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SkyTrain Noise Mitigation Study Phase 1
Vancouver

Recommendation Report and Implementation Plan

Translink Ref No. Q17-037

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SKYTRAIN NOISE MITIGATION STUDY PHASE 1
RECOMMENDATION REPORT AND IMPLEMENTATION PLAN

VANCOUVER

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Prepared by
SLR Consulting (Canada) Ltd.
200 – 1620 West 8th Avenue
Vancouver, BC V6J 1V4

for

South Coast British Columbia Transportation Authority (Translink)
400 - 287 Nelson's Court
New Westminster, BC V3L 0E7

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Prepared by: 5 May. 2020

Reviewed by: 05 May 2020

Briony Croft, Ph.D., P.Eng.
Principal Engineer - Acoustics

Pascal Everton, P.Eng.
Principal Engineer - Acoustics

EXECUTIVE SUMMARY

In 2018, TransLink commissioned a SkyTrain Noise Study in response to noise concerns raised by residents. One output of the Noise Study was recommendations for next steps, including investigations of the feasibility and effectiveness of six mitigation measures in order of priority:

1. Improvements to switch maintenance practices
2. Investigation of harder rail steel as a measure to improve long-term rail condition
3. Re-introduction of friction modifiers to improve long-term rail condition
4. Improvements to rail grinding practices to improve long-term rail condition
5. Rail dampers to reduce noise radiated from the rails and hence reduce overall noise
6. Guidelines for new residential developments near SkyTrain

The noise mitigation investigations have been divided into two phases based on the duration required to investigate each option. This report documents completion of Phase 1, including investigation of all mitigation measures except for friction modifiers and improvements to grinding practices, which form Phase 2. Although the Phase 2 mitigation investigations will take longer to complete, this report includes a preliminary assessment of the anticipated effectiveness of these measures to enable comparison of options and planning for implementation.

A preliminary Implementation Plan is provided with technical specifications, cost and schedule estimates for implementation of noise mitigation measures for the Expo and Millennium Lines. An updated Recommendation Report and Implementation Plan will be prepared in Phase 2, consolidating the outcomes and recommendations from both Phase 1 and Phase 2.

To date the noise mitigation investigations have resulted in the following conclusions and recommendations:

1. Replacement of worn switches can reduce noise levels by at least 10 dB and possibly more. Grinding and in-situ maintenance can reduce noise levels by 3-4 dB, but the main benefit of increased maintenance is in maintaining switches in their “as-new” quiet state. The noise benefit of remedial grinding work is minimal if the initial switch condition is already severely worn. It is critical to monitor switch condition and to undertake regular maintenance starting from the time of original switch installation. In this way the variation in noise as switches wear can be minimized and the noise benefit of installing a new switch can be maintained for the life of the switch. Recommendations are made for improvements to switch monitoring and maintenance practices. The implementation of these recommendations will require increased resources on an ongoing basis.

2. Specifying harder rail steel is expected to result in average noise level reductions for the Expo Line of the order of 5 dB in the long term. The additional capital cost of high strength rail steel represents less than 0.5% of the overall cost of rail replacement and is expected to be balanced by cost savings in reduced grinding requirements and longer asset life.

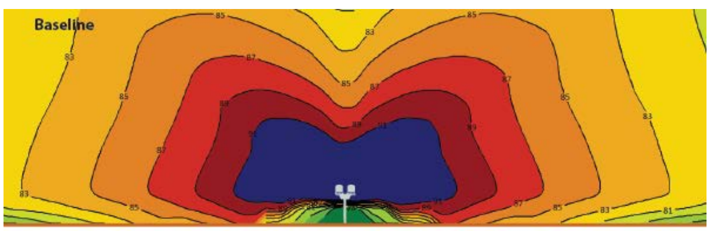
3. The potential noise benefit of friction modifiers is currently being investigated. This mitigation option is expected to have network-wide benefits by reducing rail roughness and corrugation growth rates. The mechanism for long term noise reduction is increasing the time that rail roughness and noise is at a minimum following rail grinding.

4. The potential noise benefit of acoustic rail grinding is currently being investigated. This mitigation measure would minimize noise levels achieved immediately after rail grinding.

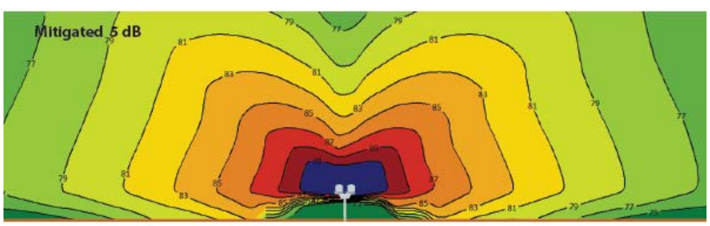
5. Rail dampers reduce noise levels by up to 6 dB in corrugated track sections based on rail damper trials undertaken on the SkyTrain network. Treatment of a total of 3.2 km of track with rail dampers is recommended initially, targeting specific locations where residential receivers are exposed to very high noise levels and investigations indicate that other mitigation measures under investigation in Phase 2 may not achieve the noise goals.

6. An interim guideline for acoustic assessment and design of new residential developments has been developed. In addition to typical assessment approaches considering average noise levels, the interim guideline requires consideration of sleep disturbance effects due to short term maximum noise levels, and also requires thermal comfort to be maintained even if windows need to be kept closed for acoustic amenity.

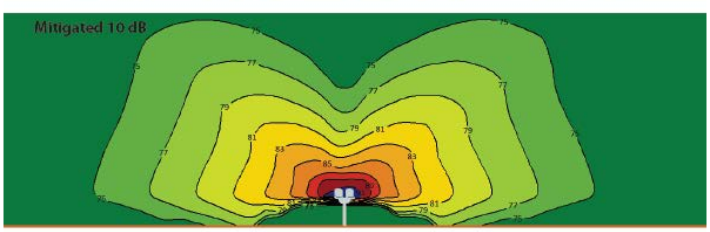
Implementation of the noise mitigation study recommendations will make a noticeable improvement to the noise environment adjacent to SkyTrain. SkyTrain noise is variable over time with changing track condition between cycles of maintenance interventions. The following figure illustrates the improvement from the current worst-case baseline to the future best case, in the form of a vertical cross-section showing train passby noise levels vs distance and height relative to the guideway. While the improvement shown is considerable (16 dB from noisiest to quietest), at most locations people would not experience a sudden reduction in noise. Instead noise levels would become more consistent, similar to the existing quietest periods in the maintenance cycle.



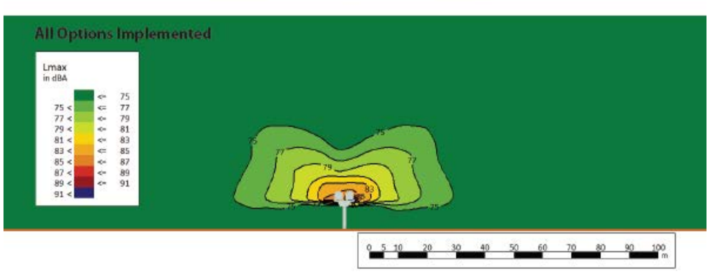
Typical Expo line noisiest areas, in times when rail surface condition is worst case before grinding. 90% of the time train passby noise levels are less than shown.



Typical Millennium line noisiest areas, in times when rail surface condition is worst case. 90% of the time train passby noise levels are less than shown.



All areas, typical train passby noise levels when rail surface condition within 5 dB of best case condition.



Noise mitigation program objective for long term stable train passby noise levels with implementation of all recommended mitigation measures.

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1.0 INTRODUCTION

1.1 Noise Mitigation Study Background

In 2018, TransLink commissioned a SkyTrain Noise Study in response to concerns raised by residents. An output of the Noise Study was recommendations for next steps, in the form of investigations of the feasibility and effectiveness of six mitigation measures in order of priority:

1. Improvements to switch maintenance practices
2. Investigation of harder rail steel as a measure to improve long-term rail condition
3. Re-introduction of friction modifiers to improve long-term rail condition
4. Improvements to rail grinding practices to improve long-term rail condition
5. Rail dampers to reduce noise radiated from the rails and hence reduce overall noise
6. Guidelines for new residential developments near SkyTrain

The recommended noise mitigation investigations are being completed in two phases. This report documents the conclusion of Phase 1, including investigation of improvements to switch maintenance practices, harder rail steel, rail dampers and the development of noise guidelines for new developments near SkyTrain. These mitigation measures are applicable to specific locations around the network with identified high noise levels. Phase 2 investigations are also underway addressing mitigation measures which require longer investigation timeframes and which have network-wide implications, ie friction modifiers and improvements to grinding practices.

SkyTrain noise levels at individual locations are not constant. Over time, noise levels increase and decrease as the result of changes in track condition. Noise can increase as a result of wear in the wheel/rail interface. Noise can decrease following a maintenance intervention such as rail grinding or switch replacement. The 2018 Noise Study and Noise Maps presented a "snapshot" of noise levels at the time of that study. This mitigation investigation takes an approach that considers normal cycles of wear and maintenance over a 12-month period, so that recommendations for implementation of mitigation are based on the most affected locations over the long term. Recommendations are also made on methods to verify and monitor the effectiveness of Phase 1 and Phase 2 noise mitigation implementation, and additional steps to take in the event that progress towards the noise goals is below expectations.

1.2 Noise Mitigation Study Outputs

This Recommendation Report summarizes the Phase 1 mitigation study investigation outcomes and provides an assessment of the potential effectiveness of the Phase 2 mitigation measures. A preliminary Implementation Plan for Expo and Millennium noise mitigation is attached as Appendix A. Future work in Phase 2 of the noise mitigation study will be incorporated and documented in an updated version of this Recommendation Report and Implementation Plan to be prepared following the Phase 2 mitigation trials.

A series of detailed reports and an interim guideline for new developments have been prepared during Phase 1 to document the investigation of the various mitigation measures, and are referenced throughout this report:

- SkyTrain Switch Maintenance Noise and Vibration Study, Aercoustics, 2 December 2019
- Skytrain Noise Mitigation Study: Benefits of Harder Rail for Reducing Noise, BC Rapid Transit Corporation (BCRTC), 28 February 2020

- Rail Damper Workstream – Nanaimo Outbound Trial Site Track Decay Rate Rail Roughness and Noise Results, SLR Consulting (Canada), 21 August 2019
- Rail Damper Workstream – Broadway Outbound Trial Track Decay Rate Rail Roughness and Noise Results, SLR Consulting (Canada), 7 March 2020
- Rail Damper Workstream – Broadway Inbound Trial Track Decay Rate Rail Roughness and Noise Results, SLR Consulting (Canada), 7 March 2020
- Interim Guidelines for New Development Environmental Noise Assessment, BKL Consultants (Draft 2)

1.3 Responsibility for Implementation

Most of the proposed mitigation measures would be implemented by BCRTC; these are described in detail in this report. The noise guidelines for new developments would be implemented by municipalities or planning authorities responsible for approving proposed residential developments.

2.0 OVERVIEW AND OBJECTIVES OF NOISE MITIGATION STUDY

2.1 Noise Goals

As identified in the Noise Report, maximum SkyTrain passby noise levels[1] of 75 dBA are generally considered acceptable at typical residential facades (with windows closed). This guideline level of 75 dBA does not represent “no noise impact”; it is a balance between the adverse effects of noise and other benefits of rail transit systems to communities. TransLink’s priorities for implementation of noise mitigation for existing tracks and existing residential areas are based on passby noise levels at facades:

- First priority: residential areas with maximum noise levels above 85 dBA
- Second priority: residential areas with maximum noise levels of 80 to 85 dBA
- Third priority: residential areas with maximum noise levels of 75 to 80 dBA

Note that when new extensions to the SkyTrain are planned, the noise impacts of these extensions would be assessed as part of the environmental impact assessment process. The noise goals assessed for new SkyTrain extensions would consider other parameters in addition to the typical maximum facade noise level goal.

2.2 Approach to Combinations of Mitigation Measures

A combination of mitigation measures will be required in some areas to reduce residential facade passby noise levels. The Phase 1 investigations quantify the benefit from several mitigation measures (harder rail steel, rail dampers and improvements to switch maintenance). The benefits of the Phase 2 network-wide mitigation measures (friction modifiers, improvements to rail grinding) are being investigated concurrently, but have not been quantified at the time of writing this report. A preliminary approach is used to consider the effect of these Phase 2 mitigation measures in this report, based on noise emissions reducing to a level that is within 5 dB of the typical best case from the existing system, ie representative of maintaining rail condition long-term in a state close to the current best case condition at any point in the track maintenance cycle.

[1] The noise parameter is the maximum noise during a train passby, measured using the fast response setting on a sound level meter (L_{AFmax}).

The overall approach to mitigation recommendations considers the localized benefit expected from some of the Phase 1 measures, and the fact that all identified mitigation measures (including Phase 2) are additive with the exception of switch maintenance improvements:

1. Switch maintenance improvements: implementation recommendations will be applied network-wide, to all switches.
2. Harder rail steels: implementation recommendations will be applied at all locations scheduled for future rail replacement, and for future SkyTrain extensions.
3. Rail grinding improvements and re-introduction of friction modifiers: expected to be recommended network wide following Phase 2 mitigation investigations.
4. Rail dampers: will be recommended for implementation at specific locations based on the residual noise priority considering the benefit achievable by the other mitigation measures, with consideration of the timeframe required to implement other mitigation measures in high noise areas.

Implementation of noise mitigation is expected to require a staged approach over several years including confirmation of the benefit of Phase 2 mitigation measures. Factors such as schedules and constraints for implementation are considered in the Phase 1 recommendations. For example, the current rail replacement program will take around 10 years to complete. Rail dampers will not be recommended for implementation in locations where the rails are due to be replaced in 2020 or 2021 but will be considered in areas where rail replacement is more than two years away. Rail dampers are initially recommended only in the highest priority areas. Rail dampers may be added to additional locations in future, if ongoing investigations and mitigation implementation performance monitoring indicates the project noise goals are not expected to be met after implementation of other mitigation measures.

2.3 Comment on Parapet Noise Barriers

As noted in the 2018 Noise Study Next Steps report, parapet noise barriers are an established SkyTrain noise mitigation measure already in use. At locations where residential receivers are located at or below the guideway deck height, increasing the height of the parapet can be an effective noise mitigation measure. If the line of sight to the rails can be broken by the parapet, noise reductions of the order of 5-10 dB can be achieved. Parapet noise barriers do not provide a benefit to all levels of high-rise buildings overlooking the tracks.

As an already known and established mitigation measure, the effectiveness of parapet noise barriers have not been investigated as part of this study. However, these remain a mitigation option for SkyTrain particularly for proposed extensions to the network. The cumulative effect of parapet barriers in conjunction with other noise mitigation measures is discussed in Section 10.0. Retrofitting new noise barriers to existing track locations would only be recommended in the event that measures to reduce noise at source are not successful in reducing noise levels.

3.0 SKYTRAIN SYSTEM OVERVIEW

The SkyTrain system commenced operations in 1986 and has undergone several expansions since. The system is comprised of around 60 km of standard gauge double track fully automated guideway on two lines, the Expo Line and the Millennium Line (which includes the Evergreen Extension). The system has 39 stations and runs up to 21 hours per day, seven days a week.

3.1 Track design, components and characteristics

Most of the system is built on elevated guideway; however, there are sections of tunnel and at-grade track. The SkyTrain track form comprises AREMA standard 115RE rails with resilient rail fasteners on concrete slab track. There are several different rail fasteners used on the system with the original Lord direct fix fasteners being replaced over time with newer Delkor Alt1 fasteners with comparable stiffness characteristics.

The spacing between rail fasteners is nominally 1000 mm for tangent track. On the Expo line, all curves have reduced fastener spacing, nominally 500 mm. On the Millennium Line and Evergreen Extension, curves of radius less than 150 m have 500 mm spacing, while curves of radius from 150 m up to 1500 m radius have 750 mm spacing. Larger radius curves and tangent track have 1000 mm spacing.

3.2 Rolling stock

The SkyTrain currently operates a rolling stock fleet of three types, Mark (MK) I, II and III. The original fleet of MK I vehicles entered service in 1986, with additional batches purchased in subsequent years. The first MK II vehicles entered service in 2001/2002, with additional vehicles added in 2009. The first MK III vehicles entered service in 2017, with more being added progressively.

All vehicle types use a linear induction propulsion system, with two linear induction motors mounted on the underside of each vehicle with a nominal air gap of 12 mm to the reaction rail installed between the running rails. Traction power is supplied via power rails mounted on the inside of the guideway parapets. All vehicle types utilize steering wheelsets and solid steel wheel designs. The maximum normal operating speed of the SkyTrain is 80 km/h.

The typical operating configuration of these vehicles is as follows:

- MK I trains operate in 6 car (most common) or 4 car sets on the Expo Line only
- MK II trains operate in 2 car sets on the Millennium Line
- MK II trains operate in 4 car (most common) or 2 car sets on the Expo Line
- MK III trains operate in 4 car sets on the Expo Line only

3.3 Switch design and switch maintenance and replacement program

In total there are 123 switches on the SkyTrain network, with 55 on the Expo Line, 36 on the Millennium Line and 32 on the Evergreen Extension. The SkyTrain uses movable point frogs (also known as “swing nose” turnouts) at all locations.

All switches are visually inspected every two weeks as a minimum, and inspected and adjusted every quarter. Twice a year every switch undergoes a preventative maintenance overhaul. These current switch maintenance practices are directed towards safe operation of equipment – minimizing noise emissions is not the primary objective. Grinding is used to maintain the rail profile through the switch, to address some surface defects and reduce impact loading, but is not normally undertaken specifically to reduce noise. A program of switch replacement is also in place as individual switches approach the end of their designed service life, with around 10 switches typically replaced each year.

3.4 Rail specifications and rail replacement program overview

At commencement of this study, the SkyTrain specification for new rails was AREMA Standard with a minimum Brinell Hardness of 310 HB. AREMA Standard hardness rail was also specified at the time of construction of the original Expo and Millennium lines. However, over time the AREMA specifications corresponding to "Standard" rail have changed. Also, some rail installed on the system is of higher hardness than the minimum specification. The existing as-constructed rail hardness around the network can be divided into the following approximate categories:

- Soft – 248 to 280 HB, approximately 34 km of track (Expo Phase 1)
- Soft to Standard – 290 to 310 HB, approximately 56 km (Expo Phase 2/3 and Millennium)
- Standard – 330 to 340 HB, approximately 3 km of track (Expo rail replacement program)
- Intermediate – 350 HB, approximately 20 km of track (Evergreen Line)
- High strength – 370 HB +, approximately 2 km of track (historical Expo rail replacements)

Normally, the life of rail in service is 25 years or more and large extents of rail are of the same grade depending on when they were originally installed. Some sections of rail are replaced to repair defects, this is undertaken by cutting out a length of rail and installing bonded joints to connect in a new section.

The rail replacement project currently underway is currently installing 330 to 340 HB standard hardness rail (based on mill certifications for the new rails already received), even though the specifications only require 310 HB.

4.0 NOISE BASELINE CONSIDERING WEAR AND MAINTENANCE CYCLES

4.1 Track condition baseline

Over time, noise levels increase and decrease as the result of changes in track condition and due to maintenance grinding. The 2018 Noise Study and Noise Maps presented a "snapshot" of noise levels at the time of that study. As an alternative to that snapshot, this mitigation investigation takes an approach that considers normal cycles of wear and maintenance over a 12 month period, so that recommendations for implementation of mitigation are based on the most affected locations long term. A 12 month period considers the scheduled rail grinding frequency at all locations where track condition is known to deteriorate rapidly, and which are categorized as being targeted for grinding yearly, half-yearly or quarterly.

In order to investigate the track condition baseline considering wear and maintenance cycles, measured weekly in car noise data collected over 1 year, from March 2018 through to March 2019 has been analysed. For each track section, the 90th percentile measured noise level represents the typical worst case track condition, while the 10th percentile measured noise level is used to represent the typical best case track condition. These percentile values are used rather than absolute maximum and minimum measured values in order to exclude any unrepresentative measurements, for example if the test train speed was lower than usual at a particular location during one of the measurement runs.

Figure 1 and Figure 2 show the difference between the measured 90th and 10th percentile noise levels along the length of the Expo and Millennium lines, both inbound and outbound. Overall, the 90th percentile (typical worst case) rail condition reflects noise levels that are on average 8 to 9 dB higher than the 10th percentile (typical best case) noise level, but in specific locations there can be a difference of 20 dB or more in noise levels between the best and worst case scenarios.

These locations correspond to areas prone to rapid corrugation formation, with large variations in track condition occurring over time.

On all lines and in both travel directions there is a minimum difference between best and worst case noise levels of the order of about 5 dB. These locations correspond to areas where corrugation does not typically appear, and the existing maintenance practices result in relatively stable long-term track condition. A primary objective for SkyTrain noise mitigation is to increase the amount of track with stable rail condition resulting in noise levels maintained within around 5 dB of the best case.

Figure 1 and Figure 2 include data for all track sections and speeds, including tunnels and surface track, to give an overview of the track condition baseline. At many locations, the noise beside the tracks will be directly correlated to the track condition. However, for environmental (trackside) noise mitigation purposes only a subset of all locations are of interest. Track sections in tunnels do not result in airborne noise impacts to residences. Lower speed surface track sections result in relatively lower noise levels, even if track condition is poor. Also, surface track sections through industrial areas or areas where residences are located at greater distances from the track are not priorities for noise mitigation. Section 4.2 discusses the noise baseline at residential facades, informing the priority locations for noise mitigation.

Figure 1 Expo Inbound and Outbound 10th to 90th percentile noise difference

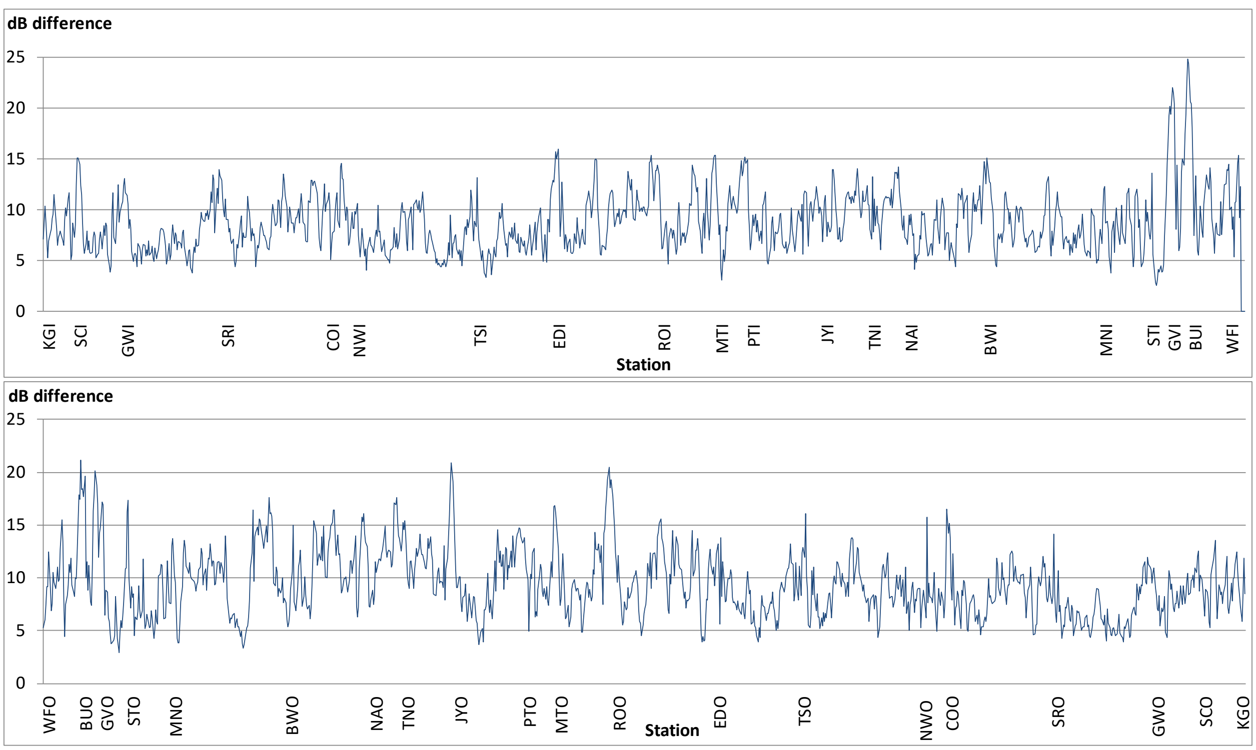
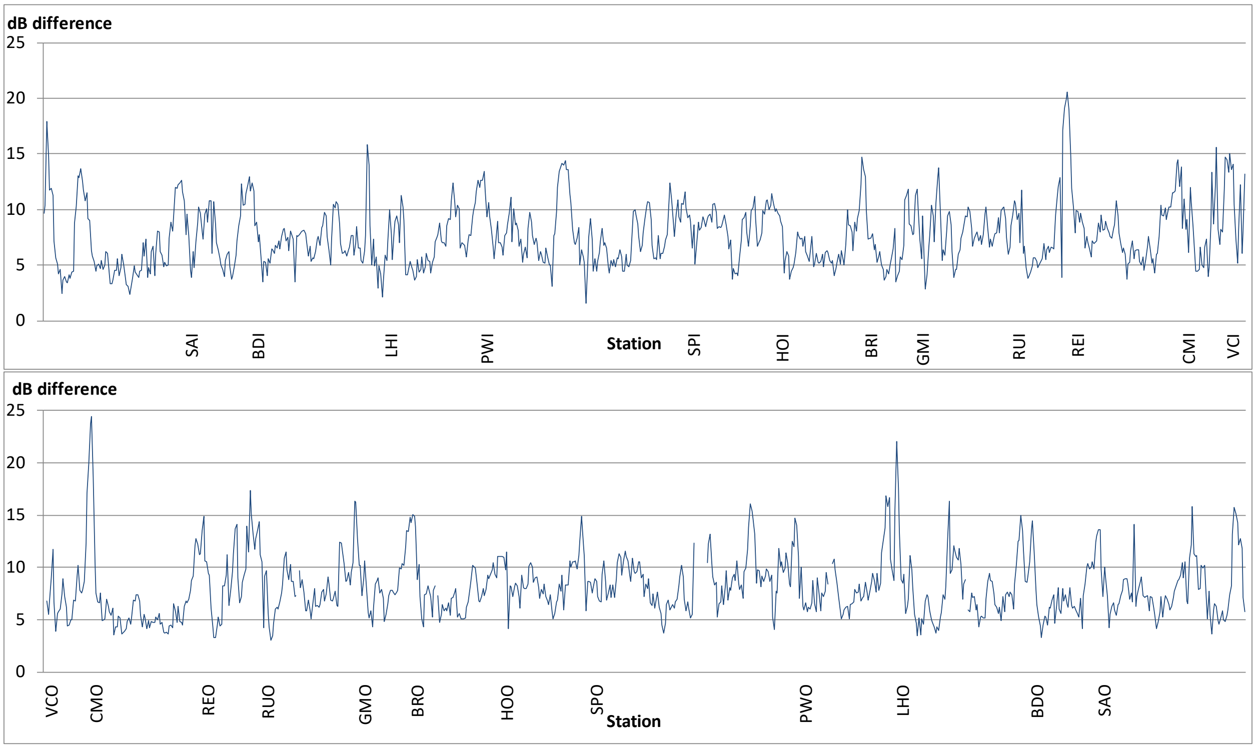


Figure 2 Millennium Inbound and Outbound 10th to 90th percentile noise difference



4.2 Residential facade noise baseline model for mitigation investigations

In order to investigate the noise baseline at residences considering wear and maintenance cycles, the noise model developed during the 2018 noise study has been revised as follows:

1. Review measured weekly in-car noise data collected over 1 year, from March 2018 through to March 2019.
2. For each track section, use the 90th percentile in-car noise level and hence track condition correction, to represent the worst case track condition over the year.
3. Revise the track condition correction in the noise model accordingly.
4. Calculate the worst case maximum noise level at residential facades.

The noise model includes surface track only. While track sections in tunnels result in increased in-car noise levels, they are not a concern for environmental noise emissions to residential areas. The calculation of track condition corrections also considers only areas where train speed is 50 km/h or greater. Higher speed sections lead to higher emitted noise levels, while at lower speeds the in-car noise level data begins to be affected by auxiliary system noise and no longer represents the track condition.

The noise modelling undertaken to support this study does not include analysis of the Surrey branch of the Expo line, which was excluded in the 2018 noise study due to low numbers of noise complaints. The Evergreen Extension has also been excluded from modelling as historical in-car noise data from this part of the network has not been correlated to track section. Although these parts of the network have not been specifically modelled, data from these areas has been included in analysis of existing noise levels, and the network-wide noise mitigation measures investigated would benefit both these areas and future extensions to the SkyTrain network.

The result of this process is a noise model indicating baseline worst case maximum noise levels at residential facades. These worst case maximum facade noise levels occur around 10% of the time only. At many locations, this version of the noise model results in facade noise levels that are considerably higher (of the order of 5 dB or more) than the noise levels identified in the 2018 noise study. These modelling results have been used in this study to identify priority locations for noise mitigation.

5.0 INVESTIGATION OF SWITCH MAINTENANCE IMPROVEMENTS

In the baseline scenario, maintenance of switches is undertaken with a focus on safe operation of the system. Switch maintenance is not currently triggered by the noise impacts of trains travelling through each switch. In this study, investigations have been undertaken to understand the potential to improve monitoring and maintenance of switches to reduce train passby noise. For full details of the investigations of this mitigation option see Aercoustics, 2019.

5.1 Description of options for alternative repair methods

Switch maintenance activities with the potential to reduce train passby noise include grinding, component replacement and full switch replacement. Grinding can be undertaken using either hand tools or rail-mounted equipment. The objective of grinding is to smooth out localized defects and transitions, maintain the target rail profile, and minimize features causing impact loads. Geometrically small discontinuities in the rail running surface increase noise by a small amount, and act as stress concentrators. Under repeated train passbys, these initially small discontinuities can lead to the formation of larger scale (and noisier) defects such as spalling or corrugation. In severe cases, these larger scale defects cannot be repaired by grinding, requiring replacement of components.

At present, SkyTrain switch maintenance targets the repair of larger scale defects, but there is potential to minimize noise long term by identifying and addressing smaller scale discontinuities by grinding. Implementation of a preventative switch grinding approach to address noise requires a method of identifying which switches would benefit from grinding, and a method to measure the effectiveness of the maintenance intervention. It is likely that undertaking more frequent grinding of switches to remove small scale defects will keep noise levels as low as possible, in addition to increasing switch life overall, by preventing the formation of more severe larger scale defects.

5.2 Measured noise reduction from switch maintenance activities

To investigate the potential noise reduction from switch maintenance, passby maximum noise measurements were taken of six switches on the SkyTrain network before and after grinding and switch replacement. The largest noise reduction measured was 11 dB following a full switch replacement. The train speed through this particular switch is 50 km/h. It is anticipated that somewhat larger noise reductions could result from replacing an 80 km/h switch with large scale defects.

The largest reduction in passby maximum noise measured in this study due to grinding was 5 dB. In several instances, grinding did not result in a measurable decrease in noise levels. This was attributed to the fact that grinding is not effective in removing large scale defects.

5.3 Description of ongoing switch monitoring and maintenance

With over 100 switches around the network, continuously monitoring all switches for changes in wayside noise levels would be extremely resource-intensive. An alternative switch condition monitoring approach is desirable. In addition to wayside noise levels, in-car noise and vibration data was collected and analysed before and after maintenance activities on the six switches with the objective of establishing an approach to monitor switch condition and develop triggers for preventative maintenance grinding.

In-car noise (as currently measured on a weekly basis) was investigated as an alternative switch condition monitoring method. However, no discernible trends were identified linking in-car noise over switches to switch maintenance activities. Therefore, use of this metric as a means to monitor switch condition and wayside train passby noise levels is not recommended.

Train axle-box vibration was found to indicate changes in vibration impact due to switch grinding and switch replacement. It is recommended that future efforts to monitor switch condition to minimize wayside noise utilize axle-box vibration measurements. Implementation of improved switch maintenance procedures informed by axle-box vibration requires a staged approach. In the first year of implementation it is recommended that additional switch passby noise data be collected to improve understanding of the correlation between axle-box vibration and wayside noise. In the longer term, it should be possible to rely on the vibration data only as a trigger for switch maintenance to minimize wayside noise.

Initial implementation of improved switch monitoring and maintenance procedures will require additional BCRTC analyst resources, and a dedicated guideway maintenance crew with associated equipment to undertake switch grinding as triggered by vibration data analysis.

5.4 Costs of increased switch condition monitoring and maintenance

The cost of increased switch condition monitoring and maintenance is related directly to the additional resources required as described in the Implementation Plan (Appendix A). The additional resources include a full time engineering analyst for the first year of implementation, a dedicated team of three guideway maintenance staff, grinding equipment and a speeder for transport to work locations.

6.0 INVESTIGATION OF HARDER RAIL STEEL

6.1 Introduction to harder rail steel mitigation measure

The primary contributor to track noise (excluding switches) is rail corrugation or poor rail running surface condition. BCRTC has observed that the older original Expo line rail is more prone to rail corrugation growth than incrementally harder steels found elsewhere on the system. The objective of the harder rail steel investigation was to quantify the noise benefits and costs of specification of harder rails for future Skytrain rail replacement programs and other projects.

BCRTC uses rail grinding to remove corrugation and to control running surface condition. The existing grinding program is executed with a combination of a BCRTC operated grinder, supplemented by a contract grinder. The BCRTC grinder typically addresses areas requiring higher frequency grinding (every six months or even quarterly in some areas). The BCRTC grinder completes approximately 60 km of track grinding per year. The remaining 60-70 km of track is ground either annually or every 2 years using contracted grinding equipment in an annual campaign.

On the Expo line, 33 km of track is ground quarterly, 20 km of track is ground twice a year and 35 km of track is ground once a year. On the Millennium line (including the Evergreen Extension), 17 km of track is ground once a year, while 21 km of track requires grinding only once every two years. Newer areas of track on the Millennium Line with harder rail steels require grinding up to eight times less often than some areas of older, softer rail on the Expo Line.

6.2 Noise benefit of harder rail steels for SkyTrain

In support of this noise mitigation study, BCRTC have undertaken analysis to determine the noise benefit of harder rail steels for SkyTrain. Full details of this analysis are provided in BCRTC, 2020. The analysis was based on in-car noise levels measured around the network on a weekly basis, using a similar approach to that described in Section 4.1 to establish the worst case facade noise baseline.

The analysis showed that recently ground track would result in best-case, in-car noise levels at typical maximum operating speeds of 75-78 dBA, regardless of the rail hardness, age, brand, or location. Since the post-grind in car noise level is consistent across all variables, it can be assumed the post-grind surface finish is very similar across the system. The influence of rail hardness on long term noise levels is identified by examining the magnitude of increase in noise levels over time between grinding intervals, by calculating the difference between best case and worst case noise level throughout a year.

It was found that the lowest hardness rail on the original Expo Line typically exhibits an 8-10 dB increase in noise level in the duration between grinding maintenance. In many cases this significant increase in sound level occurred over a short time period, as some areas are ground as often as every three months to combat rail corrugation.

Areas with harder rail steel required grinding less frequently, and even so typically exhibit a lower range of variation in noise levels in the intervals between grinding, in some cases as low as 5 dB noise increase over 2 years.

Table 1 summarizes the average long-term noise reduction benefit that is predicted for various AREMA rail grades of increasing hardness, relative to the softest rail steel currently in use on the SkyTrain Expo Line. While increasing rail hardness would not reduce the current best-case noise emissions, increasing hardness would reduce worst case maximum passby noise levels by around 5 dB on average.

Table 1 Harder Rail Steel Noise Average Benefit Long Term

AREMA Rail Grade	Minimum Hardness Specification	Noise Reduction
Historical standard (original Expo)	248 HB	-
Standard (current specification)	310 HB	2-4 dB
Intermediate	350 HB	3-5 dB
High Strength	370 HB	4-6 dB

There is potential for even greater noise benefits than indicated in Table 1. Since the use of harder rail steels would also be associated with a reduction in the frequency of grinding required at some locations, more grinding capacity would be available to address specific problem areas when required.

6.3 Other considerations in specifying harder rail steels

It has been demonstrated that increasing the rail hardness on Skytrain will provide a reduction in noise, with improved performance relative to softer rails. The BCRTC analysis also examines whether an increase in rail hardness specifications for SkyTrain could have other implications for operations or maintenance.

There are multiple transit agencies within North America now specifying and installing AREMA high strength (harder) rails. These agencies include Bay Area Rapid Transit (BART), Chicago Transit Authority (CTA), and LA Metro. The objectives of these agencies in using harder steels include reducing rail wear, controlling rolling contact fatigue and reducing the risk of rail breaks in addition to controlling corrugation growth. Consultation with these agencies has not indicated any adverse side-effects of the use of harder rail steels.

The wheel-rail hardness ratio has been the topic of many publications and discussions within various rail engineering communities, with a concern being that increasing rail hardness might result in increased rolling stock wheel wear. However, studies into this issue conclude that regardless of whether the rail or wheel is harder, increasing rail hardness will reduce overall wear on the overall wheel-rail system, which is seen as a key benefit. The analysis undertaken by BCRTC indicates that rail life could be extended as a result of harder rail steels, primarily due to reduced requirements for repeated grinding of problematic locations.

The hardness specification for Skytrain wheels is 321-363HB, which is significantly harder than the softest Expo rail, but is already similar to existing Millennium rail hardness. Work hardening of the rails and wheel treads is likely to influence wear of the system. The BCRTC analysis concludes that any increase in wheel wear from harder rails is unlikely to be significant.

The BCRTC analysis indicates that while rail corrugation resistance is improved with harder rail steels, there are some examples of intermediate hardness rail on the network with increased propensity to develop other surface defects such as spalling. Although rail hardness plays a role in resistance to these types of surface defects, they may still develop if the steel is not of good quality. Therefore, although the hardness of new rail may meet or exceed the AREMA high strength specification, the quality of the steel and manufacturing processes must be also be examined by metallurgical analysis.

Another consideration in specifying high strength rail steels is grinding induced acoustic roughness. This refers to the fact that regular maintenance rail grinding can leave residual roughness on the rail surface that results in a temporary increase in noise level (if the baseline was not corrugated) and a noticeable change in noise character. With soft rail steels, this residual grinding induced roughness wears away rapidly, however with harder rail steels the residual effects can persist for many months. This issue will be investigated and considered in the development of improved rail grinding processes for SkyTrain, as part of the Phase 2 noise mitigation investigations. Historical investigations of grinding outcomes on the SkyTrain network and elsewhere indicate that this issue can be satisfactorily mitigated by careful control of the grinding process and by specifying grinding surface finish quality requirements.

6.4 Costs of various rail steel grades

The cost of increasing rail steel hardness specifications has been calculated on the basis of the incremental cost increase to the current rail replacement program of increasing the specification from the current AREMA Standard to Intermediate or High Strength rail. Costs would be distributed throughout the duration of the rail replacement program which is currently planned over a 10 year period. The incremental cost high strength rail represents less than 0.5% of the overall cost of the rail replacement program. Furthermore, the additional cost of high strength rail would potentially be offset by reduced grinding requirements.

7.0 INVESTIGATIONS OF FRICTION MODIFIERS AND ACOUSTIC GRINDING

These two mitigation measures are currently under investigation and results will be available by end of 2021. The timeframe required to investigate these measures is based on the need to monitor rail roughness and corrugation growth rates at various trial locations over a period of months and years to quantify effectiveness. The following sections summarize the investigations of these mitigation measures and anticipated outcomes at this time.

7.1 Friction modifiers

Friction Modifier (FM) has a proven record on many systems as an effective means to reduce corrugation (roughness) growth rates on wheels and rails. Correctly applied, it adjusts the friction between the rail and the wheel tread to an intermediate level that is lower than dry rail, but significantly higher than lubricated conditions.

The Phase 2 mitigation investigations involve a pilot study as a FM proof of concept trial for SkyTrain. This pilot study will evaluate FM in a small area of track with the product applied to the top of the rail via a trackside applicator. If the trial is successful (by showing reduced roughness growth and noise with wayside application), the recommended next step would be to implement FM as sticks mounted on to rolling stock. FM sticks apply the product continuously to the wheel tread, and it is then distributed via the wheel/rail interface to form a thin film on both wheel and rail running surfaces, to achieve total system coverage. FM sticks have previously been used by SkyTrain, but the applicators on older trains would need to be upgraded with new generation equipment, and applicators would also need to be installed on the newer trains.

A location has been selected for the FM pilot study, on the Inbound track between Nanaimo Station and Commercial-Broadway Station. Measurements of rail roughness have been undertaken a few days after rail grinding to establish the baseline roughness condition. Noise, rail roughness, profile and friction measurements will be taken periodically over the next 12 months to establish baseline wear, roughness and corrugation growth rates at this location. Then the same set of measurements will be repeated with FM applied to quantify the benefits for SkyTrain.

This study is currently underway and is anticipated to be completed by end of 2021.

7.2 Improvements to rail grinding

BCRTC currently completes 130 km of maintenance grinding annually, split approx. 50/50 between BCRTC's grinder and contracted grinder. Rail grinding is a critical maintenance practice which is required to remove rail defects and correct the rail profile following wear. If track is corrugated, rail grinding also reduces roughness, corrugation and noise. Rail grinding requires balancing the amount of material to be removed with the targets for rail surface finish. If a large amount of material removal is required, for example to remove corrugation, then coarser grinding stones are used. If only a small amount of material is required to be removed, finer stones can be used to leave a better surface finish. Using finer stones is not practical for removing corrugation, as it takes too long (many passes back and forth of the grinding train) to remove enough material from the rail head to remove the corrugation.

The residual grinding surface finish (periodic scratches on rail) are a source of roughness, can possibly initiate corrugation and can increase noise directly if the track was not corrugated before grinding. The objective of acoustic grinding is to improve the surface finish after grinding, with the goal of reducing corrugation growth and not increasing noise by grinding. Achieving an improved surface finish after grinding is particularly important with harder rail steels, since with harder rail the residual grinding marks do not wear away for some time (months). The importance of acoustic grinding is evident in the number of complaints received from residents along the Evergreen Line after rail grinding – this line utilizes harder rail steel than other parts of the network, and grinding that was required to achieve the target rail profiles had the unwanted effect of increasing noise emissions.

The Phase 2 mitigation investigations of acoustic grinding involve measuring rail roughness and corrugation growth rates periodically at a number of tests sites with various rail hardness. This study will evaluate rail roughness immediately after grinding and over time. An objective of the trial is to understand which rail hardness categories would benefit from a more stringent acoustic grinding specification.

8.0 INVESTIGATION OF RAIL DAMPERS

8.1 Introduction to rail dampers

Rail dampers are a noise mitigation measure designed to reduce noise radiated from steel rails. They take the form of tuned mass-spring-damper systems that can be attached to the rail in between the normal rail fasteners, e.g. Figure 3. Rail dampers do not provide the same benefit in all situations. The benefit achievable depends on the track design, baseline track condition (roughness or corrugation), the design of the wheel, the rail damper design and the dynamic interaction of the system as a whole.

Figure 3 Installed rail damper examples

The 2018 SkyTrain Noise Study – Next Steps report identified a potential reduction in overall noise level of between 5 and 8 dB, depending on the detail of the rail damper design. In this noise mitigation study, several pilot studies have been undertaken to verify the noise benefit and to establish a preferred rail damper design that is optimized to the Vancouver system.

The following sections summarize the results of 4 rail damper pilot studies completed on the SkyTrain system:

1. Initial trial of standard Supplier A rail damper design at 1 m intervals
2. Trial of standard Supplier A rail damper design at 0.5 m intervals
3. Trial of customized rail damper design from Supplier A
4. Trial of customized rail damper design from Supplier B

8.2 Results of initial trial of standard rail dampers in Evergreen tunnel

The first trial of rail dampers on the Vancouver system took place in September 2018. A 200 m length of track in the Outbound Evergreen Line tunnel was fitted with a standard 400 mm long rail damper design, with rail dampers installed between each rail fastener at 1 m intervals. The track with dampers installed is shown in Figure 4.

Figure 4 Track with rail dampers installed

The noise benefit was measured by comparing noise levels measured inside the BCRTC test train before and after installation of the rail dampers. The rail dampers were found to reduce the in-car noise levels in the tunnel by around 4 dB. Detailed investigations of rail damper performance were undertaken including measurement of the decay of vibration along the rail (Track Decay Rate), which is closely linked to noise emissions. The conclusions from this initial trial were that the standard rail damper design in this configuration was not optimized for the Vancouver system, leading to less noise benefit from the trial than theoretically possible.

8.3 Results of Nanaimo trial of double density standard rail dampers

A recommendation arising from the initial trial in the Evergreen Line tunnel was to undertake a second trial of the standard rail damper design, but with the rail dampers installed "double density", ie with two rail damper units between each rail fastener. In order to better quantify the effect of the rail dampers on noise levels trackside, this trial was undertaken in a surface track section on the outbound track west of Nanaimo station. The microphone for the noise measurements was raised using an extension pole, so that the measured damper noise reduction is representative of a location overlooking the parapet of the guideway.

Comprehensive supporting measurements of rail roughness and track decay rate were collected in addition to noise measurements and are described in SLR (2019). The damper trial site was corrugated at the time of the trial, and therefore representative of track in "worst case" condition in terms of noise emissions. The track with rail dampers installed with two dampers per fastener is shown in Figure 5.

Figure 5 Nanaimo Outbound Track with Rail Dampers

This trial confirmed that rail dampers are an effective noise control option for SkyTrain. The overall noise reduction measured was 5 dB on average across all measured train passby events. The benefit measured was 6 dB on average for MK II and MK III trains and 4 dB on average for MK I trains.

Analysis of the trial data indicated that the performance of the rail dampers was improved by the increased installation density, but the overall noise reduction achieved was limited by the track corrugation which results in dominant noise in the 500 Hz frequency band. Similar corrugation is commonly observed around the SkyTrain network. Figure 6 shows the average passby noise spectrum with and without the rail dampers for MK II train passbys.

Figure 6 Average Passby Noise Spectrum Nanaimo Outbound Trial – MK II Trains

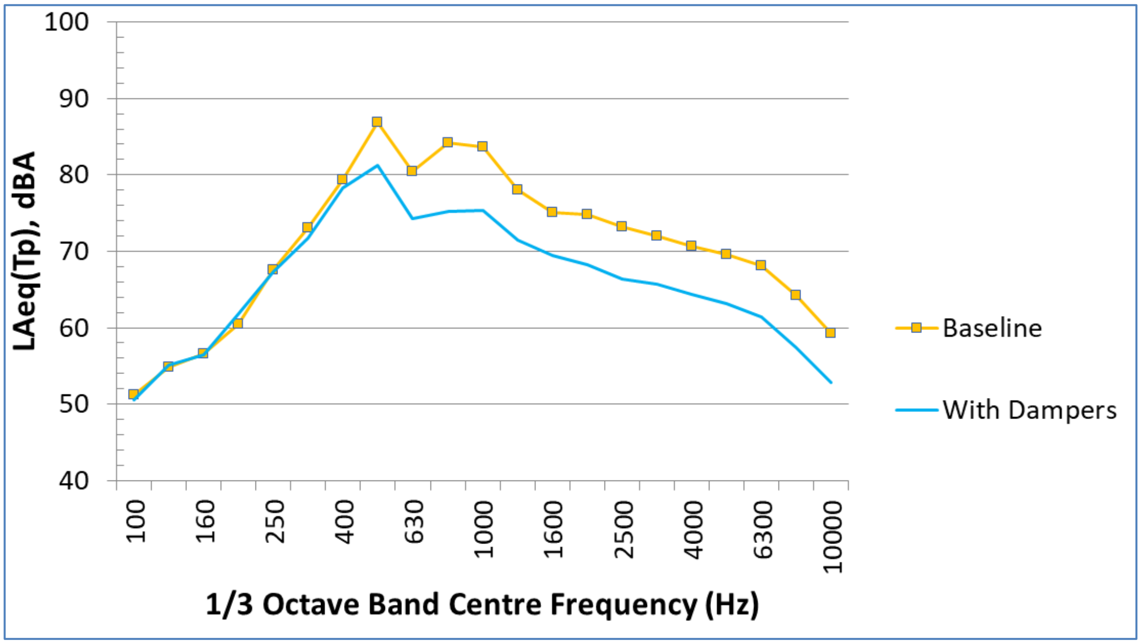


Figure 6 shows that in the dominant 500 Hz corrugation frequency band the rail dampers reduced noise by 5.5 dB, which controls the overall measured noise reduction. At higher frequencies, the rail dampers had a greater effect. In the 800 Hz frequency band, passby noise emissions were reduced by 8-9 dB after installation of the rail dampers.

A conclusion of this trial was that it may be possible to improve the damper performance further by customizing the tuning of the rail dampers to target increased effectiveness in reducing noise from SkyTrain corrugation around 500 Hz.

8.4 Results of trial of custom rail damper designs

Two rail damper suppliers were engaged to develop and manufacture customized rail dampers for the SkyTrain system. Two objectives for the customized rail damper designs were identified:

1. To be tuned to be effective around 500 Hz, ie at the dominant SkyTrain rolling noise frequency in the noisiest areas due to track corrugation.
2. To better fit the SkyTrain geometry, since the previously tested rail dampers are too long to be fitted to curved track areas on the Expo line where the fastener spacing is 500 mm.

These rail dampers have been trialled on the Expo Line west of Commercial-Broadway station, with one design installed on the inbound track and the other on the outbound track as shown in Figure 7.

Figure 7 Custom dampers Broadway Outbound (left) and Inbound (right)

Neither of the customized damper designs gave an improvement in noise reduction benefit over the results achieved with the standard damper tested previously. The customized damper trialled on the outbound track near Broadway resulted in only a 2.2 dB noise reduction, while the damper design trialled on the inbound resulted in only a 1.6 dB noise reduction. For full details of the trial and results for the custom rail damper designs, see SLR (2020).

A noise benefit of less than 2-3 dB is commonly considered to be a barely noticeable change in overall noise level. To achieve a clearly noticeable benefit, a reduction of the order of 5 dB is the goal, as was achieved by the standard rail damper design tested previously. It is concluded that the noise reduction benefit of the shorter damper designs intended to fit in both curves and tangents on the SkyTrain Expo Line is not sufficient to justify the cost of installation. The standard rail damper design with two units installed per metre of rail was more effective for noise control for SkyTrain, noting that this damper configuration can only be installed on tangent track, as these rail dampers are too long to fit in the 500 mm space available between fasteners on Expo line curves.

8.5 Rail damper implementation costs

The cost of installation of rail dampers is identified in Appendix A. This includes the cost to procure the components in addition to the resources required to install rail dampers on track. The total cost of rail dampers depends on the extent of track to be treated.

9.0 GUIDELINES FOR NOISE-SENSITIVE DEVELOPMENTS

9.1 Background and Objectives

One factor linked to the increase in SkyTrain noise complaints is the increasing densification of Vancouver and the construction of new buildings close to SkyTrain. Creating guidelines for the acoustic design of new developments was originally recommended with the objective of providing a consistent SkyTrain noise assessment approach to ensure amenity in new residential buildings.

TransLink is often involved as a stakeholder in the planning of developments in close proximity to the SkyTrain right of way, but does not have any jurisdiction over the design or approval of most developments. There is no mechanism for TransLink to require municipalities to use or enforce noise design guidelines for new developments. To be implemented, these guidelines would need to be voluntarily adopted by municipalities.

9.2 Consultation Process

A series of three workshops were held with invited stakeholders from greater Vancouver municipalities around the SkyTrain network to collect feedback, discuss the outline of a guideline and finally to present a draft Interim Guideline.

Through consultation with municipal staff, it is clear there is a need for a broader guideline for assessment of noise-sensitive developments, addressing all environmental and transportation noise sources, not just noise from SkyTrain.

The result of this process is an interim guideline for noise sensitive developments in a form that can be readily adopted by planning authorities. Since administering a noise policy for new developments is not TransLink's remit, ongoing consultation is required with other stakeholders to determine an appropriate agency to "own" the guideline moving forward, and the framework for implementation of this guideline.

10.0 RECOMMENDATIONS

10.1 Switch maintenance improvement recommendations

It is recommended that Skytrain implements an ongoing switch monitoring and maintenance program. The basis for this program is ongoing measurement and analysis of axle-box vibration from a test train circuit of the network on a weekly basis.

The data collected would be analysed with a report documenting the condition of all switches on the basis of axle-box vibration prepared bi-weekly as a minimum. This report would prioritize and direct the efforts of a dedicated switch maintenance crew who would undertake preventative maintenance grinding on identified priority switches with the goal of minimizing switch wear and hence noise in the long term.

In the initial year of the program, it is recommended that wayside noise is also measured in conjunction with axle-box vibration, at a minimum of twenty switches. This will further characterize the relationship between train speed, axle-box vibration and wayside noise. In subsequent years, it is expected that it will be possible to rely on the axle-box vibration data in isolation.

For each switch around the network a baseline condition indicator will be developed based on an understanding of the axle-box vibration level through a switch in good condition (generating minimal noise) for the typical operating speed through that switch. Monitoring this condition indicator for each switch will indicate when maintenance attention is required to minimize noise.

10.2 Harder rail steel recommendations

It is recommended that Skytrain revise their current specification for rail replacement and build projects from AREMA Standard grade hardness (310+HB) to AREMA High Strength rail (370HB+) to give the greatest noise benefit and to maximise potential maintenance cost savings. Consideration of potential side effects and risks of this change have not identified any concerns for ongoing operation or maintenance of the system, particularly noting that some areas of the SkyTrain already use high strength rail, as a result of previous rail replacement work.

10.3 Preliminary friction modifier and acoustic grinding recommendations

Investigations are currently underway to quantify the benefit of these two mitigation measures. This recommendation report will be updated following completion of these investigations (end of 2021). In the interim it is recommended that planning for implementation of both these mitigation measures continues by allocation of necessary budgets and resources. This will facilitate adoption of the final noise mitigation study recommendations without delay targeting implementation of these measures in 2022.

10.4 Rail damper implementation recommendations

It is recommended that rail dampers be installed at several locations on the Expo Line identified as being of highest priority for noise control.

Locations selected for implementation of rail dampers meet the following criteria:

1. Multiple residential properties with maximum passby facade noise level calculated in worst case baseline noise model of 90 dBA or above.
2. Train speed 60 km/h or more (rail dampers are increasingly less effective at lower speeds)
3. Rail replacement not anticipated to occur before end of 2021 – this precludes rail damper installation between Main St and Broadway - Commercial Drive Stations, and between 22nd St and New Westminster Stations.
4. Tangent track with fastener spacing of 1000 mm, to fit the best performing rail dampers.

In addition, locations recommended for rail damper installation are expected to have maximum (worst case) train passby noise levels at some residential facades above 80 dBA even after implementation of all other mitigation measures including those under investigation in Phase 2. The elevation of the receiving residences relative to the guideway also means that parapet noise barriers (if not already present) would not provide more noise benefit than rail dampers.

The resulting recommended initial rail damper implementation locations are shown in Appendix A and are summarized in Table 2. The total recommended extent of rail dampers is 3.2 km.

Table 2 Rail Damper Implementation Locations

Location	Notes
Commercial-Broadway to Nanaimo	Specific locations targeted for maximum effect in high noise areas, excluding curves and switches. Damper installation in the inbound direction may be delayed until after completion of planned Phase 2 mitigation study trials of friction modifiers in this area.
Nanaimo to 29th Avenue	Majority of full speed track sections treated (at grade tangent track, high noise areas). Different extent inbound to outbound due to lower speeds inbound on approach to Nanaimo Station
29th Avenue to Joyce Collingwood	Majority of full speed tangent track sections west of Rupert St to be treated (at grade track, high noise areas).

Future rail replacement in these areas is not yet scheduled. When rail replacement does occur in these locations, the rail dampers should be reinstated on the new rails.

Following completion of the Phase 2 mitigation investigations and ongoing monitoring of progress towards the identified noise goals it is possible that additional rail damper implementation locations may be recommended in future.

10.5 Noise sensitive development guidelines recommendations

An interim guideline for new noise-sensitive developments has been prepared. It is recommended that ownership of the guidelines be transferred to an appropriate office of the BC government since administering an environmental noise guideline is outside of TransLink's remit. Further consultation with various stakeholders is likely to be required prior to finalization.

Implementation of these guidelines by developers and adoption by municipal planning authorities is recommended to ensure that appropriate residential amenity is achieved in future development projects.

11.0 OUTCOMES OF MITIGATION IMPLEMENTATION

A series of four scenarios have been calculated to illustrate the anticipated outcomes of implementation of the noise mitigation recommendations. These scenarios have each been calculated for two situations, with and without parapet noise barriers. While not specifically investigated in this study, parapet noise barriers remain an established noise mitigation measure for SkyTrain.

Recognizing that noise emissions are variable with track condition over time, these scenarios are indicative rather than specific to an individual location. All scenarios have been calculated using a flat ground model, with the guideway deck 10 m above ground. Noise levels have been calculated out to 150 m from the track centreline, and up to an elevation of 75 m above ground level (approximately the height of a 25 storey building). In all cases, the noise levels shown are indicative of the worst case passby maximum noise levels, or the noisiest time in the maintenance cycle. At many locations, the train passby noise level for much of the year will be less than shown.

The four noise mitigation scenarios calculated for each situation and shown in Figure 8 and Figure 9 are:

1. Baseline with softer rail or rail/switch surface condition giving noise levels 10 dB higher than track in good condition. Some residential facades if located within about a 30 m

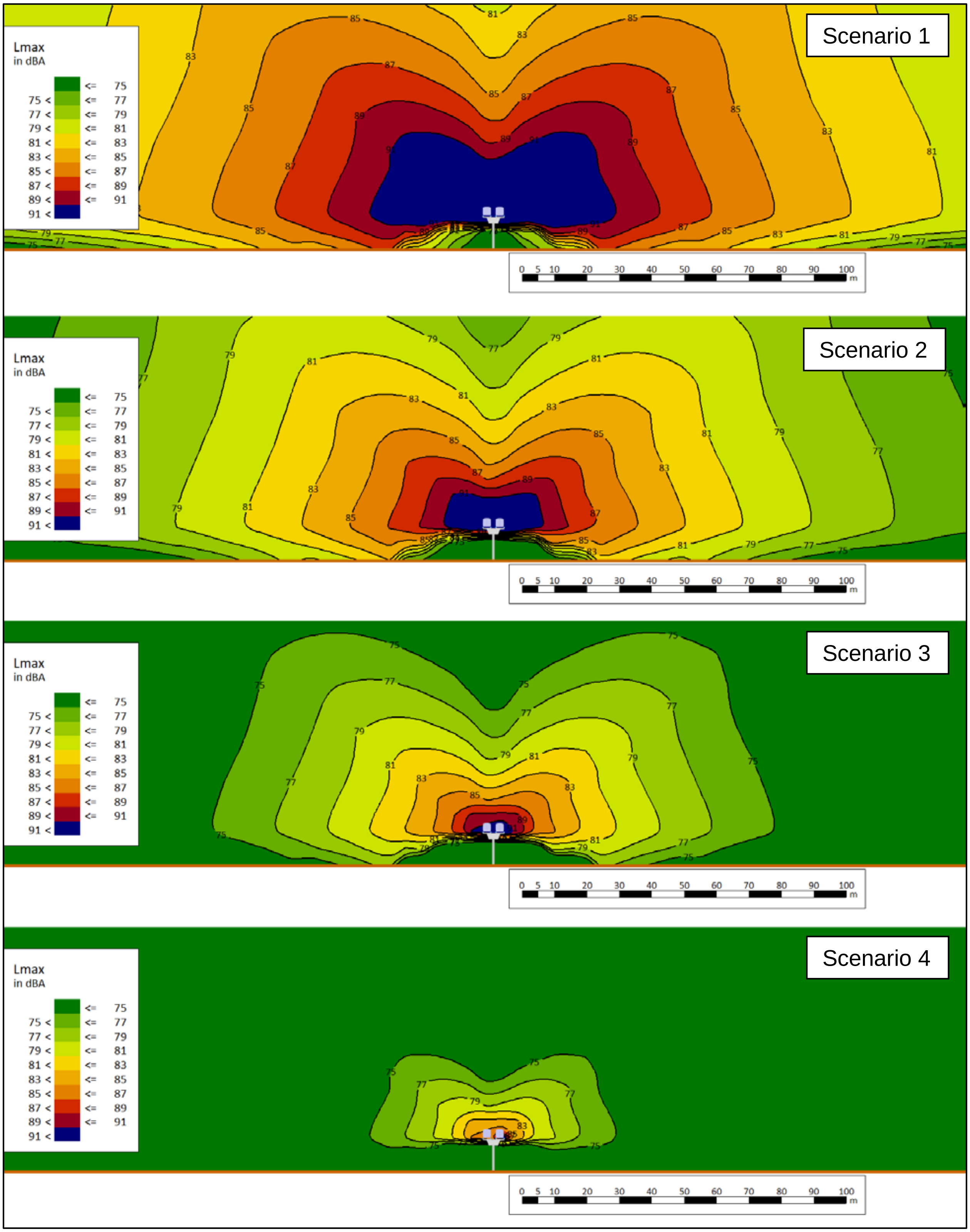
distance from the guideway are in the 90 dBA LAmax zone (or higher). This scenario is indicatively representative of some areas of the original Expo Line.

2. Harder rail steels giving typically improved surface condition, about a 5 dB benefit on average over the baseline scenario. This scenario is indicatively representative of areas adjacent to the Millennium Line, and some areas where newer rail has already been installed on the Expo Line.

3. Target with implementation of harder rail steel, friction modifiers and improved grinding (maintaining good condition), about a 10 dB benefit over the baseline. This scenario is representative of all areas of the network with successful implementation of these noise mitigation measures. Much of the Evergreen extension has noise levels close to this scenario already, primarily due to the use of harder rail steel, and resulting minimal grinding requirements.

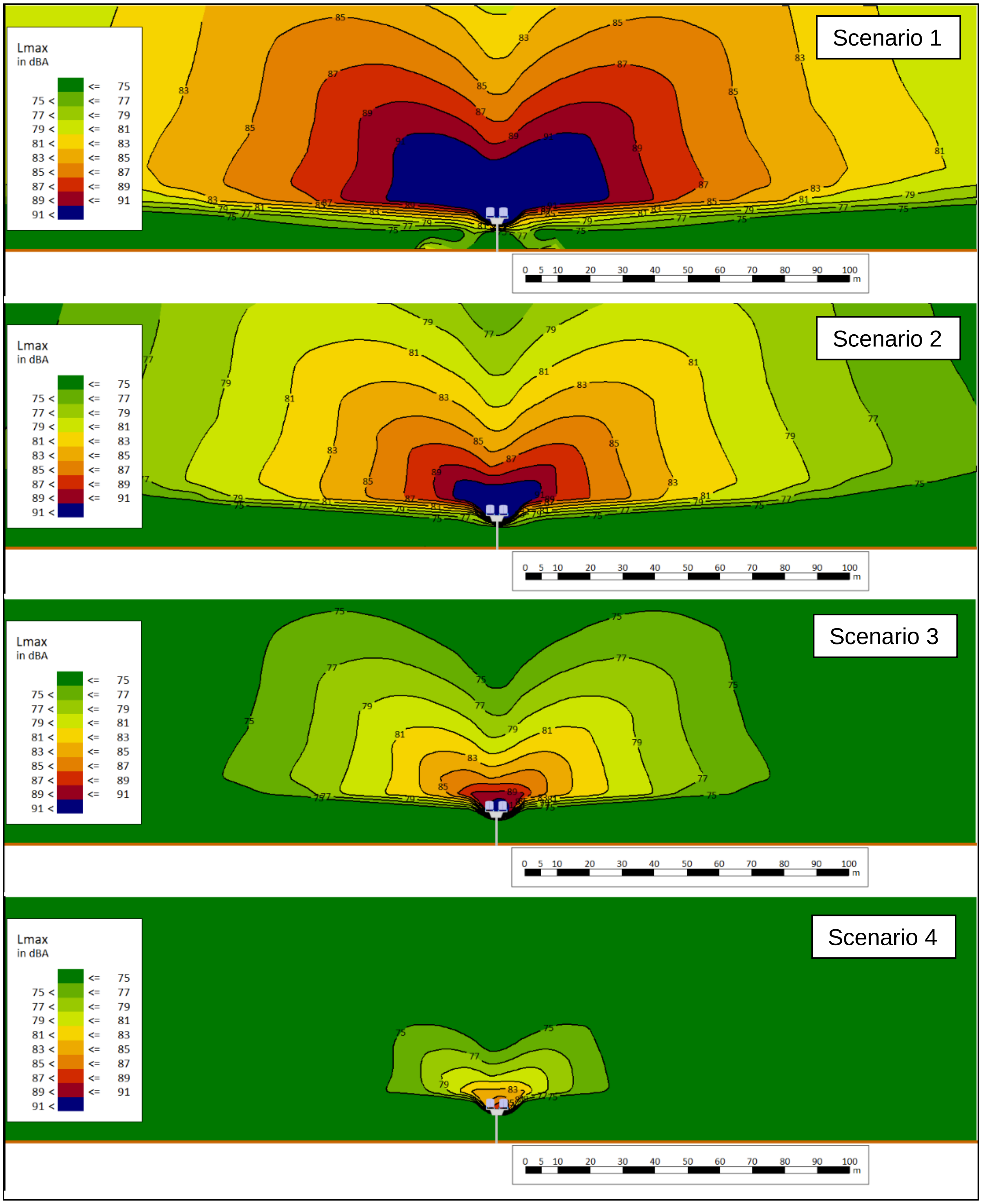
4. Full implementation of harder rail steel, friction modifiers and improved grinding, plus rail dampers giving an additional 6 dB benefit, ie a 16 dB benefit over the baseline. Rail dampers are expected to be needed only at particular locations, subject to ongoing verification of success of the mitigation project. Additional rail dampers may be recommended in future if the identified noise goals are not achieved at particular locations following implementation of other mitigation measures.

Figure 8 SkyTrain Maximum Noise Cross Sections Without Parapet Barriers



Note: See preceding paragraphs for descriptions of Scenario 1 - 4

Figure 9 SkyTrain Maximum Noise Cross Sections With Parapet Barriers



Note: See preceding paragraphs for descriptions of Scenario 1 - 4

11.1 Discussion of predicted outcomes and timeframes for implementation

Following the recommended plan for implementation of mitigation is expected to result in the following outcomes and timeframe:

1. Switch monitoring – implementation of a switch monitoring and maintenance program is expected to result in a reduction in noise from switches network wide from the time of implementation (2020) onwards.

2. Expo Line Rail replacement – rail replacement with harder rail steel is expected to result in reduced noise levels at specific rail replacement locations. Rail replacement has occurred or is scheduled to occur in the following locations through to the end of 2021:

    a. Stadium / Chinatown to Main St / Science World (currently underway)
    b. 22nd Street to New Westminster scheduled in 2020 and 2021
    c. Main Street to Broadway scheduled in 2021

    Rail replacement in other Expo line locations would follow through to about 2030, with no specific schedule available at this time.

3. Friction Modifier and improvements to rail grinding – implementation of these mitigation measures is expected to occur from 2022 onwards and have network-wide benefits.

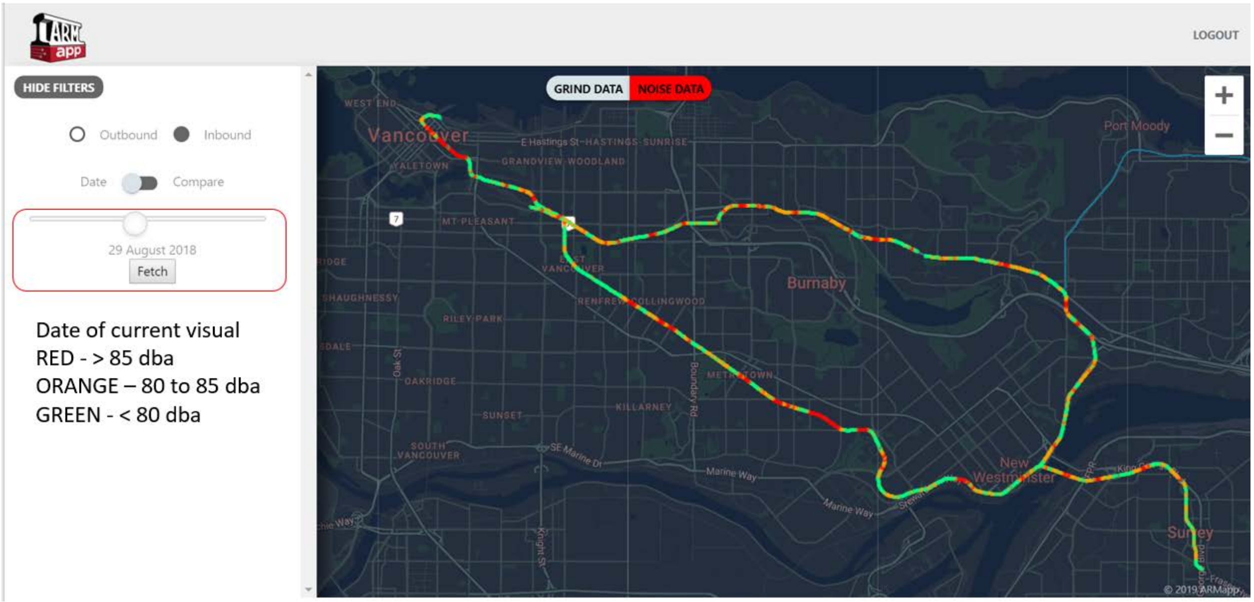
4. Rail dampers – implementation of this mitigation measure at the identified highest priority locations is expected to reduce noise levels between Commercial / Broadway station and Joyce Station with installation in 2020 / 2021.

12.0 VERIFICATION OF MITIGATION PROGRAM EFFECTIVENESS

12.1 Ongoing measurement of test train in-car noise levels

The ongoing monitoring and verification of noise mitigation program effectiveness has several components. The first is ongoing monitoring of track condition by measurement of in-car noise levels as currently undertaken by BCRTC each week. It is recommended that this data be presented visually – an example of this is shown in Figure 9. The in-car noise data could either be presented as a direct noise level (as shown), or as the noise level difference above the best case rail condition for each location. Presentation of results as a difference from best case condition is recommended as in this way the proportion of the network with noise levels within 5 dB of the best case (an overall Key Performance Indicator for the mitigation program) can be visualized. This approach also removes the effects of train speed and tunnels on the data presented.

Figure 10 Example visualization of rail condition



12.2 Passby noise measurements at representative locations

Undertaking an ongoing annual series of measurements of train passby noise at representative locations around the network is recommended to enable direct reporting of the effectiveness of the noise mitigation program in the long term and a point of comparison for the use of in-car noise data to monitor track condition.

The key requirements of these measurement locations are as follows:

1. All measurement locations should be publicly accessible and reproducible in future years
2. All measurements should utilize a microphone elevated above rail height. If noise barriers are present, then the microphone must be located above the top of the barrier.
3. The preferred horizontal offset distance for measurements is 15 m to 30 m from the near track centreline. Other offset distances between 5 m and 50 m of the near track centreline are acceptable if measuring at the preferred distance is not feasible.
4. All measurement locations should enable measurement of train passby noise without excessive influence from road traffic noise (this may require measurement closer to the tracks than the preferred range at some locations).

A total of 15 representative measurement locations have been identified around the network and are described in Appendix A.

It is recommended that measurements at all locations are completed in spring or summer. While the timing of the measurements is somewhat arbitrary, this would place the measurements around 6 months after completion of the annual contract rail grinding campaign. At all locations, measurements should be undertaken a minimum of two months after rail grinding. A total of 20 train passby events should be measured at each location in each direction for a total of 40 train passby events.

12.3 Annual reporting on mitigation program effectiveness

The final component of ongoing monitoring and verification of effectiveness is annual reporting. This annual reporting should include assessment of track condition variation (90th percentile vs 10th percentile) using the in-car noise data. Monitoring this parameter is recommended to track progress towards the noise goals. The objective is to see that over time, the difference between the best case and worst case noise levels decreases indicating track condition and hence noise levels are stable over time and are maintained close to best case condition.

Annual reporting would also document the results of the passby noise measurements at representative locations and provide direct feedback on SkyTrain noise emissions and trends over time. Annual reporting provides a mechanism to review the mitigation program effectiveness and make recommendations for additional mitigation at specific locations if required.

13.0 CONCLUSIONS

This report describes the results of investigations of the feasibility and effectiveness of four noise mitigation measures, with two other mitigation measures still under investigation. Recommendations are provided for implementation of noise mitigation for SkyTrain, considering the interactions between the various mitigation measures.

The primary conclusion of the study is that reducing noise from SkyTrain is feasible in the long term. The key factor in this conclusion is that parts of the network are already much quieter than others – the objective of noise mitigation is to achieve the current best-case noise emissions across more of the network, and to keep noise levels as low as possible in between maintenance cycles.

Achieving a meaningful noise reduction in a cost-effective way will require a combination of different noise mitigation measures. Progressing the implementation of all six mitigation measures as described in this report and the attached preliminary implementation plan is recommended.

14.0 STATEMENT OF LIMITATIONS

This report has been prepared and the work referred to in this report has been undertaken by SLR Consulting (Canada) Ltd. (SLR) for Translink, hereafter referred to as the “Client”. It is intended for the sole and exclusive use of Translink. The report has been prepared in accordance with the Scope of Work and agreement between SLR and the Client. Other than by the Client and as set out herein, copying or distribution of this report or use of or reliance on the information contained herein, in whole or in part, is not permitted unless payment for the work has been made in full and express written permission has been obtained from SLR.

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global environmental solutions

Calgary, AB
#200, 708 – 11th Avenue SW
Calgary, AB T2R 0E4
Canada
Tel: (403) 266-2030
Fax: (403) 263-7906

Edmonton, AB
6940 Roper Road
Edmonton, AB T6B 3H9
Canada
Tel: (780) 490-7893
Fax: (780) 490-7819

Guelph, ON
105 – 150 Research Lane
Guelph, ON N1G 4T2
Canada
Tel: (226) 706-8080
Fax: (226) 706-8081

Grande Prairie, AB
9905 97 Avenue
Grande Prairie, AB T8V 0N2
Canada
Tel: (780) 513-6819
Fax: (780) 513-6821

Kamloops, BC
8 West St. Paul Street
Kamloops, BC V2C 1G1
Canada
Tel: (250) 374-8749
Fax: (250) 374-8656

Kelowna, BC
107 - 1726 Dolphin Avenue
Kelowna, BC V1Y 9R9
Canada
Tel: (250) 762-7202
Fax: (250) 763-7303

Markham, ON
200 - 300 Town Centre Blvd
Markham, ON L3R 5Z6
Canada
Tel: (905) 415-7248
Fax: (905) 415-1019

Nanaimo, BC
9 - 6421 Applecross Road
Nanaimo, BC V9V 1N1
Canada
Tel: (250) 390-5050
Fax: (250) 390-5042

Ottawa, ON
400 – 2301 St. Laurent Blvd.
Ottawa, ON K1G 4J7
Canada
Tel: (613) 725-1777
Fax: (905) 415-1019

Prince George, BC
1586 Ogilvie Street
Prince George, BC V2N 1W9
Canada
Tel: (250) 562-4452
Fax: (250) 562-4458

Regina, SK
1048 Winnipeg Street
Regina, SK S4R 8P8
Canada
Tel: (306) 525-4690
Fax (306) 525-4691

Saskatoon, SK
620-3530 Millar Avenue
Saskatoon, SK S7P 0B6
Canada
Tel: (306) 374-6800
Fax: (306) 374-6077

Toronto, ON
36 King Street East, 4th Floor
Toronto, ON M5C 3B2
Canada
Tel: (905) 415-7248
Fax: (905) 415-1019

Vancouver, BC (Head Office)
200-1620 West 8th Avenue
Vancouver, BC V6J 1V4
Canada
Tel: (604) 738-2500
Fax: (604) 738-2508

Victoria, BC
303 – 3960 Quadra Street
Victoria, BC V8X 4A3
Canada
Tel: (250) 475-9595
Fax: (250) 475-9596

Whitehorse, YT
6131 6th Avenue
Whitehorse, YT Y1A 1N2
Canada
Tel: (867) 688-2847

Winnipeg, MB
1353 Kenaston Boulevard
Winnipeg, MB R3P 2P2
Canada
Tel: (204) 477-1848
Fax: (204) 475-1649

Yellowknife, NT
1B Coronation Drive
Yellowknife, NT X1A 0G5
Canada
Tel: (867) 688-2847