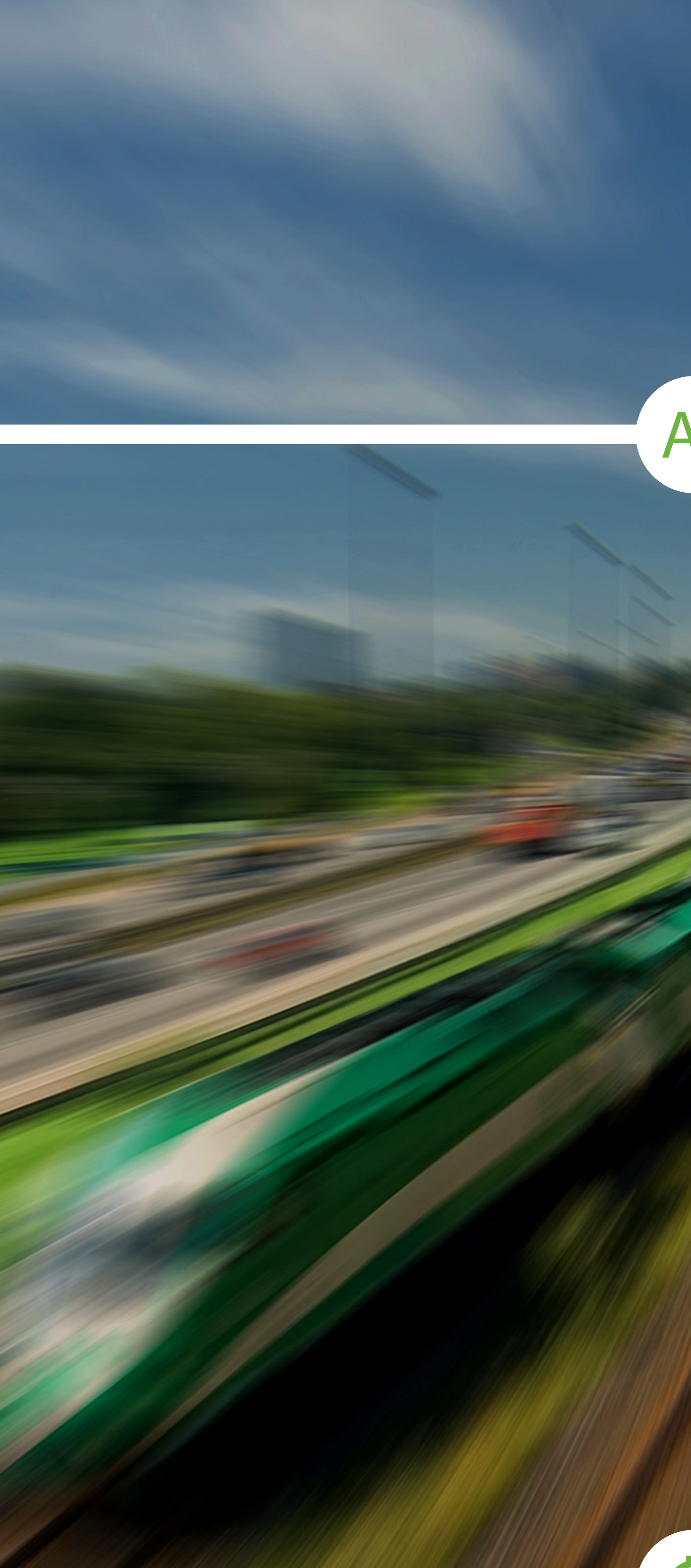

Appendix 8E

Noise & Vibration Impacts

December 2010

METROLINX
An agency of the Government of Ontario

APPENDIX 8E

Noise & Vibration Impacts

December 2010

Prepared for:

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EXECUTIVE SUMMARY

Metrolinx operates a comprehensive transportation system of bus and commuter rail lines in the Greater Toronto and Hamilton Area (GTHA). The system includes the GO rail network, which is an essential part of Metrolinx's service to the area commuters. GO Transit currently provides commuter rail service on seven corridors in the GTHA, using conventional diesel locomotives and non-powered, bi-level coaches in push-pull configuration.

Metrolinx has initiated a study of the electrification of the entire GO Transit rail system as a future alternative to diesel trains now in service. The Electrification Study examines how the future GO rail services will be powered – using electricity, enhanced diesel technology or other means – when improved services are implemented in the future. The Electrification Study assesses the benefits and costs of a full range of technology options, including enhanced diesel, electric and alternative technologies. The Electrification Study considers the existing GO Transit network, the proposed network expansions to St. Catharines, Kitchener/Waterloo, Allandale, Bloomington, Bowmanville, as well as the future Pearson Air Rail Link via six short-listed electrification options. The Electrification Study is intended to provide Metrolinx's Board of Directors with the information needed to decide how GO trains will be powered in the future.

As part of the overall evaluation, the effects of the new technologies on noise and vibration have been considered. The main objective of these studies is to consider the relative noise and vibration benefits of the various electrification options compared to a Reference Case that assumes Tier 4 diesel locomotives over the entire network.

Screening-level noise and vibration modeling was conducted for the Reference Case and electrification options over all the corridors. Modelling inputs, methodology, and assumptions are detailed in this White Paper. The results of the modeling were used to define "Zones of Influence" based on criteria contained in the *MOEE / GO Transit Draft Protocol for Noise and Vibration Assessment* (1994). The resulting Zones of Influence were used to identify potentially affected populations. An overall evaluation of each electrification option was then considered based on the affected populations and the predicted changes in the overall sound and vibration levels for each corridor.

Based on the assessment results, there is a slight positive benefit for noise and vibration for two of the options (i.e., total or near-total electrification of the entire rail network) due to the widespread electrification of multiple corridors. Other options remain neutral for noise and vibration, even though individual corridors within each option may see a slight positive benefit in switching from diesel to electric locomotives.

GLOSSARY OF TERMS

Term	Definition
A-weighting	A frequency weighting network used to simulate the relative response of the human ear to sound at typical outdoor ambient volume levels. It de-emphasizes the high (i.e., 6.3 kHz and above) and low (i.e., below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz.
Airport Rail Link (ARL)	Express rail shuttle service between Union Station and Toronto Pearson International Airport.
Background Ambient Noise Level	The background ambient noise level due to existing road traffic and industrial noise sources.
Day-Night Average Sound Level (DNL)	A 24-hour time-averaged Leq, adjusted by a 10 decibel penalty for sounds occurring during the night period (i.e., 23:00h and 07:00h local time).
Daytime	Defined as the hours from 07:00h to 19:00h.
Decibel (dB)	A logarithmic measure of any physical quantity and commonly used in the measurement of sound. The decibel (dB) provides the possibility of representing a large span of values in a simple manner.
Energy Equivalent Sound Level (Leq)	An energy-average level over a specified period of time that has the same sound energy as the actual fluctuating (i.e., unsteady) sound over the same period. The time period is generally included as a suffix to the label (i.e., Leq(24) for the 24 hour equivalent sound level). An Leq value expressed in dBA is a good, single value descriptor of the annoyance of noise.
Evening	Defined as the hours from 19:00h to 23:00h.
Geographic Information System (GIS)	Computer tool that captures, stores, analyzes, manages and presents data that are linked to physical locations. For example the mapping of population data.
GTHA	Greater Toronto and Hamilton Area.
Network Options	An alternative to the Reference Case network, involving the use of a short listed rolling stock technology on one or more GO lines.
Night	Defined as the hours from 23:00h to 07:00h.
Noise	Any unwanted sound. "Noise" and "sound" are often used interchangeably for assessment purposes.
Ontario Ministry of the Environment (MOE, formerly MOEE)	Provincial body mandated with developing, implementing and enforcing regulations and other programs and initiatives aimed at addressing environmental issues that have local, regional and/or global effects. Also formerly known as the Ontario Ministry of the Environment and Energy (MOEE).
Peak Particle Velocity (PPV)	The maximum instantaneous peak velocity in a vibration signal.

Term	Definition
Reference Case	The base case against which future technology and network options are compared. This base case incorporates existing attributes and approved/planned enhancements of GO's rolling stock, rail infrastructure and service levels.
Root-Mean-Square (RMS) Velocity	The square root of the average of the squared amplitude of a velocity signal.
Sound from Trains Environmental Assessment Method (STEAM)	A calculation algorithm developed by the Ontario Ministry of the Environment for the assessment of train noise.
United States Federal Transit Administration (U.S. FTA)	An operating agency of the United States Department of Transportation responsible for supporting public transit systems throughout the United States.
Zone of Influence (ZOI)	Zone defined by the distance from the centre of the rail corridor within which GO & ARL operations are expected to result in a notable change in noise or vibration relative to existing ambient levels.

NOTE: Use hereafter of the terms "we", "our" or similar means "Delcan/Arup Joint Venture team".

1. INTRODUCTION

1.1 Context

Metrolinx operates a comprehensive transportation system of bus and commuter rail lines in the Greater Toronto and Hamilton Area (GTHA). The system includes the GO rail network, which is an essential part of Metrolinx's service to the area commuters. GO Transit currently provides commuter rail service on seven corridors in the GTHA, using conventional diesel locomotives and non-powered, bi-level coaches in push-pull configuration.

In late 2008, Metrolinx published a Regional Transportation Plan – The Big Move – a multimodal vision for regional transportation to strengthen the economic, social and environmental sustainability of the Greater Toronto and Hamilton Area. The Big Move sets out a fast, frequent and expanded regional rapid transit network as a key element of the plan. The plan includes establishing Express Rail and Regional Rail services at speeds and frequencies that could be enhanced by system electrification.

1.2 GO Electrification Study

Metrolinx has initiated a study of the electrification of the entire GO Transit rail system as a future alternative to diesel trains now in service. The Electrification Study is examining how the future GO rail services will be powered – using electricity, enhanced diesel technology or other means – when improved services are implemented in the future. The Electrification Study will assess the benefits and costs of a full range of technology options, including enhanced diesel, electric and alternative technologies. The Electrification Study will consider the existing GO Transit network, the proposed network expansions to St. Catharines, Kitchener/Waterloo, Allandale, Bloomington, Bowmanville, as well as the future Pearson Air Rail Link.

The Final Report of the Electrification Study will be based on the results of a comparative analysis of network options as outlined in Appendix 1. The comparative analysis of network options considers 6 broad evaluation categories:

- Environmental & Health;
- User Benefits/Quality of Life;
- Social-Community;
- Economic;
- Financial; and
- Deliverability.

The final stage of the Study (Stage 5) involves conducting a detailed assessment of corridor/technology scenarios in terms of the above evaluation categories. However, for the purposes of the detailed assessment, the 6 broad evaluation categories listed above were each broken into sub-categories. The sub-categories are geared towards specific realms of knowledge and technical specialization in order to promote a comprehensive analysis.

1.3 Noise & Vibration White Paper

The evaluation category that is relevant to this White Paper is Environmental & Health Impacts, which is divided into the following 6 sub-categories:

- Emissions Reductions;
- Noise and Vibration;
- Health;
- Terrestrial Ecosystem;
- Aquatic Ecosystem; and
- Effects on Parks / Public Open Space.

This White Paper describes the approach for the noise and vibration assessment to be conducted under the overarching Environmental & Health Impacts category. Included in this paper are sections providing:

- An overview of the considerations associated with the noise and vibration discipline;
- The objectives addressed by the noise and vibration discipline;
- Assumptions for the noise and vibration discipline;
- Criteria, indicators and data sources for the noise and vibration assessment;
- Assessment of Options;
- Conclusions; and
- References.

2. OVERVIEW OF NOISE & VIBRATION CONSIDERATIONS

This noise and vibration assessment evaluates the relative benefits of various options for electrification of GO Transit's rail system. A short-list of six electrification options was considered, representing electrification of different parts of the network as well as electrification of the complete network. These options were compared to the Reference Case, operating scenario using Tier 4 diesel technology throughout the rail network.

The influence of noise and vibration was considered in comparing the six electrification options. For noise and vibration, the relative benefit depends strongly on the magnitude of the change between the Reference Case and the electrification option being considered. In addition, any potential benefit depends on the current noise and vibration levels in the affected areas. Since sound and vibration behave logarithmically, a relatively large change in level is necessary to result in significant perceptible benefits.

The benefit of electrification also depends on where a receptor is situated. Locomotive noise and vibration emissions are most concentrated within or immediately adjacent to the rail corridor and become less influential farther away. Therefore, it is of interest to know how many people live within a certain distance of the corridors, where the benefit is greatest.

2.1 Noise

Sounds of varying types are present throughout our environment and humans evaluate its influence in a subjective way. Unwanted sounds, or noise, tend to produce annoyance that leads to emotional responses and various social and societal issues. Naturally-occurring sounds are generally well-accepted by people, while noise associated with human activities can be a concern. Most human activities generate noise, and as development expands into the environment, the evaluation of potential noise effects on the surroundings is often a consideration.

Sound travels through a fluid medium, such as air, as a pressure wave (i.e., oscillating air pressures). The pressure fluctuations and frequency content of the waves are sensed by the ear and interpreted by the brain as sound. The loudness, frequency content, and duration of the sound produce its character. The relative loudness of a sound can be measured using various parameters, but is commonly expressed in sound pressure at a distance from a source. The ear is capable of resolving a wide dynamic range of sound pressure levels from micropascals (i.e., one millionth of a pascal or 10^{-6} pascals) to terapascals (i.e., trillions or 10^{12} pascals). As a result, a logarithmic scale (i.e., based on powers of 10) is used to express sound quantities to make them more meaningful. The unit of this scale is the decibel (dB). The reference level for sound pressure is 20 micropascals (i.e., 2×10^{-5} pascals) which is considered the threshold of human hearing. By definition, a sound pressure of 20 micropascals is equivalent to 0 dB.

Due to the wide dynamic range of the ear, fairly large changes in sound pressure are necessary to be perceived. Table 1 summarizes the human perception of various changes in sound level.

Table 1 – Accepted Human Perception of Changes in Sound Level

Change in Sound Level (dB)	Human Perception of Change
<3	Imperceptible change
4 – 5	Just-perceptible change
6 – 9	Clearly noticeable change
> 10	Substantial change (perceived as twice or half as loud)

The relative loudness of a sound to the human ear also varies by its frequency (i.e., pitch), with the highest sensitivity at the frequencies of speech (i.e., mid-frequencies) and less sensitivity at low or high frequencies. This frequency response is approximated using frequency weighting scales, with the A-weighting network being the most common for environmental noise parameters. Hence, sound parameters are often expressed in A-weighted decibels (dBA).

Finally, the time-varying aspect of a sound, or the ear's exposure to a sound, influences the overall psychological response. The energy equivalent sound level (Leq) represents the energy-average over a specified time period that would have the same sound energy as the fluctuating (i.e., unsteady) sound over the same period. Common time periods for Leq values include 1-hour, 8-hour (i.e., usually the night-time from 23:00h to 07:00h), 16-hour (i.e., usually the daytime from 07:00h to 23:00h), and 24-hour. Decades of research on the human response to noise has shown that longer durations of the energy equivalent sound level expressed in A-weighted decibels is a good, single number descriptor of the influence of noise, particularly for transportation noise. As a result, most environmental noise criteria are expressed using this parameter.

In the absence of specific descriptors, the term "sound level" can normally be considered to be a sound pressure level expressed in A-weighted decibels. A summary of typical sound levels is shown in Table 2. Other common sound levels include the passby sound level, which is the maximum sound pressure level (Lmax) experienced at a point during a short duration vehicle passby. A summary of the maximum passby noise from various transportation sources is summarized in Figure 1. While these maximum values may approach some of the levels in Table 2, which are commonly sustained sound levels, they are importantly of shorter duration (i.e., passby levels) and thus have less impact on the average.

Table 2 – Range of Sound Levels for Typical Noise Sources

Sound Levels		Sources of Noise
Human Perception	Sound Pressure Level (dBA)	
Deafening	125	Sonic booms
	120	Threshold of Feeling / Pain
	115	Maximum level, hard rock band concert
	110	Accelerating Motorcycle at a few feet away
Very Loud	105	Loud auto horn at 3 m away
	100	Dance club / maximum speech output at 1 m
	95	Jack hammer at 15 m distance
	90	Indoors in a noisy factory
Loud	85	Heavy truck pass-by at 15 m distance
	80	School cafeteria / Vacuum Cleaner at 1.5 m
	75	Near edge of major Highway
	70	Inside automobile at 60 km/h
	65	Normal human speech at 1 m distance
Moderate	60	Background noise levels in department store
	55	
	50	
	45	Typical background noise levels in an office
Faint	40	Typical background noise levels in a library
	35	
	30	Broadcast Studio
	25	Average whisper
Very Faint	20	Deep woods on a very calm day
	15	
	10	
	5	Human breathing
	0	Threshold of human hearing (20 micropascal reference level)

Sound pressure level is used to express the magnitude of sound at a point in space, such as a residence, and is useful to describe a person's response to the sound. Sound pressure depends on a number of factors including distance from the source, direction, and atmospheric conditions. As a sound wave radiates from a source and spreads out, it has less energy at any point in space. As a result, its sound level is lower. In other words, the magnitude of a sound decays with distance from a source, so the farther one moves away, the quieter the source becomes. Figure 2 shows an example of how sound decays with distance from a line source such as a rail line. At sufficient distance, a noise source becomes inaudible relative to the existing ambient sounds. As a result, the evaluation of noise effects can generally be confined to the local area surrounding the source.

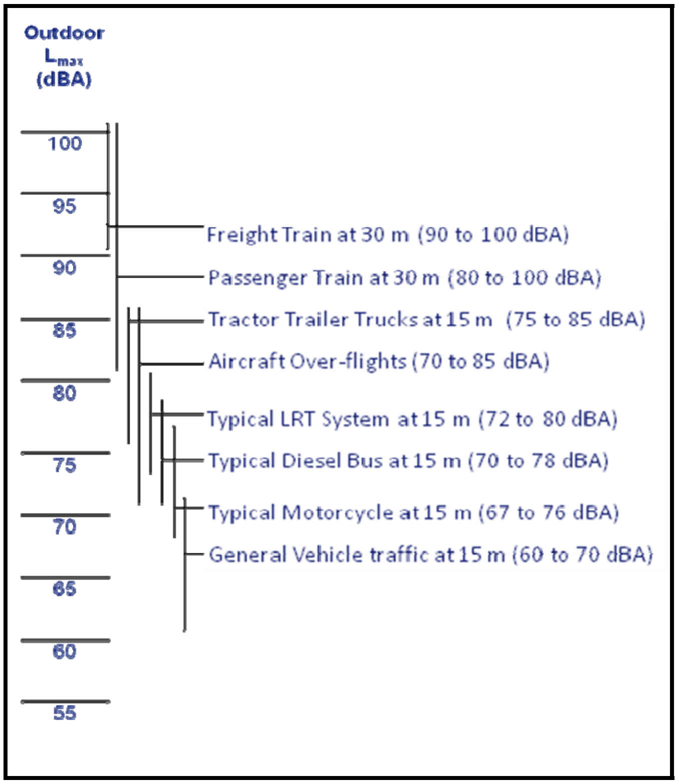

Figure 1 – Typical Maximum Passby Sound Levels of Various Transportation Sources

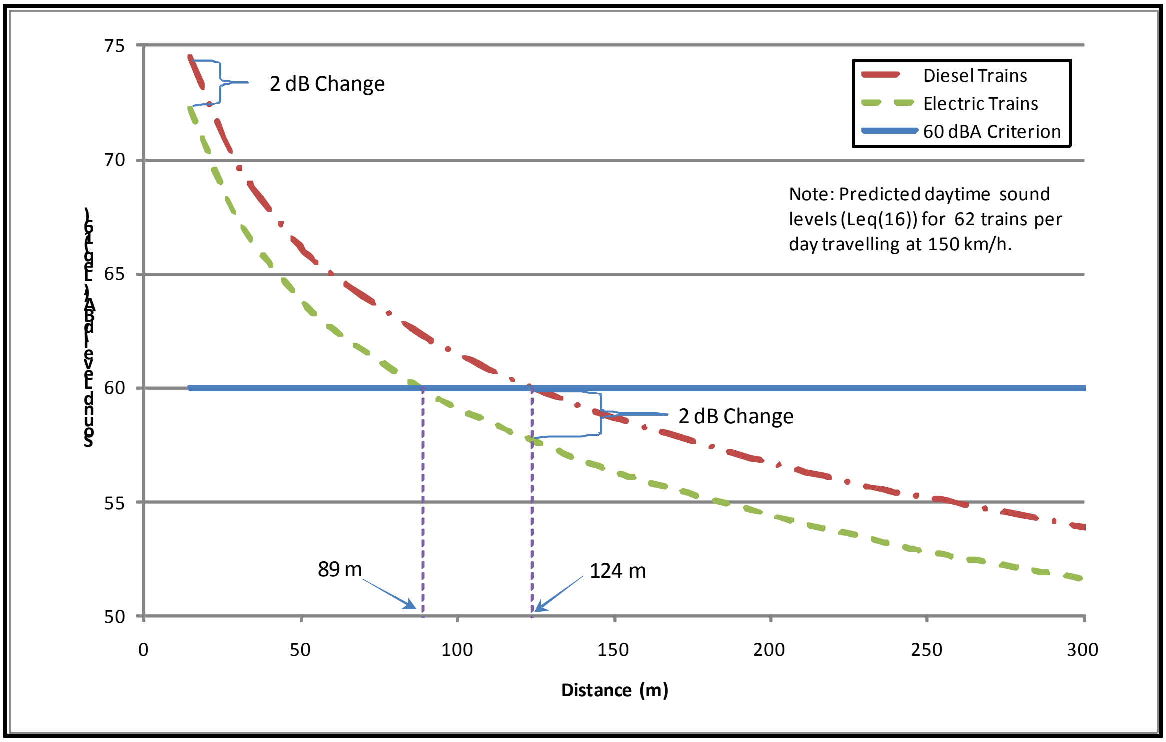

Figure 2 – Example Decay of Sound Levels with Distance

All modes of transportation generate noise to some degree, particularly those associated with mechanical systems or moving parts, such as wheels or engines. For ground transportation, including automobiles and trains, the main sources of noise emanate from the wheels (i.e., interaction with the road or rail) and the engine. The influence of wheel noise is shown in Figure 2 above, where the overall difference between the two curves is 2 dB at any distance even though the diesel locomotive is 3 dB louder than the electric locomotive. The smaller difference is due to the wheel-generated noise of the locomotives and rail cars that is present for both technologies. Such differences of 2 to 3 dB are in fact small in dealing with sound, and as shown in Table 1, represent imperceptible changes to the average person.

Compared to the automobile, both diesel- and electric-powered passenger rail services offer an efficient way of transporting people, with a net reduction in noise emissions compared to single-occupancy vehicles. The service levels considered in the Reference Case and each of the electrification options reflect increased commuter ridership, meaning fewer cars on the road. Since the benefits of removing this road traffic would be nearly equal for the Reference Case and each of the electrification options, the key consideration is the reduction in noise emissions related to powering the locomotives for each option relative to the Reference Case.

2.2 Vibration

Vibrations travel through solid mediums as waves in a similar way to how sound travels through fluid mediums. Vibration is an oscillating motion with no net movement (i.e., moves positively or negatively around a reference point) that can be described in terms of displacement, velocity or acceleration. Displacement is generally the easiest to understand. For a vibrating floor, it represents the distance the floor moves away from its static position. Velocity is the instantaneous speed of the floor's movement and acceleration is the rate of change of the speed. The response of humans, buildings, and equipment to vibration is most accurately described using velocity and acceleration; hence, these are most commonly used in evaluating vibration. As shown in Figure 3, the peak particle velocity (PPV) is the maximum instantaneous velocity (positive or negative) produced in a vibration signal. This parameter corresponds well to evaluating potential building damage since it relates to the stresses a building would experience. However, it takes some exposure time for humans to respond to vibration, typically something more like the average vibration. Hence, the root-mean-square (RMS) velocity, which describes a "smoothed" or statistically averaged vibration amplitude, is used when evaluating human response to vibration.

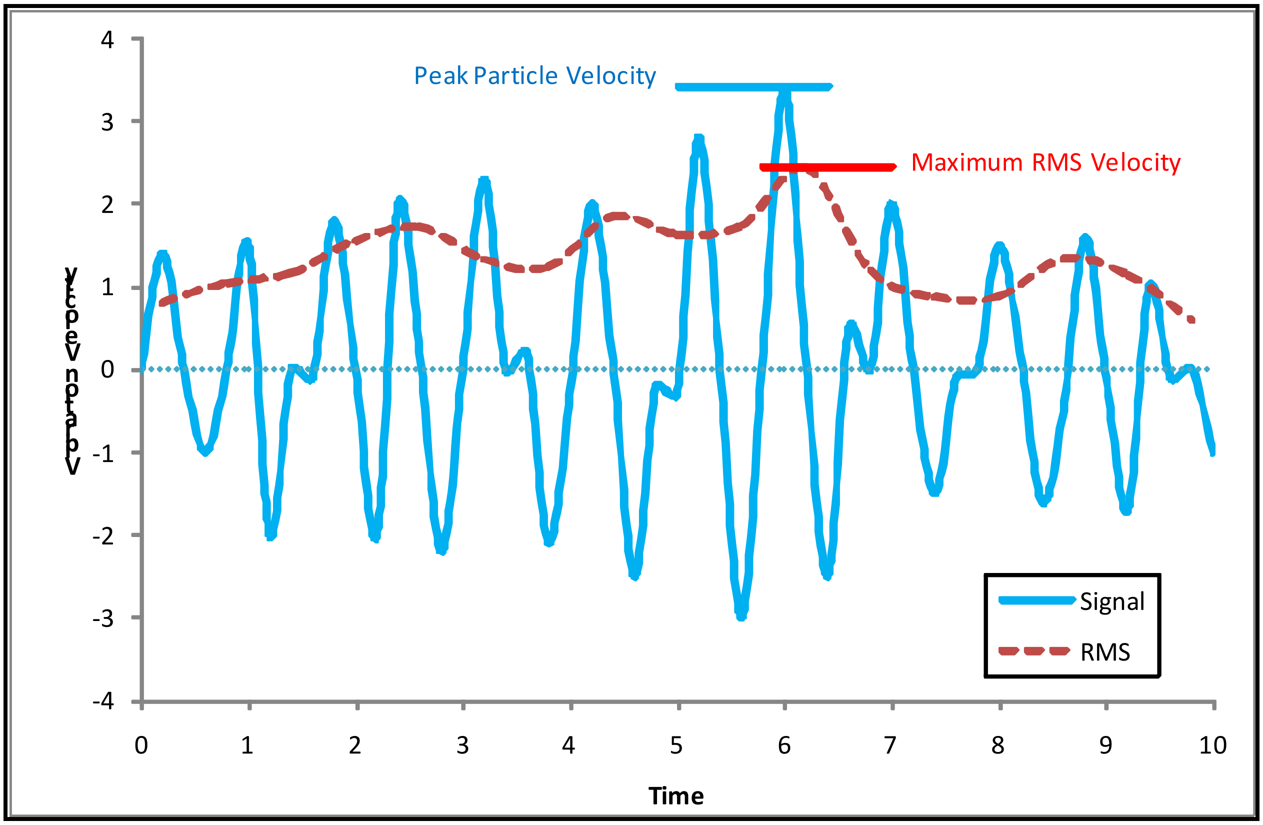

Figure 3 – Vibration Velocity Parameters

Similar to noise, vibration can also create nuisance effects that lead to annoyance and concern by affected receptors. These can include perceptible movements of structures or effects such as window or picture rattling. Perceptible vibrations are typically generated by large moving masses or very loud sound levels (i.e., sound-induced vibration) at close distances to a receptor. As a result, vibration impacts are normally associated with large or heavy modes of transport, such as trains, airplanes, or large trucks rather than lighter modes of transport such as automobiles. Vibration levels can also differ within a mode of transport; for example trains tend to produce higher vibration emissions than lighter rail vehicles such as Light Rail Transit or Diesel/Electric Motive Units. Figure 4 shows typical vibration velocity levels for various transportation sources expressed as average (root-mean-square or RMS) velocities in mm/s. Vibration velocity can also be expressed in decibels similar to sound, but are denoted as VdB to differentiate from sound decibels. Throughout this assessment vibration decibels are referenced to a vibration level of 1 microinch per second, or 2.54×10^{-5} mm/s.

Vibration velocities in the 0.05 to 0.1 mm/s (i.e., 65 to 72 VdB) range represent the lower extreme of human vibration perception and are generally barely perceptible, if at all. Velocities in the 0.14 to 0.2 mm/s (i.e., 75 to 78 VdB) range may generate just perceptible vibration in residences which often causes annoyance. More frequent events (i.e., passbys every 5 to 10 minutes) use the lower end of this range while infrequent events use the higher range of the perception threshold. Based on these ranges, a change of at least 3 VdB would be necessary to change the perception from barely perceptible to just perceptible (i.e., 72 VdB to 75 VdB). Differences of less than 3 VdB are unlikely to be noticeable.

Vibration effects tend to be highly localized however, as ground-borne vibrations tend to decay much quicker over distance than sound, except in very unique ground circumstances. Hence, vibration zones of influence tend to be much smaller than their sound counterparts.

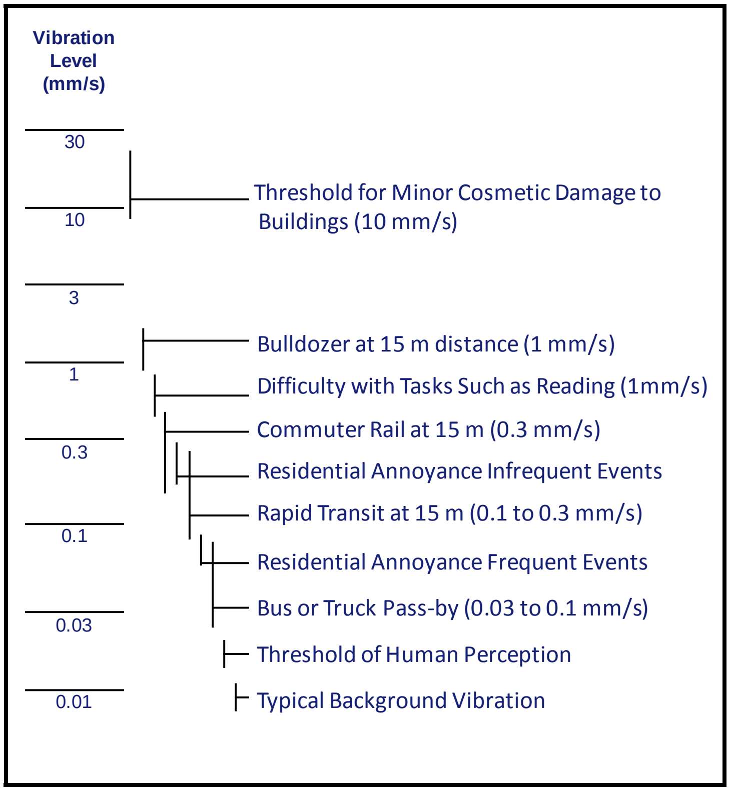

Figure 4 – Typical Passby Vibration Levels of Various Transportation Sources

3. OBJECTIVES ADDRESSED BY DISCIPLINE

Appendix 1, *High Level Decision Making Framework*, identified a key objective relevant to noise and vibration under the 'Community and Land Use' category as:

> *The selected technology should be implemented in a manner that will minimize adverse community/social impacts including aesthetic impacts and impacts from noise and vibration.*

This objective was also presented at a March 31, 2010 Stakeholder workshop for public comment. The noise and vibration assessment was designed to assess the change in noise and vibration levels in the local adjacent communities due to the proposed electrification options. The results will be used to help minimize the community/social impacts.

Findings from the noise and vibration assessment may also be used to influence other disciplines, including social, health & safety, and economic considerations, to ensure the overall objectives of the *High Level Decision Making Framework* are addressed.

This study is designed to identify zones (i.e., influence areas) where GO Transit's contributions to train noise or train-induced vibrations would trigger the need to investigate mitigation measures, based on the approach and criteria in the MOEE/GO Transit Draft Protocol (MOEE/GO Transit, 1994). The approach was based on that used for the Georgetown South and Airport Shuttle, and other applicable projects to the extent possible. However, for consistency and comparison purposes, screening-level calculations were conducted to estimate the corridor setbacks where the level of noise or vibration would suggest mitigation may be required. For train noise, the MOE "Sound from Trains Environmental Analysis Method (STEAM)" algorithms were used to determine the Zones of Influence (MOEE/GO Transit, 1994). For vibration, screening-level calculations using the methods of the United States Department of Transportation (DOT) - Federal Transit Administration (FTA) were used to determine the zone of influence (U.S. DOT, 2006). These zones were then used along with identified population density and sensitive receptors for the Reference Case and the various electrification options to quantify potential noise and vibration impacts for each option.

As the calculations are screening-level, they are not intended to accurately reproduce absolute sound or vibration levels in a specific area, which would be highly site-specific. Rather, they propose a consistent methodology that can be used to appropriately assess the potential change in conditions between various electrification options, thereby allowing the assessment of a preferred alternative.

4. ASSUMPTIONS FOR THE NOISE AND VIBRATION ASSESSMENT

The following is a list of assumptions relating to the purpose of this assessment:

- The noise and vibration assessment contributes to Stage 5 of the Electrification Study, which is the detailed assessment stage and involves the comparison of six network options.
- The assessment is designed to evaluate electrification options relative to the Tier 4 diesel reference case with the intention of generating information helpful for decision making by Metrolinx.
- Several assumptions on the network operation were necessary to allow a useful, consistent inter-comparison of alternatives. The assessment is not intended to accurately predict absolute sound or vibration levels.
- This assessment is not intended to replace the detailed noise and vibration assessments that would be required as part of future environmental assessments for any sections of the network subject to changes in infrastructure or changes from currently approved service levels.

The following is a list of assumptions relating to the scenarios considered in the assessment:

- The 'benchmark' or 'base case' used as the point of comparison for the six short-listed electrification options is the Reference Case.
- The Reference Case is a hypothetical operating scenario with defined service levels and schedules for each of the seven GO Transit rail corridors plus the ARL shuttle service.
- The Reference Case is based on operation of Tier 4 diesel locomotives on GO Transit corridors and diesel multiple unit vehicles (DMUs) on the Airport Rail Link (ARL).
- The six short-listed electrification options under evaluation are as summarized in Table 3 and represent replacement of diesel locomotives with electric locomotives, and for the ARL, replacement of DMUs with electric multiple unit vehicles (EMUs).
- The evaluation period is for the years 2020 – 2049.

The previous noise and vibration analyses for the Georgetown South and Airport Rail Link (ARL), and others were relied on to the extent possible. Screening-level noise and vibration modeling was performed using accepted rail noise/vibration propagation models to achieve consistent and comparable results between rail corridors. The inputs for the assessment were derived from data provided by the Delcan/Arup team, including:

- GO Transit and ARL service levels and schedules based on the information identified in the reference case documentation.
- Diesel and electric train and vehicle (i.e., DMU / EMU) characteristics (i.e., locomotive horsepower, sound power levels, number of and size of cars, etc.). Train and DMU/EMU engines were assumed to operate at full horsepower (both propulsion engine and auxiliary hotel power engine) and representative peak speed over each segment of the corridor.

Shielding of sensitive impact areas, such as residential outdoor living areas, by houses and structures was not considered in the modelling, nor were other variable factors such as ground type or terrain.

These assumptions were necessary to make the assessment manageable and consistent, and thus allow inter-comparison of alternatives. However, the absolute results for the corridors may not be accurate representations as a result.

Table 3 – Summary of the Network Electrification Options Considered

Corridor	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
Lakeshore West (LW)	Diesel	Diesel	Electric	Electric	Electric	Electric	Electric
Milton (MT)	Diesel	Diesel	Diesel	Diesel	Electric	Electric	Electric
Georgetown (GT)	Diesel	Electric	Diesel	Electric	Electric	Electric	Electric
ARL	Diesel	Electric	Diesel	Electric	Electric	Electric	Electric
Barrie (BA)	Diesel	Diesel	Diesel	Diesel	Diesel	Electric	Electric
Richmond Hill (RH)	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Electric
Stouffville (ST)	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Electric
Lakeshore East (LE)	Diesel	Diesel	Electric	Electric	Electric	Electric	Electric

Notes: Diesel = Tier 4 Diesel; Electric = Electrified

The following additional assumptions were applied relating to the technical approach used in the assessment:

- All rail lines are composed of continuous welded rail and devoid of significant defects that could increase noise or vibration emissions.
- Noise emissions for the various propulsion technologies are at maximum speed and were scaled to three speed ranges (i.e., less than 50 kph, 50 to 100 kph, 100 to 150 kph) for analysis purposes.
- Noise emissions from the entire train (i.e., locomotives and coaches) were estimated using the scaled locomotive noise plus the wheel noise predicted by STEAM at the associated speed.
- The appropriate scaled noise emissions from one of the three speed ranges were applied to individual corridor rail segments based on the corresponding corridor speed limits.
- Additional wheel noise was included for GO trains via 2 additional coaches to account for heavier locomotives, maintenance issues, or transient (acceleration/deceleration) effects. This assumption would tend to exaggerate the predicted absolute sound levels, but is consistently applied and hence does not influence the change between diesel and electrification.
- Noise emissions associated with acceleration or deceleration were not accounted for specifically since they are expected to be comparable on average to noise emissions from trains moving at their speed limit (i.e., added wheel noise at speed will offset any difference in engine noise). The additional wheel noise effects conservatively included for trains would account for this variability.
- The effects of increased noise or vibration due to discontinuities at switches, wheel squeal, or brake noise were not specifically included as such effects would be highly localized. The analysis also includes additional wheel noise effects as a conservatism to account for such effects.
- Vibration emissions were assumed to scale linearly with drive axle weight.

- Rail traffic was located in the centre of each corridor where multiple tracks exist.
- Idling at stations, layovers and maintenance yards was not considered since these emissions are generally localized, brief and small in relation to emissions from travelling locomotives.
- Deadhead train movements were not considered, as they are expected to be minor relative to the conservatisms in the analysis.
- Future train movements were distributed into time of day categories (i.e., day or night) based on the existing train schedules in an equivalent distribution and conservatively rounded up where partial trips may apply.
- Some minor simplifications of the geometry of the GO Transit network were made (e.g., track orientation relative to north), the effects of which were verified to be small via sensitivity tests.
- Receptors were exposed to a full unobstructed view of the rail line, with flat terrain and absorptive ground (i.e., grass, soft soil) in the intervening space.
- Daytime ambient sound levels were assumed to be 55 dBA (16-hr Leq) near the corridors to establish the zone of influence. Actual ambient levels are expected to be higher for most developed areas; however a lower assumed ambient is expected to exaggerate the influence of any change due to electrification. As such it leads to somewhat overestimated zones of influence for both diesel and electric trains. This approach was necessary to achieve a consistent and manageable analysis of the entire network.
- Nighttime ambient sound levels were assumed to be 50 dBA (8-hr Leq) near the corridors to establish the zone of influence. Actual ambient levels are expected to be higher for most developed areas; however a lower assumed ambient is expected to exaggerate the influence of any change due to electrification. As such it leads to somewhat overestimated zones of influence for both diesel and electric trains. This approach was necessary to achieve a consistent and manageable analysis of the entire network.
- Passengers who use GO Transit on a daily basis would experience less noise or vibration effects compared to residences adjacent to the corridor as their outdoor exposure time is brief and generally accepted as a necessary consequence of using the transit system.

5. CRITERIA, INDICATORS, AND DATA SOURCES

Table 4 summarizes the criteria, indicators and data sources used in the noise and vibration assessment. Table 5 lists the various data that served as inputs to the assessment, as well as the sources of those data. Tables 6 and 7, and Figures 5 and 6 summarize the data inputs used in the assessment.

Table 4 – Noise & Vibration Detailed Assessment Criteria, Indicators and Data Sources

Criteria	Rationale	Indicators	Data Sources
Potential to affect the local noise environment	Diesel and electric options have differing noise characteristics and result in differing requirements for mitigation.	• Extent of noise Zone of Influence (i.e., areas where noise levels may exceed applicable thresholds). • Feasibility of mitigation.	See Table 5.
Potential to affect the local vibration environment	Diesel and electric options have different locomotive and train characteristics, resulting in differing ground-borne vibration effects and mitigation requirements.	• Extent of vibration Zone of Influence (i.e., areas where vibrations may exceed applicable thresholds). • Feasibility of mitigation.	See Table 5.

Table 5 – Data Sources and Notes

Data	Data Source & Notes
Railway Operations	
• Railway network layout/geometry	Provided for proposed expanded rail network by Delcan Arup Joint Venture. See Figure 5 and 6.
• Daily and hourly GO traffic volumes	Reference Case – Final Workbook (Delcan Arup Joint Venture, 2010). See Table 6 for summary.
• Daily and hourly ARL traffic volumes	Georgetown South Service Expansion and Union-Pearson Rail Link Environmental Project Report (Metrolinx, 2009). See Table 6 for summary.
• GO train speeds	Provided for existing conditions between corridor mileposts by Delcan Arup Joint Venture. Trains assumed to operate at speed limit.
• ARL speeds	Assumed to be the same as GO train speeds.
GO & ARL Emissions	
• Noise Emissions	Based on data provided by Delcan Arup Joint Venture for different train technologies. See Table 7 for summary.
• Vibration Emissions	Based on data provided by Delcan Arup Joint Venture for different train technologies. See Table 7 for summary.
Propagation Modelling	
• Selected noise model	MOE STEAM algorithm (MOE, 1990)
• Selected vibration model	FTA Transit Noise and Vibration Impact Assessment (U.S. DOT, 2006)
Applicable Thresholds	
• Noise & Vibration	Draft Protocol for Noise and Vibration Assessment Ontario Ministry of the Environment/GO Transit, 1994)

Figure 5 – Overview of GO Transit Rail Network

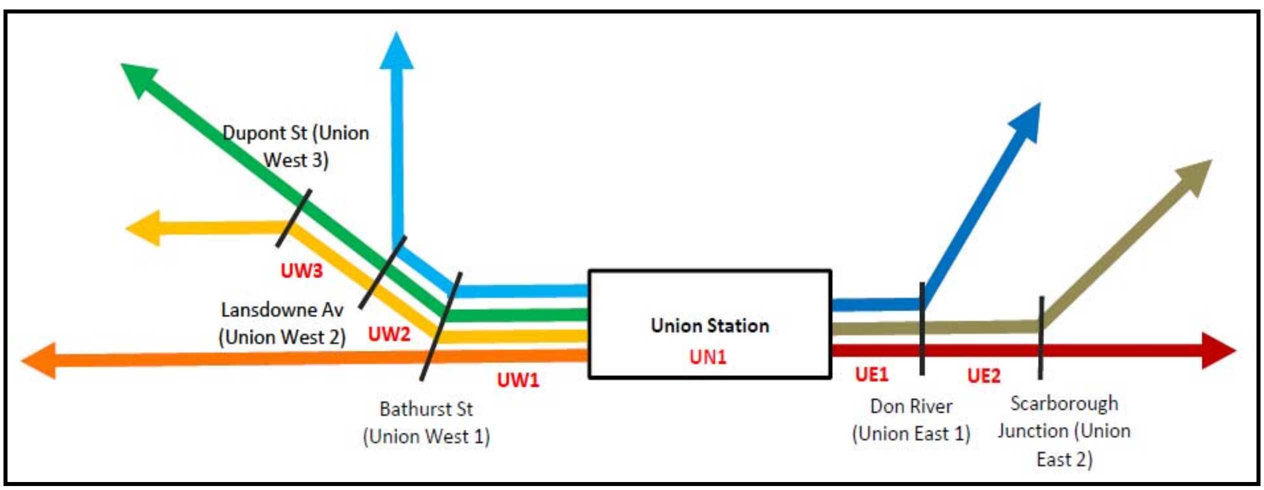

Figure 6 – GO Transit Rail Corridors near Union Station

Table 6 – Summary of Railway Operational Inputs

Rail Corridor			Train (ARL) Volumes		
Rail Line	**Segment Description**	**Label [1]**	**Daytime 07:00 to 23:00 [2,3]**	**Nighttime 23:00 to 07:00 [2,3]**	**Total [4]**
Union East	Union E1 - Union to Don River	UE1	213	26	239
	Union E2 - Don River to Scarborough Jctn	UE2	160	21	181
Union West	Union W1 - Union to Bathurst St	UW1	275 (128)	31 (12)	306 (140)
	Union W2 - Bathurst St to Lansdowne Av	UW2	177 (128)	15 (12)	192 (140)
	Union W3 - Lansdowne Av to Dupont St	UW3	124 (128)	10 (12)	134 (140)
Lakeshore East	Union E2 to Pickering	LE1	98	16	114
	Pickering to Oshawa 2	LE2	98	16	114
	Oshawa 2 to Bowmanville	LE3	15	-	15
Lakeshore West	Union W1 to Oakville	LW1	98	16	114
	Oakville to Hamilton-James	LW2	98	16	114
	Hamilton Jctn to Hamilton TH+B	LW3	98	16	114
	Hamilton-James to St Catherine's	LW4	8	-	8
Milton	Union W3 to Meadowvale	MT1	62	5	67
	Meadowvale to Milton	MT2	53	5	58
Georgetown	Union W3 to Pearson Airport (ARL)	GT1	62 (128)	5 (12)	67 (140)
	Brampton to Georgetown	GT2	62	5	67
	Georgetown to Kitchener	GT3	21	-	21
Barrie	Union W2 To Bradford	BA1	53	5	58
	Bradford to Allandale	BA2	15	-	15
Richmond Hill	Union E1 to Richmond Hill	RH1	53	5	58
	Richmond Hill to Bloomington	RH2	15	-	15
Stouffville	Union E2 to Mt Joy	ST1	62	5	67
	Mt Joy to Lincolnville	ST2	21	-	21

ARL = Airport Rail Link
[1] See Figures 5 and 6 for locations of segments.
[2] In some instances train schedules could not be accurately apportioned to day or night since the reference values spanned both periods. In these cases, train volumes were assumed to occur during both periods.
[3] Train volumes apportioned to day and night time periods based on current train schedules. Some differences may occur due to rounding.
[4] Totals may over-estimate trains per day due to double-counting of some nighttime trips (see note [2]). These simplifications will not affect the inter-comparison of the assessment results.

Table 7 – Summary of GO & ARL Noise and Vibration Emissions

Technology	Configuration	Noise Emissions [1] (dBA)	Adjustment for Drive Axle Weight [2] (VdB)	Vibration Level at 28m and 50 km/h [3] (VdB)
Diesel Locomotive	1 locomotive, 10 coach	89	0.0	75 (0.14 mm/s)
Electric Locomotive	1 locomotive, 10 coach	86	-3.0	72 (0.10 mm/s)
EMU	1 locomotive, 12 coach	82	-4.2	71 (0.09 mm/s)
Dual – Electric Mode	1 locomotive, 10 coach	86	0.0	75 (0.14 mm/s)
Dual – Diesel Mode	1 locomotive, 10 coach	89	0.0	75 (0.14 mm/s)
DMU (ARL)	2 locomotive / coach	86	-3.9	71 (0.09 mm/s)
EMU (ARL)	2 locomotive / coach	82	-4.9	70 (0.08 mm/s)

Data Source: *Delcan Arup Joint Venture, 2010.*

[1] Maximum exterior noise levels at 15 m from track, train moving.

[2] Adjustment determined based on ratio of drive axle weight to reference diesel locomotive.

[3] U.S. FTA vibration model for diesel train on continuous welded rail at 50 km/h and 28m (75 VdB ref 2.54E-5 mm/s; or 0.14 mm/s RMS).

6. ASSESSMENT OF OPTIONS

The basic assessment methodology and parameters are set out in the preceding sections (Section 2, 3 and 4). The results of the screening-level noise and vibration modeling were used to establish Zones of Influence in which the applicable criteria could be triggered. Graphical Information Systems were used to visualize influence areas and determine affected populations and sensitive receptors for each electrification option. The data on affected populations was then used to compare the various options for the GO Electrification study versus a Reference Case that assumes Tier 4 diesel locomotives over the entire network. The study indicators were used to qualitatively rate technology options with respect to each individual criterion and corridor. An overall rating was then derived for noise/vibration for each electrification option, based on the rankings for the individual criteria.

6.1 MOEE/GO Transit Draft Guideline

The MOEE / GO Transit Draft Protocol (1994) has never been formally adopted, but provides an outline of an approach considered acceptable by the regulators and as such, is considered relevant to the study. It is further relevant in that it has been applied in evaluating other corridors. It was assumed that 'dB' referenced in the MOEE / GO Draft Protocol refers to 'dBA', the typical unit of measurement used in environmental noise assessments.

Noise

The objective of the MOEE / GO Draft Protocol is that the daytime (i.e., 07:00 – 23:00) Leq(16h) produced by future rail service operation of the GO Transit project under assessment, does not exceed the higher of:

a. The ambient sound level (combined with the sound level from existing rail activity); or
b. 55 dBA.

Furthermore, the MOEE / GO Draft Protocol also suggests that the night-time Leq (8h) produced by the future rail service operation of the GO Transit project does not exceed the higher of:

a. The ambient sound level (combined with the sound level from existing rail service); or
b. 50 dBA.

The MOEE / GO Draft Protocol states that impact at a point of reception shall be expressed in terms of the Adjusted Noise Impact. The Adjusted Noise Impact is based on the difference between pre-project noise (including ambient and existing rail noise) and post-project noise (including ambient and future rail noise). Where the pre-project noise (i.e., the ambient noise) is less than 55 dBA Leq during the daytime or 50 dBA Leq during the nighttime, these minimum values are taken as the applicable pre-project noise (i.e., daytime ambient of 55 dBA or nighttime ambient of 50 dBA).

Due to the variable, site-specific ambient sound levels throughout each corridor, the current assessment assumed that the ambient sound levels could fall below the minimum criteria of the MOEE/GO Transit Draft Protocol (i.e., 55 dBA daytime, and 50 dBA nighttime). This assumption is expected to be conservative considering the built-up areas around the rail corridors where actual ambient levels could be in the 55 – 70 dBA range. However, use of the minimum criteria in the MOEE / GO Transit Draft Protocol provides a useful reference for comparison appropriate for this assessment.

In addition, according to the MOEE / GO Draft Protocol the predicted impacts are rated with respect to the following objectives:

Adjusted Impact Level	**Impact Rating**
0 - 2.99 dB	Insignificant
3 - 4.99 dB	Noticeable
5 – 9.99 dB	Significant
>10 dB	Very Significant

The above objectives compare well to the human response to changes in sound levels per Table 1. In cases where the Adjusted Noise Impact is considered “Significant” or greater (i.e. 5 dB or greater), the potential to mitigate will be evaluated based on administrative, operational, economic and technical feasibility. This criterion of a 5 dB change was used as the basis for defining the Zones of Influence for sound. Given the prior assumption that the ambient sound levels would be based on the minimum criteria of 55 dBA (day) and 50 dBA (night), a change of 5 dB or greater would be triggered in the current assessment when predicted levels exceeded 60 dBA (day) or 55 dBA (night).

Vibration

The objective of the MOEE / GO Draft Protocol is that the RMS vibration velocity produced from GO Transit project at a point of reception does not exceed the higher of:

a. 0.14 mm/s (i.e., 75 VdB) at a point of vibration assessment; or
b. The vibration levels from existing operations when they exceed 0.14 mm/s.

Furthermore, the MOEE / GO Draft Protocol stipulates that the requirement to evaluate mitigation occurs only if the vibration velocity exceeds the objective by 25% or more (i.e., the greater of 0.174 mm/s or 77 VdB, or a 25% increase over existing levels). For the purposes of the screening-level evaluation, Zones of Influence based on vibration impact were assessed where the predicted levels exceed the 0.14 mm/s criterion (i.e., 75 VdB). A 25% change over existing vibration levels approximately correlates to a change of 2-3 VdB. Such a change would be considered important relative to the MOEE / GO Transit Draft Protocol and would represent a perceptible benefit of an electrification option.

6.2 Determination of Zones of Influence

As noted, the Zones of Influence for noise and vibration were determined based on:

- A change of 5 dB above typical ambient levels for noise (assumed at 55/50 dBA for day/night respectively), or an overall level of 60 dBA (day) and 55 dBA (night); and
- For vibration, a perceptibility limit of 0.14 mm/s maximum RMS passby velocity.

Using the provided inputs, the STEAM and FTA models were iterated to determine setback distances from the rail corridor for noise and vibration, respectively, where the above criteria were met. As the rated speed varies through each section of the corridors, three representative speed ranges were evaluated and then applied to the appropriate section of track. The results of the modeling are summarized in Table 8 for day and night noise levels (based on corresponding train volumes) and peak passby vibration for each speed range. The highest setback distance is identified in bold. The extremes of these setbacks correspond to the maximum for the Reference Case (all diesel technology) and the minimum for electrification of the entire network (Option 18, all electric technology).

Table 8 – Summary of Setback Distances for Zones of Influence

Line	Location	Option	Daytime Noise Setbacks (m)			Nighttime Noise Setbacks (m)			Vibration Setbacks (m)		
			< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h
Multiple Tracks Combined (near Union Station)	Union to Bathurst St (UW1)	Ref	**143**	**260**	**370**	112	204	-	28	47	-
		Option 1	**124**	**227**	**323**	102	187	266	28	47	70
		Option 2	**132**	**241**	**343**	99	181	259	28	47	70
		Option 3	**112**	**206**	**293**	88	162	232	28	47	70
		Option 11	**105**	**192**	**273**	84	154	220	28	47	70
		Option 15	**98**	**179**	**256**	79	145	208	21	36	50
		Option 18	**98**	**179**	**256**	79	145	208	21	36	50
	Bathurst St to Lansdowne Ave (UW2)	Ref	**116**	**212**	**302**	79	145	207	28	47	70
		Option 1	**95**	**174**	**247**	67	123	176	28	47	70
		Option 2	**116**	**212**	**302**	79	145	207	28	47	70
		Option 3	**95**	**174**	**247**	67	123	176	28	47	70
		Option 11	**86**	**158**	**225**	62	113	162	28	47	70
		Option 15	**79**	**144**	**205**	56	103	148	21	36	50
		Option 18	**79**	**144**	**205**	56	103	148	21	36	50
	Lansdowne Ave to Dupont St (UW3)	Ref	**101**	**183**	**260**	67	123	176	28	47	70
		Option 1	**77**	**144**	**200**	54	98	141	28	47	70
		Option 2	**101**	**183**	**260**	67	123	176	28	47	70
		Option 3	**77**	**140**	**200**	54	98	141	28	47	70
		Option 11	**67**	**123**	**175**	48	87	126	21	36	50
		Option 15	**67**	**123**	**175**	48	87	126	21	36	50
		Option 18	**67**	**123**	**175**	48	87	126	21	36	50
	Union to Don River (UE1)	Ref	**104**	**210**	**270**	88	161	230	28	47	70
		Option 1	**104**	**210**	**270**	88	161	230	28	47	70
		Option 2	**91**	**166**	**237**	73	134	191	28	47	70
		Option 3	**91**	**166**	**237**	73	134	191	28	47	70
		Option 11	**91**	**166**	**237**	73	134	191	28	47	70
		Option 15	**91**	**166**	**237**	73	134	191	28	47	70
		Option 18	**74**	**136**	**194**	63	115	165	21	36	50
	Don River to Scarborough Jctn (UE2)	Ref	**87**	**158**	**226**	77	141	201	28	47	70
		Option 1	**87**	**158**	**226**	77	141	201	28	47	70
		Option 2	**72**	**132**	**188**	61	111	159	28	47	70
		Option 3	**72**	**132**	**188**	61	111	159	28	47	70
		Option 11	**72**	**132**	**188**	61	111	159	28	47	70
		Option 15	**72**	**132**	**188**	61	111	159	28	47	70
		Option 18	**62**	**114**	**162**	55	101	144	21	36	50
Barrie	Union W2 To Bradford (BA1)	Ref	**44**	**79**	**113**	32	57	82	28	47	70
		Option 1	**44**	**79**	**113**	32	57	82	28	47	70
		Option 2	**44**	**79**	**113**	32	57	82	28	47	70
		Option 3	**44**	**79**	**113**	32	57	82	28	47	70
		Option 11	**44**	**79**	**113**	32	57	82	28	47	70
		Option 15	**31**	**56**	**81**	22	41	58	21	36	50
		Option 18	**31**	**56**	**81**	22	41	58	21	36	50
	Bradford to Allandale (BA2)	Ref	20	36	51	-	-	-	**28**	**47**	**70**
		Option 1	20	36	51	-	-	-	**28**	**47**	**70**
		Option 2	20	36	51	-	-	-	**28**	**47**	**70**

Line	Location	Option	Daytime Noise Setbacks (m)			Nighttime Noise Setbacks (m)			Vibration Setbacks (m)		
			< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h
		Option 3	20	36	51	-	-	-	28	47	70
		Option 11	20	36	51	-	-	-	28	47	70
		Option 15	15	26	37	-	-	-	21	36	50
		Option 18	15	26	37	-	-	-	21	36	50
Georgetown	Union W3 to Pearson Airport including ARL (GT1)	Ref	80	145	206	54	99	141	28	47	70
		Option 1	51	94	134	38	70	100	21	36	50
		Option 2	80	145	206	54	99	141	28	47	70
		Option 3	51	94	134	38	70	100	21	36	50
		Option 11	51	94	134	38	70	100	21	36	50
		Option 15	51	94	134	38	70	100	21	36	50
		Option 18	51	94	134	38	70	100	21	36	50
	Brampton to Georgetown (GT2)	Ref	48	87	124	32	57	82	28	47	70
		Option 1	34	62	89	22	41	58	21	36	50
		Option 2	48	87	124	32	57	82	28	47	70
		Option 3	34	62	89	22	41	58	21	36	50
		Option 11	34	62	89	22	41	58	21	36	50
		Option 15	34	62	89	22	41	58	21	36	50
		Option 18	34	62	89	22	41	58	21	36	50
	Georgetown to Kitchener (GT3)	Ref	25	44	63	0	0	0	28	47	70
		Option 1	18	32	45	-	-	-	21	36	50
		Option 2	25	44	63	-	-	-	28	47	70
		Option 3	18	32	45	-	-	-	21	36	50
		Option 11	18	32	45	-	-	-	21	36	50
		Option 15	18	32	45	-	-	-	21	36	50
		Option 18	18	32	45	-	-	-	21	36	50
Lakeshore East	Union E2 to Oshawa (LE1, LE2)	Ref	64	116	166	65	119	169	28	47	70
		Option 1	64	116	166	65	119	169	28	47	70
		Option 2	45	83	118	46	84	121	21	36	50
		Option 3	45	83	118	46	84	121	21	36	50
		Option 11	45	83	118	46	84	121	21	36	50
		Option 15	45	83	118	46	84	121	21	36	50
		Option 18	45	83	118	46	84	121	21	36	50
	Oshawa to Bowmanville (LE3)	Ref	20	36	51	0	0	0	28	47	70
		Option 1	20	36	51	-	-	-	28	47	70
		Option 2	15	26	37	-	-	-	21	36	50
		Option 3	15	26	37	-	-	-	21	36	50
		Option 11	15	26	37	-	-	-	21	36	50
		Option 15	15	26	37	-	-	-	21	36	50
		Option 18	15	26	37	-	-	-	21	36	50
Lakeshore West	Union W1 to Hamilton (LW1, LW2, LW3)	Ref	64	116	166	65	119	169	28	47	70
		Option 1	64	116	166	65	119	169	28	47	70
		Option 2	45	83	118	46	84	121	21	36	50
		Option 3	45	83	118	46	84	121	21	36	50
		Option 11	45	83	118	46	84	121	21	36	50
		Option 15	45	83	118	46	84	121	21	36	50
		Option 18	45	83	118	46	84	121	21	36	50
	Hamilton to St. Catherines (LW4)	Ref	15	25	35	0	0	0	28	47	70
		Option 1	15	25	35	-	-	-	28	47	70
		Option 2	15	25	35	-	-	-	28	47	70
		Option 3	15	25	35	-	-	-	28	47	70

Line	Location	Option	Daytime Noise Setbacks (m)			Nighttime Noise Setbacks (m)			Vibration Setbacks (m)		
			< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h	< 50 km/h	50 to 100 km/h	> 100 km/h
		Option 11	15	25	35	-	-	-	**28**	**47**	**70**
		Option 15	15	25	35	-	-	-	**28**	**47**	**70**
		Option 18	15	18	25	-	-	-	**21**	**36**	**50**
Milton	Union W3 to Meadowvale (MT1)	Ref	**48**	**87**	**124**	32	57	82	28	47	70
		Option 1	**48**	**87**	**124**	32	57	82	28	47	70
		Option 2	**48**	**87**	**124**	32	57	82	28	47	70
		Option 3	**48**	**87**	**124**	32	57	82	28	47	70
		Option 11	**34**	**62**	**89**	22	41	58	21	36	50
		Option 15	**34**	**62**	**89**	22	41	58	21	36	50
		Option 18	**34**	**62**	**89**	22	41	58	21	36	50
	Meadowvale to Milton (MT2)	Ref	**44**	**79**	**113**	32	57	82	28	47	70
		Option 1	**44**	**79**	**113**	32	57	82	28	47	70
		Option 2	**44**	**79**	**113**	32	57	82	28	47	70
		Option 3	**44**	**79**	**113**	32	57	82	28	47	70
		Option 11	**31**	**56**	**81**	22	41	58	21	36	50
		Option 15	**31**	**56**	**81**	22	41	58	21	36	50
		Option 18	**31**	**56**	**81**	22	41	58	21	36	50
Richmond Hill	Union E1 to Richmond Hill (RH1)	Ref	**44**	**79**	**113**	32	57	82	28	47	70
		Option 1	**44**	**79**	**113**	32	57	82	28	47	70
		Option 2	**44**	**79**	**113**	32	57	82	28	47	70
		Option 3	**44**	**79**	**113**	32	57	82	28	47	70
		Option 11	**44**	**79**	**113**	32	57	82	28	47	70
		Option 15	**44**	**79**	**113**	32	57	82	28	47	70
		Option 18	**31**	**56**	**81**	22	41	58	21	36	50
	Richmond Hill to Bloomington (RH2)	Ref	20	36	51	0	0	0	**28**	**47**	**70**
		Option 1	20	36	51	-	-	-	**28**	**47**	**70**
		Option 2	20	36	51	-	-	-	**28**	**47**	**70**
		Option 3	20	36	51	-	-	-	**28**	**47**	**70**
		Option 11	20	36	51	-	-	-	**28**	**47**	**70**
		Option 15	20	36	51	-	-	-	**28**	**47**	**70**
		Option 18	15	26	37	-	-	-	**21**	**36**	**50**
Stouffville	Union E2 to Mount Joy (ST1)	Ref	**48**	**87**	**124**	32	57	82	28	47	70
		Option 1	**48**	**87**	**124**	32	57	82	28	47	70
		Option 2	**48**	**87**	**124**	32	57	82	28	47	70
		Option 3	**48**	**87**	**124**	32	57	82	28	47	70
		Option 11	**48**	**87**	**124**	32	57	82	28	47	70
		Option 15	**48**	**87**	**124**	32	57	82	28	47	70
		Option 18	**34**	**62**	**89**	22	41	58	21	36	50
	Mount Joy to Lincolnville (ST2)	Ref	25	44	63	0	0	0	**28**	**47**	**70**
		Option 1	25	44	63	-	-	-	**28**	**47**	**70**
		Option 2	25	44	63	-	-	-	**28**	**47**	**70**
		Option 3	25	44	63	-	-	-	**28**	**47**	**70**
		Option 11	25	44	63	-	-	-	**28**	**47**	**70**
		Option 15	25	44	63	-	-	-	**28**	**47**	**70**
		Option 18	18	32	45	-	-	-	**21**	**36**	**50**

6.3 Assessment Results

The area and affected population in the Zones of Influence for each option was determined using GIS for each corridor and segment. The average affected area and population across all the corridors were assessed for the overall option. These results are presented in Table 9. Since electrification produces less noise compared to diesel (see

Table 7), the Zones of Influence decrease in size with the addition of more electrification in each option. As a result, every option sees a decrease in the overall Zone of Influence compared to the Reference Case. This result is expected as electric locomotives are quieter than diesel locomotives and EMUs quieter than DMUs.

Table 9 also shows the decrease in daytime and nighttime sound level and the decrease in passby vibration level at the Reference Case distance for each option, by corridor and track segment. Similarly to the Zones of Influence, the sound and vibration levels both decrease relative to the Reference Case with increasing electrification. Overall decreases in sound or vibration level for each option were assessed using a weighted average of the corridor values by affected 2021 population.

Generally, electrification of a specific corridor lowers the sound levels by the overall difference between the sound emissions of the diesel and electric technologies (i.e., 3 dB between diesel and electric locomotives, and 3 dB between DMUs and EMUs on the ARL) excepting some reduction due to the influence of wheel noise (i.e., most corridors will not see the full 3 dB reduction, but something closer to 2 dB). The overall average sound level reduction generally becomes smaller again (i.e., on the order of 1-2 dB) due to the influence of those corridors that see no change from the louder diesel trains. Similar results can be seen for vibration. No changes greater than 3 dB are seen for any corridor, segment, or option. Importantly, changes of this magnitude are small and generally remain imperceptible to most people.

Table 9 – Summary of Assessment Results by Corridor and Segment

			UE1	UE2	UW1	UW2	UW3	LE1	LE2	LE3	LW1	LW2	LW3	LW4	MI1	MI2	GT1	GT2	GT3	BA1	BA2	RH1	RH2	ST1	ST2
			Union East	Union East	Union West	Union West	Union West	Lakeshore East	Lakeshore East	Lakeshore East	Lakeshore West	Lakeshore West	Lakeshore West	Lakeshore West	Milton	Milton	Georgetown	Georgetown	Georgetown	Barrie	Barrie	Richmond Hill	Richmond Hill	Stouffville	Stouffville
Opt	**Measure [1]**	**Overall [2]**	*Union to Don River (Union E1)*	*Don River to Scarborough Jctn (Union E2)*	*Union to Bathurst St (Union W1)*	*Bathurst St to Lansdowne Av (Union W2)*	*Lansdowne Av to Dupont St (Union W3)*	*Union E2 to Pickering*	*Pickering to Oshawa 2*	*Oshawa 2 to Bowmanville*	*Union W1 to Oakville*	*Oakville to Hamilton-James*	*Hamilton Jctn to Hamilton TH+B*	*Hamilton-James to St Catherine's*	*Union W3 to Meadowvale*	*Meadowvale to Milton*	*Union W3 to Pearson Airport (ARL)*	*Brampton to Georgetown*	*Georgetown to Kitchener*	*Union W2 To Bradford*	*Bradford to Allandale*	*Union E1 to Richmond Hill*	*Richmond Hill to Bloomington*	*Union E2 to Mt Joy*	*Mt Joy to Lincolnville*
Ref Case	Zone of Influence (m^2)	91937436	1099678	5814666	966811	1375061	949018	6118444	5629386	1360129	10874709	8482831	566033	2383784	6112172	2124369	7248819	2224218	1943057	10879837	4070226	5166708	1698120	3930909	918451
	Population within ZOI 2021	280994	9470	44418	12809	15064	8412	19464	6846	2510	35884	7411	3362	3444	19573	1543	21931	6595	1795	23408	830	20236	1350	13127	1512
1	Zone of Influence (m^2)	87163142	1070011	5050028	844597	1131577	751852	6118444	5629386	1360129	10874709	8482831	566033	2383784	6112172	2124369	5006976	1599792	1392201	10879837	4070226	5166708	1698120	3930909	918451
	% Change in ZOI	-5%	-3%	-13%	-13%	-18%	-21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-31%	-28%	-28%	0%	0%	0%	0%	0%	0%
	Population within ZOI 2021	261165	9256	38634	11332	12323	7949	19464	6846	2510	35884	7411	3362	3444	19573	1543	15134	4734	1303	23408	830	20236	1350	13127	1512
	% Change in ZOI Population	-7%	-2%	-13%	-12%	-18%	-6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-31%	-28%	-27%	0%	0%	0%	0%	0%	0%
	Change in Sound Level, Day (dB)	-0.5	0	0	-1	-1	-2	0	0	0	0	0	0	0	0	0	-3	-2	-2	0	0	0	0	0	0
	Change in Sound Level, Night (dB)	-0.4	0	0	-1	-1	-2	0	0	0	0	0	0	-	0	0	-2	-2	-	0	-	0	0	0	0
	Change in Vibration Level (VdB)	-0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-3	-3	0	0	0	0	0	0
2	Zone of Influence (m^2)	81635986	851079	5050028	894795	1375061	949018	4436417	4023173	1025523	7863348	6068523	398351	2383784	6112172	2124369	7248819	2224218	1943057	10879837	4070226	5166708	1698120	3930909	918451
	% Change in ZOI	-11%	-23%	-13%	-7%	0%	0%	-27%	-29%	-25%	-28%	-28%	-30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Population within ZOI 2021	250362	7210	38634	11943	15064	8412	13767	4313	1905	26045	5372	2353	3444	19573	1543	21931	6595	1795	23408	830	20236	1350	13127	1512
	% Change in ZOI Population	-11%	-24%	-13%	-7%	0%	0%	-29%	-37%	-24%	-27%	-28%	-30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Change in Sound Level, Day (dB)	-1	-1	-1	-1	0	0	-2	-2	-2	-2	-2	-2	-2	0	0	0	0	0	0	0	0	0	0	0
	Change in Sound Level, Night (dB)	-1	-1	-2	-1	0	0	-2	-2	-2	-2	-2	-2	-	0	0	0	0	-	0	-	0	0	0	0
	Change in Vibration Level (VdB)	-1	0	0	0	0	0	-3	-3	-3	-3	-3	-3	-3	0	0	0	0	0	0	0	0	0	0	0
3	Zone of Influence (m^2)	77647214	851079	5050028	763798	1131577	751852	4436417	4023173	1025523	7863348	6068523	398351	2383784	6112172	2124369	5006976	1599792	1392201	10879837	4070226	5166708	1698120	3930909	918451
	% Change in ZOI	-16%	-23%	-13%	-21%	-18%	-21%	-27%	-29%	-25%	-28%	-28%	-30%	0%	0%	0%	-31%	-28%	-28%	0%	0%	0%	0%	0%	0%
	Population within ZOI 2021	236423	7210	38634	10358	12323	7949	13767	4313	1905	26045	5372	2353	3444	19573	1543	15134	4734	1303	23408	830	20236	1350	13127	1512
	% Change in ZOI Population	-16%	-24%	-13%	-19%	-18%	-6%	-29%	-37%	-24%	-27%	-28%	-30%	0%	0%	0%	-31%	-28%	-27%	0%	0%	0%	0%	0%	0%
	Change in Sound Level, Day (dB)	-1	-1	-1	-2	-1	-2	-2	-2	-2	-2	-2	-2	-2	0	0	-3	-2	-2	0	0	0	0	0	0
	Change in Sound Level, Night (dB)	-1	-1	-2	-2	-1	-2	-2	-2	-2	-2	-2	-2	-	0	0	-2	-2	-	0	-	0	0	0	0
	Change in Vibration Level (VdB)	-1	0	0	0	0	0	-3	-3	-3	-3	-3	-3	0	0	0	-3	-3	-3	0	0	0	0	0	0
11	Zone of Influence (m^2)	75016585	851079	5050028	712927	1019477	643943	4436417	4023173	1025523	7863348	6068523	398351	2383784	4367976	1508816	5006976	1599792	1392201	10879837	4070226	5166708	1698120	3930909	918451
	% Change in ZOI	-18%	-23%	-13%	-26%	-26%	-32%	-27%	-29%	-25%	-28%	-28%	-30%	0%	-29%	-29%	-31%	-28%	-28%	0%	0%	0%	0%	0%	0%
	Population within ZOI 2021	227401	7210	38634	9740	11082	6817	13767	4313	1905	26045	5372	2353	3444	14005	1080	15134	4734	1303	23408	830	20236	1350	13127	1512
	% Change in ZOI Population	-19%	-24%	-13%	-24%	-26%	-19%	-29%	-37%	-24%	-27%	-28%	-30%	0%	-28%	-30%	-31%	-28%	-27%	0%	0%	0%	0%	0%	0%
	Change in Sound Level, Day (dB)	-1	-1	-1	-2	-2	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3	-2	-2	0	0	0	0	0	0
	Change in Sound Level, Night (dB)	-1	-1	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-	-2	-2	-2	-2	-	0	-	0	0	0	0
	Change in Vibration Level (VdB)	-1	0	0	0	0	-3	-3	-3	-3	-3	-3	-3	0	-3	-3	-3	-3	-3	0	0	0	0	0	0
15	Zone of Influence (m^2)	70637028	851079	5050028	665406	934236	643943	4436417	4023173	1025523	7863348	6068523	398351	2383784	4367976	1508816	5006976	1599792	1392201	7764819	2938449	5166708	1698120	3930909	918451
	% Change in ZOI	-23%	-23%	-13%	-31%	-32%	-32%	-27%	-29%	-25%	-28%	-28%	-30%	0%	-29%	-29%	-31%	-28%	-28%	-29%	-28%	0%	0%	0%	0%
	Population within ZOI 2021	219041	7210	38634	9162	10152	6817	13767	4313	1905	26045	5372	2353	3444	14005	1080	15134	4734	1303	16781	605	20236	1350	13127	1512
	% Change in ZOI Population	-23%	-24%	-13%	-28%	-33%	-19%	-29%	-37%	-24%	-27%	-28%	-30%	0%	-28%	-30%	-31%	-28%	-27%	-28%	-27%	0%	0%	0%	0%
	Change in Sound Level, Day (dB)	-2	-1	-1	-3	-3	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3	-2	-2	-2	-2	0	0	0	0
	Change in Sound Level, Night (dB)	-2	-1	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-	-2	-2	-2	-2	-	-2	-	0	0	0	0
	Change in Vibration Level (VdB)	-2	0	0	-3	-3	-3	-3	-3	-3	-3	-3	-3	0	-3	-3	-3	-3	-3	-3	-3	0	0	0	0
18	Zone of Influence (m^2)	65137098	695894	3617610	665406	934236	643943	4436417	4023173	1025523	7863348	6068523	398351	1721056	4367976	1508816	5006976	1599792	1392201	7764819	2938449	3671995	1295831	2799533	697230
	% Change in ZOI	-29%	-37%	-38%	-31%	-32%	-32%	-27%	-29%	-25%	-28%	-28%	-30%	-28%	-29%	-29%	-31%	-28%	-28%	-29%	-28%	-29%	-24%	-29%	-24%
	Population within ZOI 2021	195414	5760	27771	9162	10152	6817	13767	4313	1905	26045	5372	2353	2558	14005	1080	15134	4734	1303	16781	605	14273	1020	9324	1180
	% Change in ZOI Population	-30%	-39%	-37%	-28%	-33%	-19%	-29%	-37%	-24%	-27%	-28%	-30%	-26%	-28%	-30%	-31%	-28%	-27%	-28%	-27%	-29%	-24%	-29%	-22%
	Change in Sound Level, Day (dB)	-2	-2	-2	-3	-3	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3	-2	-2	-2	-2	-2	-2	-2	-2
	Change in Sound Level, Night (dB)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-	-2	-2	-2	-2	-	-2	-	-2	-2	-2	-2
	Change in Vibration Level (VdB)	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3

[1] Changes in sound or vibration level are assessed at the Reference Case setback distance for the Zone of Influence (ZOI), hence they are relative to the Reference Case.

[2] Overall option values associated with ZOI and population figures are based on arithmetic averages across the corridors. Overall option values associated with sound or vibration levels are based on a weighted average by affected population across the corridors.

In order to assess the relative overall benefit of each option, a qualitative rating scale was established based on the quantitative results. The rating scale is presented in Table 10 for both noise and vibration. The rating scale is based on the human perception to changes in sound and vibration per the MOEE / GO Transit Draft Protocol and Table 1.

Table 10 – Scale for Qualitative Scoring

Effect	Noise	Vibration
Strong Positive	Reduction of >6 dB	Reduction of >6 VdB
Moderate Positive	Reduction of 4-5 dB	Reduction of 4-5 VdB
Slight Positive	Reduction of 2-3 dB	Reduction of 2-3 VdB
Neutral	Change of 0-1 dB	Change of 0-1 VdB
Slight Negative	Increase of 2-3 dB	Increase of 2-3 VdB
Moderate Negative	Increase of 4-5 dB	Increase of 4-5 VdB
Strong Negative	Increase of >6 dB	Increase of >6 VdB

Table 11Table 11 details the outcome of the application of the qualitative rating scale to the assessment results. Although many electrified corridors experience a reduction of 2-3 dB that would be considered a slight positive benefit individually, the overall option network-wide does not see the same result on average until the majority of the corridors are electrified (i.e., Options 15 and 18) due to the influence of the louder diesel trains on non-electrified corridors. This result is expected given the relatively small improvement in sound or vibration offered by switching technologies between diesel or electric locomotives. In practice, the actual sound character could be quite different between a diesel and electric locomotive due to different frequency content characteristics (e.g., less rumbling sound). Such a difference could make the change in technology more noticeable to some people. However, the overall sound levels are not expected to change appreciably in spite of any potential perceived difference in sound character; hence the overall improvement is a slight positive benefit at best.

Table 11 – Summary of the Magnitude of Effects of Electrification

Option	Noise	Vibration
1	Neutral effect from imperceptible (< 2 dB) overall reductions affecting 261,165 people in 2021 (i.e., 7% less than the reference case)	Neutral effect from negligible reductions in perceptible vibration (< 1 VdB) affecting 261,165 people in 2021 (i.e., 7% less than the reference case)
2	Neutral effect from imperceptible (< 2 dB) overall reductions affecting 250,362 people in 2021 (i.e., 11% less than the reference case)	Neutral effect from negligible reductions in perceptible vibration (< 1 VdB) affecting 250,362 people in 2021 (i.e., 11% less than the reference case)
3	Neutral effect from imperceptible (< 2 dB) overall reductions affecting 236,423 people in 2021 (i.e., 16% less than the reference case)	Neutral effect from negligible reductions in perceptible vibration (< 1 VdB) affecting 236,423 people in 2021 (i.e., 16% less than the reference case)
11	Neutral effect from imperceptible (< 2 dB) overall reductions affecting 227,401 people in 2021 (i.e., 19% less than the reference case)	Neutral effect from negligible reductions in perceptible vibration (< 1 VdB) affecting 227,401 people in 2021 (i.e., 19% less than the reference case)
15	Slight benefit from just perceptible (i.e. 2-3 dB) overall reductions affecting 219,041 people in 2021 (i.e., 22% less than the reference case)	Slight benefit from minor reductions in perceptible vibration (i.e. 2-3 VdB) affecting 219,041 people in 2021 (i.e., 22% less than the reference case)
18	Slight benefit from just perceptible (i.e. 2-3 dB) overall reductions affecting 195,414 people in 2021 (i.e., 30% less than the reference case)	Slight benefit from minor reductions in perceptible vibration (i.e., 2-3 VdB) affecting 195,414 people in 2021 (i.e., 30% less than the reference case)

Table 12 summarizes the overall qualitative evaluation for each of the six short-listed electrification options. All options see a neutral benefit, excepting total or near-total electrification of the entire rail network (i.e., Options 15 and 18) which see a slight positive benefit due to the wide electrification of multiple corridors.

Table 12 – Overall Qualitative Scoring

Option	Noise	Vibration
1	Neutral	Neutral
2	Neutral	Neutral
3	Neutral	Neutral
11	Neutral	Neutral
15	Slight Benefit	Slight Benefit
18	Slight Benefit	Slight Benefit

7. CONCLUSIONS

Table 11 and Table 12 summarize the findings of the assessment. Based on these results, a slight positive benefit for noise and vibration could be realised for total or near total electrification of the rail network (i.e., Options 15 and 18) due to the wide electrification of multiple corridors. Although other options do not see a notable net overall benefit, individual corridors within each option may also see a slight positive benefit in switching from diesel to electric locomotives.

APPENDIX 8E-1 – REFERENCES

Delcan Arup Joint Venture. (June 18, 2010). *Reference Case Final Workbook, Issue 2*. Toronto, ON: Delcan Arup Joint Venture.

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