts and the number of those parts to be included with the phase 2 vehicle acquisition could provide a more efficient and cost-effective process.

2. It is not clear how SFMTA plans to repair and overhaul components. Many transit properties use unit exchange (UTEX) or Repair and Return (R&R) processes with rebuild or maintenance repair kits in some areas and UTEX/R&R on other components. Maintenance, rebuild and repair kits are far cheaper than buying complete assemblies that may either sit on the shelf for years or be cannibalized for parts.

3. SFMTA has approved major suppliers for the LRV4s. Siemens is a builder not an operator/maintainer and it is a lot easier for them to sell complete assemblies whenever available instead of piece parts. SFMTA should consider working with the major suppliers to obtain specific parts to speed delivery and reduce markups. This requires a mature maintenance organization such as SFMTA, but it allows procurement of individual parts or larger assemblies that are closer attuned to SFMTA maintenance capabilities.

4. A year of operations has provided some experience to draw from to refine the spare parts requirements. As more experience is gained SFMTA should provide opportunities to modify the spare parts list at various times during the Phase 2 procurement. SFMTA should also monitor the warranty parts inventory so it is available throughout the production and warranty period and does not specifically rely on parts from the assembly line.

## Section 13. Contract Modifications

**Description**
The SFMTA Board has approved six contract modifications to date incorporating multiple changes to the contract both in terms of numbers of vehicles provided and changes to the vehicle itself. The changes to the vehicles can generally be classified as follows:

- Operations improvements are intended for the driver or operator of the car
- Maintenance improvements are for maintainability, accessibility and availability. The goal is reduced dwell times and unscheduled maintenance that will be captured in improved MDBF
- Passenger improvements are primarily for comfort and visual controls
- Safety improvements, and there is only one, for a dead man switch

A summary of the key components of each contract modification is as follows:

| Modification | Date | Scope | Value |
|---|---|---|---|
| Initial NTP | 9/30/14 | Initial order for 24 LRVs plus associated spare parts and training | $146 M |
| Mod 1 | 3/15/15 | increase the number of Phase 1 vehicles from the initial 24 to a total of 64 plus added spare parts. | $147 M |
| Mod 2 | 10/30/15 | Approved the list of major suppliers, clarified the purpose for the contract Allowance and modified the payment structure | $0 |
| Mod 3 | 8/16/16 | Approved an updated list of major suppliers, modified the radio/CAD/AVL systems on the vehicles and modified the vehicle and documentation delivery schedules | $20 M |
| Mod 4 | 7/11/17 | Added 4 additional LRV4s increasing the total to 68. | $16 M |
| Mod 5 | 10/22/19 | Approved partial funding for additional track brakes. | $0.5 M |
| Mod 6 | 11/5/19 | Approved additional funding for track brakes, initial funding to initiate the redesign of the seating and other minor modifications to the LRV4s. This also includes a provision to plan for the acceleration of the delivery schedule for the phase 2 (replacement) vehicles by 14 to 16 months at an initial cost of $5.6 M | $10 M |

The source of funding for each modification was not included in the modification discussion but according to SFMTA staff the total amount of the contract including expansion vehicles and option vehicles is still within the not-to-exceed contract amount due to the lower than expected rate of escalation. The escalation cost savings have thus become a de facto contingency fund.

A proposed contract modification 7 is in process. The major items planned for this modification include fully funding the track brakes and seating modifications for both phase 1 and 2 vehicles, modification to the cameras/monitors (potentially deferred pending results of testing), providing additional training and other minor vehicle modifications. For an estimated amount of $30 M. Additionally, Mod 7 also completes the funding for accelerating vehicle production at an additional cost of $21 M bringing the total acceleration cost to $26.7 M. The acceleration will be accomplished by adding a second production line to be used. This will allow the existing Breda fleet to be replace 14 to 16 months earlier than planned.

The original schedule was based on SFMTA's anticipated time to commission vehicles. They have found they are able to commission more vehicles concurrently allowing for the faster vehicle production.

SFMTA has a continuing concern regarding the viability and maintainability of the current Breda fleet. The Breda vehicles are at the end of their useful life, requires substantial maintenance to keep them in service and importantly SFMTA is finding it more and more difficult to obtain parts. Some of the suppliers have gone out of business which is further exacerbating the maintenance issues

## Recommendations

SFMTA's acquisition of a new LRV fleet from Siemens Industry is an important step to improving transit reliability in San Francisco. The project has benefited from the very competitive pricing received in the 2014 bids, the relatively flat rise in inflation which has saved in the price escalation clauses in the contract and the location of the manufacturing facility located 2-hours from the City which has allowed ready access to the plant and Siemens staff.

The overall process, however, has not been without its difficulties. There have been some notable vehicle failures discussed above. The LRV4s are different from the existing Breda fleet, which poses transitional issues for LRV operators, particularly those that operate in a Breda car one day and a Siemens car the next day. Spare parts have not been readily available towards the end of the procurement leading to delays the delivery of the final two vehicles.

As SFMTA moves towards issuing a Notice to Proceed for the Phase 2, 151-vehicle replacement fleet we recommend:

1. All issues with the phase 1 LRVs be resolved with repair strategies in place and repairs completed on a sufficient number of vehicles to determine the issue is satisfactorily addressed.

2. Lessons learned from the phase 1 procurement be gathered from all parties involved with the new vehicles including SFMTA program staff, Siemens and their key suppliers, funding partners, operators, maintainers and riders. These lessons can then be used to modify the procurement documents for the phase 2 LRVs

3. SFMTA schedule a Design Review of the Phase 2 LRV4s prior to issuing a planned Notice to Proceed (NTP) for the phase 2 LRV4s to verify that the improvements and warranty fixes are captured in the remaining vehicle order.

4. The contract be amended to clarify MDBF attainment and clarify consequences of non or delayed attainment (retention, partial hold on SFCTA funding) of the contractual requirement.

5. The spare parts requirements be revised based on the experience gained over the past year with the new LRV4 vehicles. This should include a specific spare parts plan including a listing of spare parts that Siemens shall maintain in San Francisco for warranty repairs (section 1.2.2.2 of exhibit 5 to the contract). The requirement for a separate warranty replacement stock should be enforced as opposed to allowing warranty parts to come from the assembly line stock.

6. SFCTA should continue monitoring repair solutions and any new issues that may arise during the production and roll-out of the phase 2 LRV4s. The monitoring should include a checklist of issues and their resolution that can be addressed on a regular basis with SFMTA program staff and as appropriate with labor representatives.

Attachment 2


# PROGRAM MANAGEMENT OVERSIGHT FOR SFMTA LIGHT RAIL VEHICLE PROCUREMENT

**Prepared For**

San Francisco County Transportation Authority

**Prepared By**

T·Y·LIN INTERNATIONAL
engineers | planners | scientists

**February 25, 2020**

# PMOC Role

Conduct program management oversight for the San Francisco Municipal Transportation Agency's (SFMTA's) Siemens Light Rail Vehicle (LRV ) repairs.

- Consider potential causes and mitigations to the current range of issues including coupler bolt failures, door opening and closing issues, wheel flats and reliability.
- Make recommendations to SFMTA and SFCTA regarding vehicle performance and accountability.

August 2019 through February 2020

# Actions

- Document Review
- 3-Day Deep Dive
- Weekly Commissioning Team Meetings
- Meeting with Operators and Union Representatives
- Safety Protocol monitoring
- On-Site Observations
- Summary Issues Reports;
  - Executive Summary
  - Issues Discussions
  - Recommendations

# Warranty Issues Resolved

| Issues | Repair Solutions | Cost/ Responsibility | Timeline |
|---|---|---|---|
| **Door Safeguards** | Additional sensitive edges added to doors. | Warranty repair | Complete |
| **Pantographs** | Electrical shunts added and nuts/bolts replaced | Warranty repair | Complete |
| **Aux. Power Supply** | Brackets modified | Warranty repair | Complete |
| **Hydraulic Power Unit** | Motor-driver boards, wiring and control valves have been reengineered | Warranty repair | Complete |

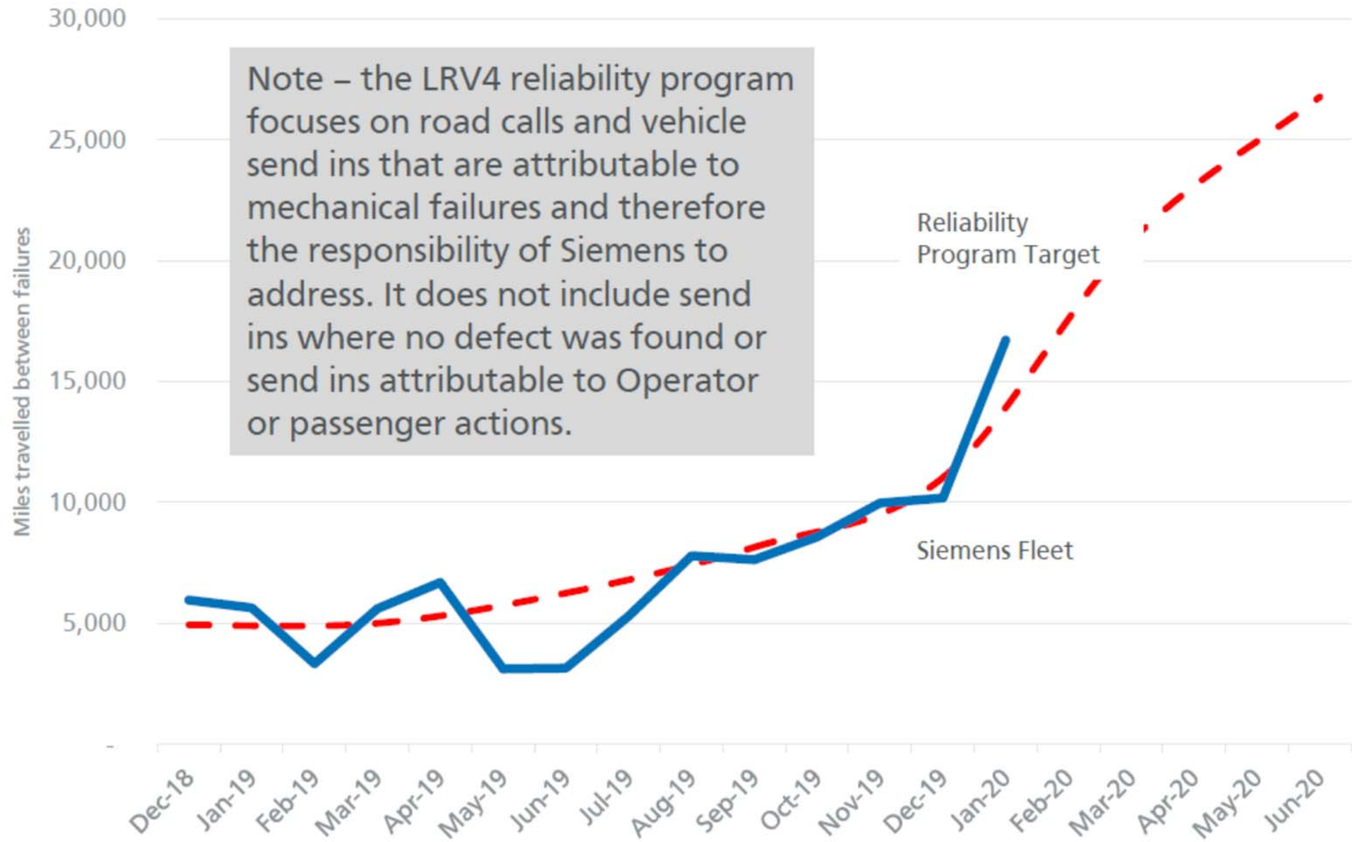
# Issues In-Progress

| Issues | Repair Solution | Cost/Responsibility | Timeline |
|---|---|---|---|
| **Wheel Flats** | Phase 1 LRV4s being retrofitted with additional set of track brakes | $1.75 M at SFMTA cost | March 2020 |
| **Couplers** | Temporary fix (shear pin replacements) in place<br>Second round of investigation and testing is underway. | Warranty repair | Testing and analysis to be completed in February, with repairs starting in June |
| **Cameras** | SFMTA evaluating camera and monitor size and type | $1.6M at SFMTA cost for upgrade (estimate) | Timing for upgrade to be determined |
| **Seating** | Revised seating style and height have been identified | $20.2 M at SFMTA cost for upgrade (estimate) | To be determined (Mod 7) |
| **CCTV** | Modify software to improve integration | Warranty repair | To be determined |
| **Door Adjustment** | Adjustments have been made and testing is in progress | Warranty repair | To be determined |
| **Brake Control Unit** | Analysis of brake lock-ups is on-going | Warranty repair | To be determined |

# Reliability

| Issue | Repair Solution | Cost/ Responsibility | Timeline |
|---|---|---|---|
| LRV Availability | 65 of 68 LRV4s commissioned. Daily availability of LRV4s in January was 43. Improving due to warranty repairs | Siemens | Commissioning of final 3 LRV4s scheduled for Spring/Summer |
| Mean Distance Between Failure (MDBF) | Improved from 4,000 miles in July to approximately 17,000 miles in January | Siemens | SFMTA projects 25,000 miles to be achieved in June 2020 |
| Spare Parts | Improved estimates of spare parts inventory need<br>SFMTA and Siemens to prepare Spare Parts Plan | SFMTA/Siemens | September |

# LRV4 Reliability Program




*January figures are preliminary and subject to change*

# Findings and Recommendations

- Good Progress – repairs being completed, increased availability, improved MDBF
- Resolve Phase 1 repair strategies (e.g. shear pins)
- Hold Lessons Learned workshop including SFMTA program management, operators, mechanics, SFCTA before Phase 2 NTP
  - Spare parts, revise based on Phase 1 experience, assure availability
  - Additional vehicle modifications
  - Delivery/Commissioning timing
- Design reviews prior to approval to proceed with Phase 2 (Mod 7)
  - Assure warranty repairs and requirements of Mods 1-7 are included
- MDBF attainment
  - Clarify timing to meet requirement, consequences of non or delayed attainment (retention, SFCTA partial funding hold)
- Continue SFCTA oversight/monitoring at least through attainment of MDBF requirement and Phase 1 warranty repairs