Appendix H
Noise and Vibration Technical Report

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1.0 Noise and Vibration Study Introduction

The City of Cincinnati has contracted with Parsons Brinckerhoff (PB) to prepare an Environmental Assessment (EA) document, pursuant to the National Environmental Policy Act (NEPA). As part of the preparation of the EA, a noise and vibration technical study was completed as presented in this document. The following sections describe the potential noise and vibration impacts of the proposed Build Alternatives.

1.1 Sound Descriptors

Noise levels are measured in units called decibels. Since the human ear does not respond equally to all frequencies (or pitches), measured sound levels (in decibels at standard frequency bands) often are adjusted or weighted to correspond to the frequency response of human hearing and the human perception of loudness. The weighted sound level is expressed in single-number units called A-weighted decibels (dBA) and is measured with a calibrated noise meter.

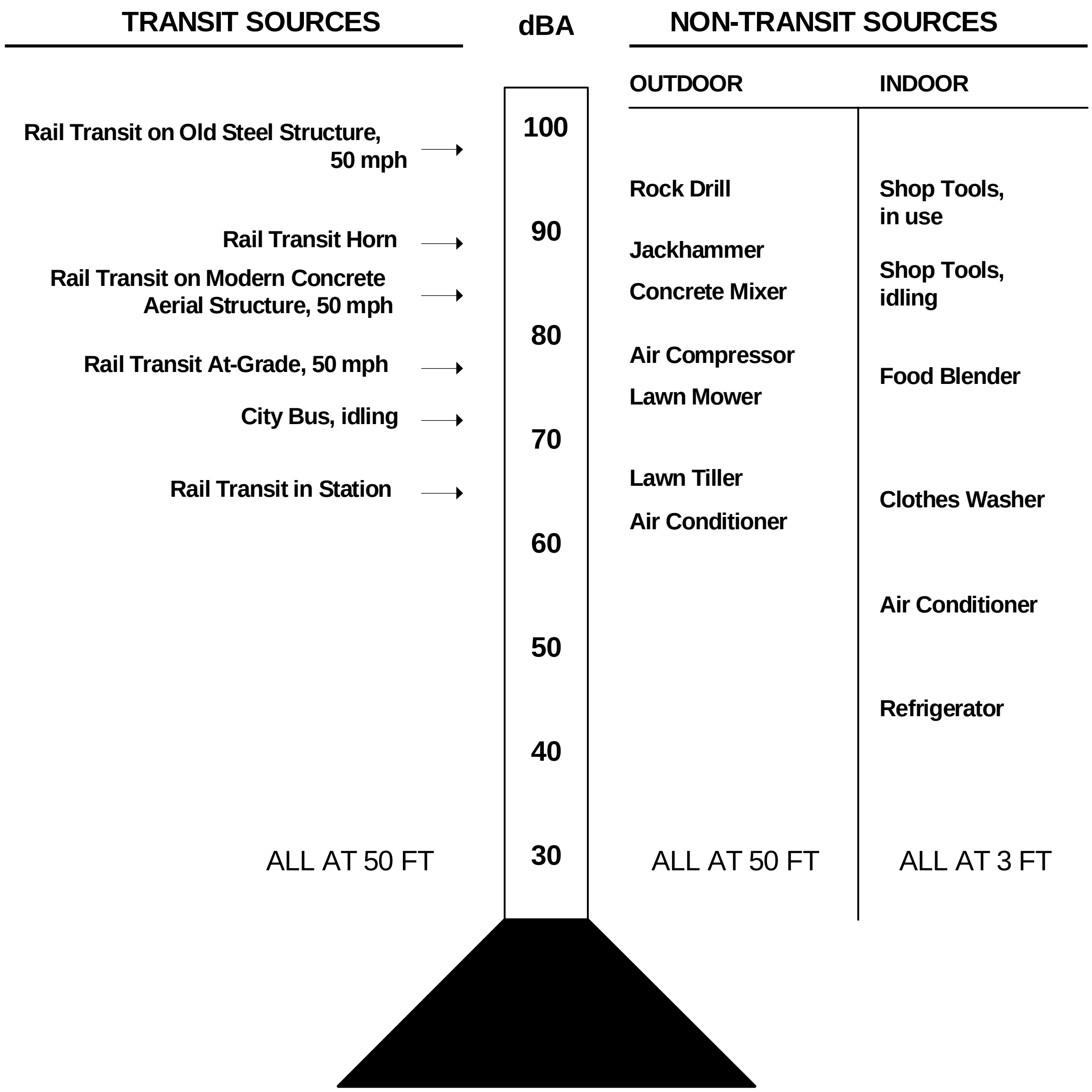
Road traffic noise and other noises found in communities tend to fluctuate from moment to moment, depending on whether a noisy truck passes by, an airplane flies over, a horn blows, or children scream as they play in a nearby schoolyard. To measure this noise accurately, noise energy (expressed in dBA) produced by different activities are averaged over a period of time in order to obtain a single number. This single number is called the equivalent continuous noise level, or L_{eq}. In other words, L_{eq} is the average sound level over a period of time. It is represented in terms of a constant noise level with the same energy content. For a one hour study, the abbreviation L_{eq}(h) can be used. The term "L_{eq}" can represent any time period. Another noise measure considers people's increased sensitivity to noise during sleeping hours. This measure is calculated by measuring noise levels over a 24-hour period to calculate what is called the day-night sound level, or L_{dn}.

The Federal Transit Administration (FTA) uses both L_{eq} and L_{dn} to evaluate transit noise effects. Use of L_{eq} and L_{dn} is appropriate because these levels are sensitive to the frequency of occurrence and duration of noise events, including transit operations, which may be characterized by infrequent noise. This section uses both L_{eq} and $L_{dn.}$

1.2 Human Perception of Changes in Noise Levels

The average individual's ability to perceive change in noise levels is well documented. Generally, change in noise levels less than 3 dBA will barely be perceived by most listeners, whereas a 10-dBA change normally is perceived as a doubling (or halving) of noise levels. The general principle on which most noise acceptability criteria are based is that a change in noise is likely to cause annoyance whenever it intrudes upon the existing ambient noise (i.e., annoyance depends upon the noise that exists before the start of a new noise-generating project or expansion of an existing project). Community noise levels in urban areas usually range between 45 dBA, the daytime level in a typical quiet living room, and 75 dBA, the approximate noise level near a sidewalk adjacent to heavy traffic. For reference and orientation to the decibel scale, representative environmental noises and their respective dBA levels are shown in Figure 1-1.

Figure 1-1. Common Indoor and Outdoor Noise Levels



Source: *Guidance Manual for Transit Noise and Vibration Impact Assessment*, FTA, May 2006

1.3 FTA Noise and Vibration Criteria for Transit Projects

The basic goals of noise criteria, as they apply to transit projects, are to minimize the adverse noise and vibration impacts on the community and to provide feasible and reasonable noise control where necessary and appropriate. Several types of criteria are used to assess the impacts of noise and vibration from transportation projects. These include Federal Highway Administration (FHWA) highway traffic noise abatement criteria and FTA transit noise guidelines.

Several types of criteria are used to assess the impacts of noise and vibration from transportation projects. These include FHWA highway traffic noise abatement criteria and FTA transit noise guidelines. Both the FHWA and FTA criteria are based on land use category. For this study, the proposed transit alignments do not include any modification or expansions to existing roadways and therefore impact assessment can be evaluated based solely using FTA transit guidelines. The FTA guidelines for land use categories and noise metrics used in impact assessment are presented in Table 1-1.

Table 1-1. FTA Guidelines Land Use Categories and Metrics for Transit Noise

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor L_{eq} (h)*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land used as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor L_{eq} (h)*	Institutional land uses with primary daytime and evening use. This category includes schools, libraries, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material.

* L_{eq} for the noisiest hour of transit-related activity during hours of noise sensitivity.

1.3.1 FTA Noise Impact Assessment Based on Project Noise Exposure

The FTA noise impact criteria presented in Table 1-2 is used for assessing transit noise impacts by comparing the existing exterior noise levels and the future exterior noise levels generated solely from transit line operations and these criteria are broken down by three land use categories. Furthermore, not only are there different levels of acceptable (and non-acceptable) noise levels for each category, but what noise descriptors required to complete the assessment also varies by land use type. For example, for residential land uses adjoining a transit corridor, the cumulative for 24-hour L_{dn} Level needs to be determined reflecting a greater sensitivity to noise during the nighttime hours when people are sleeping. Whereas, for land uses involving daytime and evening uses the noise measurement used is the noisiest hour of transit–related activity is the noise descriptor which must be determined for noise measurement and future line operations. The FTA noise impact criteria, categorizes project noise levels into three levels of impact defined as “No Impact”, “Moderate Impact”, or “Severe Impact” based on the allowable project-generated noise exposure over the existing ambient conditions.

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Table 1-2. Noise Levels Defining Impact for Transit Projects

Existing Noise Exposure* L_{eq} (1-hr) or L_{dn} (dBA)	Project Noise Impact Exposure, * L_{eq} (1-hr) or L_{dn} (dBA)					
	Category 1 or 2 Sites			Category 3 Sites		
	No Impact	Moderate Impact	Severe Impact	No Impact	Moderate Impact	Severe Impact
51	<54	54-60	>60	<59	59-65	>65
52	<55	55-60	>60	<60	60-65	>65
53	<55	55-60	>60	<60	60-65	>65
54	<55	55-61	>61	<60	60-66	>66
55	<56	56-61	>61	<61	61-66	>66
56	<56	56-62	>62	<61	61-67	>67
57	<57	57-62	>62	<62	62-67	>67
58	<57	57-62	>62	<62	62-67	>67
59	<58	58-63	>63	<63	63-68	>68
60	<58	58-63	>63	<63	63-68	>68
61	<59	59-64	>64	<64	64-69	>69
62	<59	59-64	>64	<64	64-69	>69
63	<60	60-65	>65	<65	65-70	>70
64	<61	61-65	>65	<66	66-70	>70
65	<61	61-66	>66	<66	66-71	>71
66	<62	62-67	>67	<67	67-72	>72
67	<63	63-67	>67	<68	68-72	>72
68	<63	63-68	>68	<68	68-73	>73
69	<64	64-69	>69	<69	69-74	>74
70	<65	65-69	>69	<70	70-74	>74
71	<66	66-70	>70	<71	71-75	>75
72	<66	66-71	>71	<71	71-76	>76
73	<66	66-71	>71	<71	71-76	>76
74	<66	66-72	>72	<71	71-77	>77
75	<66	66-73	>73	<71	71-78	>78
76	<66	66-74	>74	<71	71-79	>79
77	<66	66-74	>74	<71	71-79	>79
>77	<66	66-75	>75	<71	71-80	>80

Source: Transit Noise and Vibration Impact Assessment, FTA, May 2006

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1.3.2 Ground-Borne Vibration and Criteria

The analysis of ground-borne vibration requires a discussion of both ground-borne vibration levels and interior noise levels resulting from ground-borne vibration. Ground-borne noise refers to the noise effects that are caused by ground-borne vibration. For example, ground-borne vibration from a passing train can cause building floors and walls to vibrate and produce sound. The noise levels resulting from this effect depend on the amplitude and frequency of the vibration produced; the path of vibration propagation, and the acoustical characteristics of the structure and the receiving room. Vibration levels are expressed in V dB are 1 micro inch/second and noise levels are expressed in dBA. Vibration can be measured in terms of the displacement, velocity, or acceleration of ground movement. Similar to noise, vibration levels are often recorded on a logarithmic scale expressed as decibels, but vibration levels are denoted as “V dB” to differentiate them from sound levels. Additionally, the greater the acoustical absorption in the room, the lower the overall noise level.

Several factors can influence vibration levels at a receiver location. The important physical parameters associated with rail activity that can influence vibration levels fall into the following four categories:

- Operational and vehicle factors: speed, vehicle suspension, and flat or worn wheels;
- Guide-way factors: rail conditions, guide-way type, rail support system, and the mass and stiffness of the guide-way structure;
- Geological factors: stiffness and internal damping of the soil and the depth to bedrock; and
- Receiver factors: coupling of the building foundation to the soil and the propagation of vibration through the building.

Ground-borne vibration and ground-borne noise from light rail transit operations are governed by the criteria shown in Table 1-3. These criteria address maximum vibration levels associated with a single event, unlike noise levels, which are associated with cumulative exposure within a 24-hour period. To address the cumulative effects of multiple vibration events the criteria are divided into “frequent” and “infrequent” event categories.

Table 1-3. FTA Ground-Borne Vibration and Noise Impact Criteria[1]

Land Use Category	Ground-Borne Vibration Impact Levels		Ground-Borne Noise Impact Levels	
	Frequent Events [2]	Infrequent Events [3]	Frequent Events [2]	Infrequent Events [3]
Category 1: Buildings where low ambient vibration is essential for interior operations.	65 V dB [4]	65 V dB [4]	NA [5]	NA [5]
Category 2: Residences and buildings where people normally sleep.	72 V dB	80 V dB	35 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 V dB	83 V dB	40 dBA	48 dBA

Source: Transit Noise and Vibration Impact Assessment (FTA, May 2006)
Vibration levels expressed in V dB are 1 micro inch/sec and noise levels expressed in dBA.
1. “Frequent Events” are defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

2. "Infrequent Events" are defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.
3. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the heating/ventilation/air conditioning (HVAC) systems and stiffened floors.
4. Vibration-sensitive equipment is not sensitive to ground-borne noise.

1.4 Noise Prediction Methodology

The noise exposure calculations were completed following the procedures and methodologies described in the FTA *Transit Noise and Vibration Guidance Manual* (May 2006). The procedure predicts vehicle noise emissions and quantifies the attenuation of sound as it travels from the vehicle to noise-sensitive receptor locations along the Build Alternatives. In this study, residents along the streetcar alignment are the primary focus. Schools, churches, libraries, medical facilities, and parkland are also of concern. The principal sources of noise that are likely to cause annoyance to residences living adjacent to transit MSF include: moving transit cars with auxiliary equipment, trains negotiating tight curves (wheel squeal noise), car wash facilities, shop repair work and pings and bangs emanating from train car coupling and train wheels passing through switches and joints in the special track work included in the MSF. These sources produce randomly occurring noises that are of considerably different character than typical community background noise and therefore, if higher than the background noise level, they can be noticeable and intrusive.

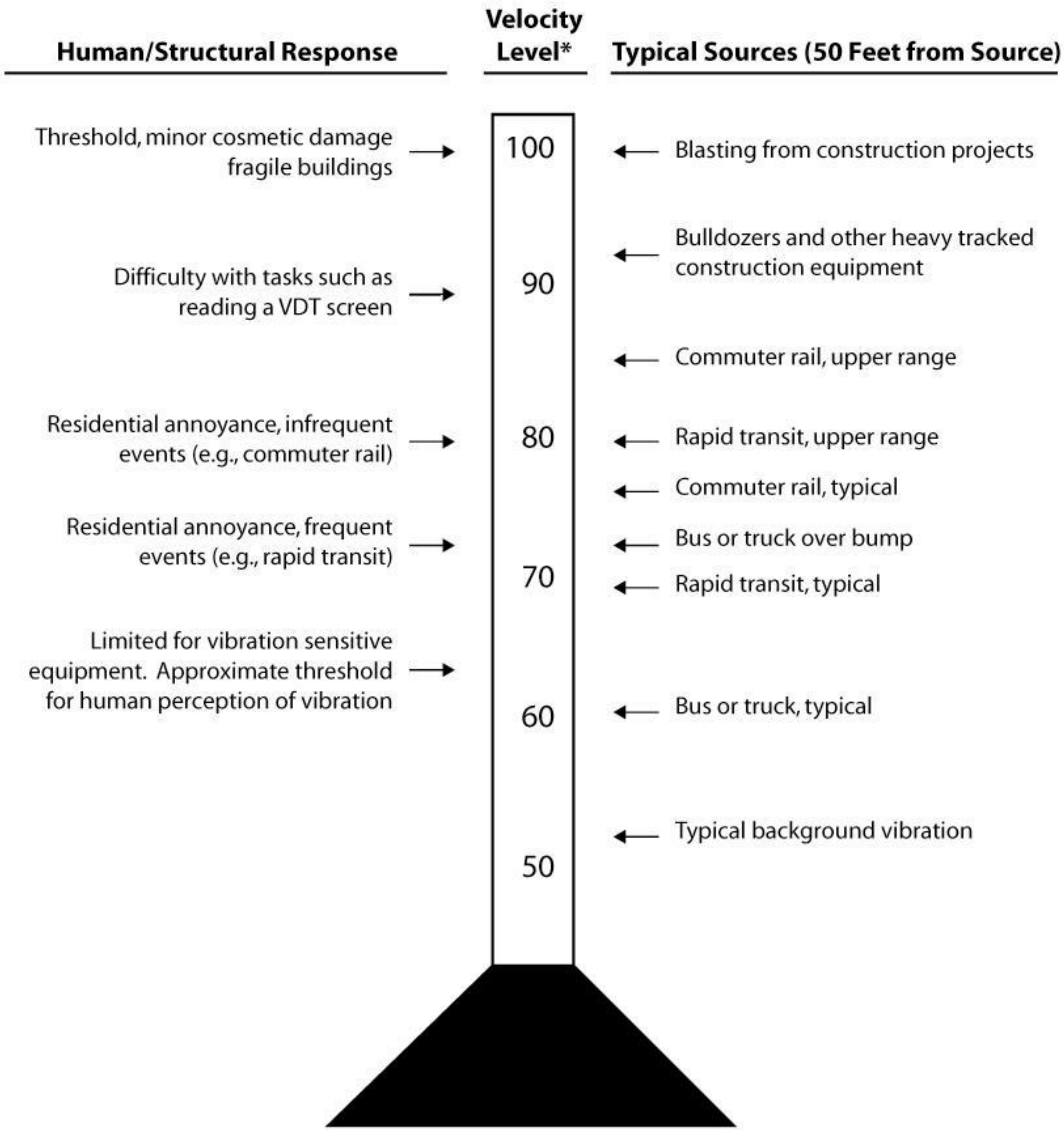
Every noise prediction must characterize three elements: 1) the noise source, 2) the sound propagation path, and 3) the affected noise receptor. For a given type of vehicle, noise emissions depend upon the operating conditions. Noise generated by line operation movements along the proposed modern Streetcar alignment was determined using pass-by frequency (headway) and vehicle travel speed data provided along each segment of the transit corridor.

Noise generated from maintenance and storage facility (MSF) related activities was calculated based on the reference Sound Exposure Levels (SEL dBA), screening distances and calculation procedures provided in Chapters 4, 5, and 6 of the FTA manual (May 2006). Total noise exposure from all of the operations and maintenance activities was determined by applying distance reduction correction, usage factors and any shielding by buildings or other obstructions from the site boundary.

1.5 Vibration Prediction Methodology

Future vibration velocity predictions were made for Streetcar traveling at their operating speeds and with their tracks located at various distances to each of the representative receptor sites identified in Figure 2-1. Estimated vibration levels were determined followed procedures contained in Chapter 10 of the FTA 2006 *Transit Noise and Vibration Guidance Manual*.

Figure 1-2. Common Vibration Sources and Levels



* RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second.
Source: FTA, *Transit Noise and Vibration Impact Assessment*, Final Report, April 1995.

2.0 Existing Noise and Vibration Levels

2.1 Noise Monitoring Site Selection

Information about the existing land uses surrounding the proposed streetcar Build Alternatives were reviewed to select representative noise monitoring sites. The FTA land use category classification is presented in Table 1-1. The most relevant noise assessment locations include sites where nighttime sensitivity to noise is of utmost importance. The nighttime sensitive sites are described under the FTA Category 2 includes land uses such as residences, hospitals, and hotels. Daytime sensitive land uses, are grouped under the FTA Category 3, includes schools, churches, and libraries. Eight representative locations (R1 through R8) scattered throughout the study area along the Build Alternatives and two representative locations (R9 and R10) for the MSF were selected based on several factors, the most important of which was the site's sensitivity to changes in noise levels, proximity to the proposed build alternative and to provide adequate geographic coverage within the study area. Existing noise levels measured at a given location as considered representative of general noise conditions at all other nearby similar properties within reasonable distance of the alignment. Noise measurement sites were selected based on a review of the existing land uses in the project study area in association with the proposed Streetcar alignment. All noise monitoring sites were selected at noise sensitive properties that would be in close proximity to the proposed Build Alternatives. Additionally, noise monitoring sites were selected to provide adequate geographic coverage of the study area and measured noise levels at a given receptor location are considered representative of the ambient noise environment of that portion of the study area. Representative noise impact assessment locations are depicted in Figure 2-1. All ten noise monitoring locations are evaluated as FTA Category 2 land uses. The addresses of these properties are provided in Table 3-1 and Table 3-2 for the Build Alternatives and the MSF locations, respectively.

A calibrated Bruel and Kjaer Type 2231 sound level meter with its Type 4165 condenser microphone and windshield was used at the noise-monitoring sites. The sound level meter was mounted on a tripod at a height of approximately 5.5 feet above ground level. At the end of the preset time period of 20 minutes, the statistical levels and the L_{eq} noise levels were read on the digital display of the meter. All noise measurements were collected under acceptable weather and road surface conditions consisting of rain free days with wind speed of less than 12 miles per hour (mph).

2.2 Existing Noise Levels

Existing noise levels for the Build Alternatives were measured over a two day time period on November 4th and 5th, 2009. Noise measurements were collected during peak, off peak midday and during late night time periods. Noise measurements were recorded for duration of 20 minutes per monitoring time period. The short-term duration noise level readings were then averaged using the methodology contained in the Appendix D section of the FTA *Transit Noise and Vibration Guidance Manual* to determine the day-noise (L_{dn}) noise level. The L_{dn} level is used to determine if noise generated from the line operations will result in impact at any of representative noise measurement locations identified within the project study area corridor.

The measured noise levels and the estimated day-night noise levels at the eight monitoring sites are summarized and presented in Table 2-1. Existing day-night L_{dn} noise levels throughout the study area are typical of noise levels found in urban communities. The principal source of ambient noise within the study area corridor is primarily motor vehicles. The proposed streetcar alignment will follow existing major transportation routes, most of the communities directly adjacent to the proposed Build Alternatives are currently exposed to moderate to high ambient noise levels. Measured peak daytime noise levels ranged from a maximum peak hour noise level (L_{eq} 1hr) of 73 dBA at site R8 to a minimum noise level of 57 dBA at Site R1. For the MSF locations, existing L_{dn} ranged from 59 dBA at Site R9 to 67 dBA at Site 10. Estimated 24 hour day-night noise levels (L_{dn}) ranged from 69 dBA at Site R8 to 61 dBA at Site R1. Estimated L_{dn} for the MSF locations ranged from 54 dBA at Site R10 to 56 dBA at Site R9.

2.3 Existing Vibration Levels

Vibration can be measured in terms of the displacement, velocity, or acceleration of ground movement. To identify project-related vibration impacts, the maximum root-mean-squared (RMS) velocity is evaluated because it correlates well with human response. Similar to noise, vibration levels are often recorded on a logarithmic scale expressed as decibels, but vibration levels are denoted as “V dB” to differentiate them from sound levels. Common sources of vibration and their maximum velocity levels are shown in Figure1-2.

The FTA impact assessment procedure does not require the measurement of baseline vibration levels to determine if vibration from line operations will result in an impact to the adjoining communities. Potential vibration impacts from line operation movements are determined based on vibration threshold levels which must be exceeded. These vibration limits are provided in Table 1-3. Existing vibration levels within the transit corridor are currently predominately generated from motor vehicles traveling on adjacent roadways. Typical vibration levels caused by road traffic movements are typically in the 50 to 60 V dB range and are considered below the minimum threshold of perception.

Figure 2-1. Noise Monitoring & Prediction Locations

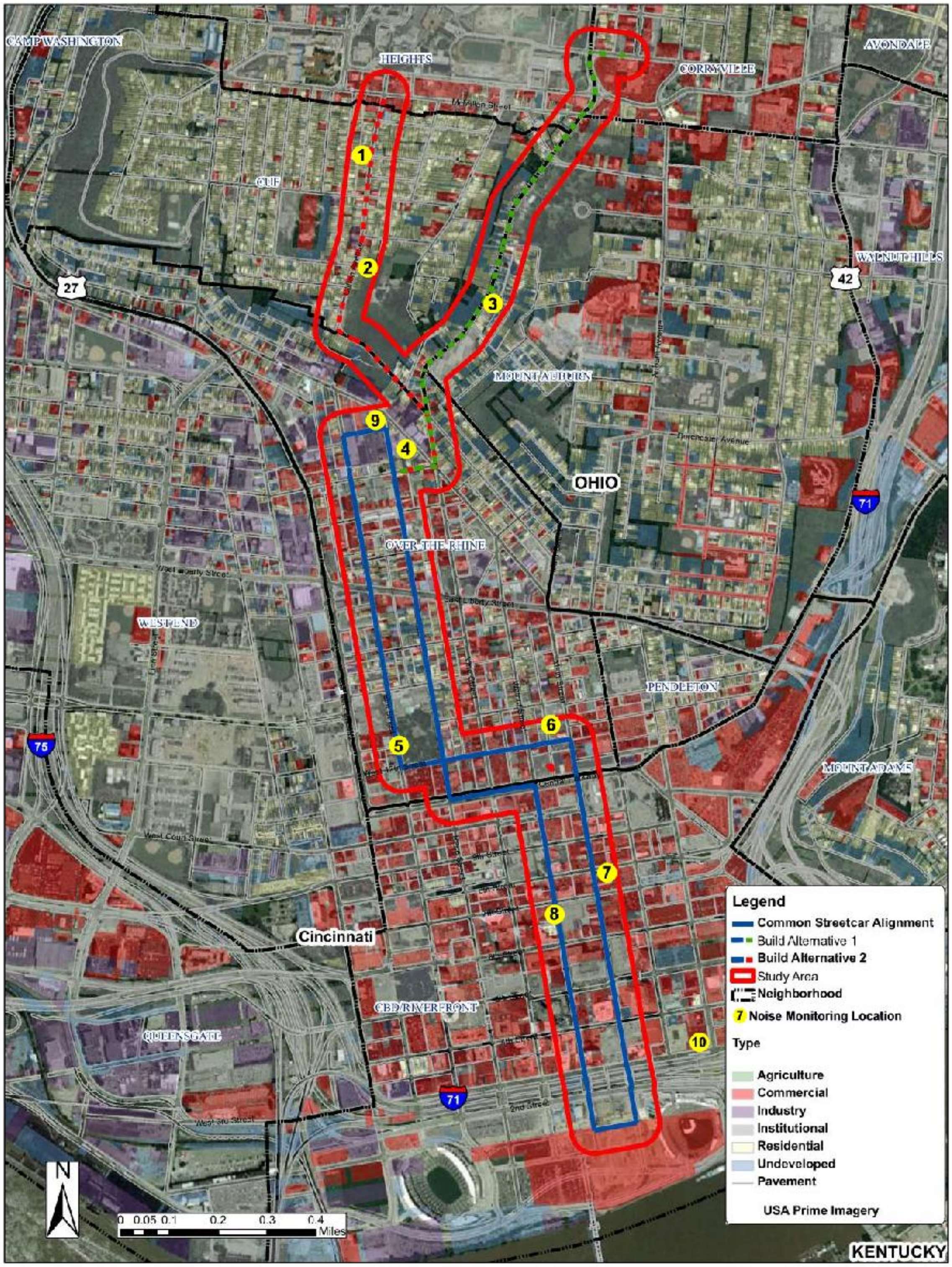


Table 2-1. Summary of Noise Measurements for Build Alternatives

Receptor Number	Address	Date	Start Time	L_{eq} (1-hr)* (dBA)	Estimated L_{dn}
		11/5/2009	7:56 AM	62	
		11/4/2009	9:22 AM	61	
	2409 Clifton Ave	11/4/2009	1:34 PM	62	61
		11/5/2009	3:57 PM	62	
		11/4/2009	9:06 PM	57	
		11/5/2009	8:23 AM	66	
		11/4/2009	9:54 AM	64	
2	2148 Clifton Ave	11/4/2009	1:12 PM	61	62
		11/5/2009	4:21 PM	64	
		11/4/2009	9:25 PM	58	
		11/5/2009	7:26 AM	70	
		11/4/2009	8:40 AM	69	
3	2216 Vine St	11/4/2009	2:05 PM	68	68
		11/5/2009	3:29 PM	71	
		11/4/2009	9:32 PM	64	
		11/5/2009	9:40 AM	68	
		11/4/2009	12:14 PM	66	
4	1900 Race St	11/4/2009	3:09 PM	67	65
		11/5/2009	5:15 PM	65	
		11/4/2009	9:18 PM	60	
		11/5/2009	9:00 AM	65	
		11/4/2009	11:44 AM	64	
5	1211 Elm St	11/4/2009	3:02 PM	63	64
		11/5/2009	4:51 PM	65	
		11/4/2009	9:50 PM	60	
		11/5/2009	7:23 AM	66	
		11/4/2009	8:40 AM	68	
6	1201 West 12th St	11/4/2009	1:07 PM	63	63
		11/5/2009	4:20 PM	65	
		11/4/2009	9:09 PM	58	
		11/5/2009	7:53 AM	72	
		11/4/2009	9:20 AM	70	
7	722 Main St	11/4/2009	1:45 PM	69	67
		11/5/2009	3:20 PM	70	
		11/4/2009	9:45 PM	62	
		11/5/2009	8:20 AM	73	
		11/4/2009	9:50 AM	71	
8	641 Walnut St	11/4/2009	2:15 PM	70	69
		11/5/2009	3:45 PM	73	
		11/4/2009	9:50 PM	65	

***** Noise measurements were recorded for 20 minute duration per reading.

3.0 Noise and Vibration Impact Assessment

This section describes the potential noise and vibration impacts resulting from the operation of the proposed Cincinnati Streetcar project.

3.1 Noise Analysis Findings

3.1.1 Build Alternatives

The proposed Streetcar alignment provides for new fixed-guide-way transit service for downtown Cincinnati. The service would be operated by low-floor, articulated streetcar vehicles electrically powered by an overhead catenary system. The vehicles would operate along a new fixed located primarily within existing rights of way. The guide-way would be double-tracked and located within traffic lanes that would be shared with other vehicular traffic. The new fixed-guide-way system would include stations, bus transit transfer locations, transfer location from/to future regional rail transit service and other operating systems and structures. A maintenance shop and storage yard for the vehicles and traction power substations would also be provided.

In general, the resultant noise level determined at a given location is a function of distance from the noise receptor to the tracks, as well as transit vehicle travel speeds, and the total number of train pass-bys that are forecasted on the system within a 24-hour weekday cycle. The proposed streetcar system will operate within the existing roadway network. As a result, all movements from block to block will be made utilizing the existing traffic light signaling system that controls the movement of all traffic. Consequently, a horn noise control system required at each street crossing will not be required and therefore horn noise can be removed as a noise exposure component which is normally added in determining the total noise at a received at a given site.

Noise impacts related to streetcar operations were determined at the eight representative residential sites identified within the study area. Table 3-1 presents a summary of the estimated noise levels and impact assessment from streetcar operations. The noise analysis findings indicate that the principal source of ambient noise along the Build Alternative is road traffic that would continue to be the dominant noise source in the future with or without streetcar operations. The existing L_{dn} noise levels at the eight monitoring sites were determined to be in the range of 61 to 69 dBA. The predicted L_{dn} noise levels from future streetcar operations are expected to be the range of 48 to 52 dBA. Noise levels generated from line operations are significantly lower than the Moderate Impact thresholds shown in Table 3-1. Consequently, noise generated from line operation on the streetcar system is not expected to cause noise impact within the study area corridor.

Table 3-1. Projected Noise Exposure Levels and Impact Assessment for Streetcar Line Operations Using FTA Criteria with the Build Alternatives

Site #	Description	Approximate Distance to Track	Average Streetcar Travel Speeds	Existing Noise Levels	FTA Moderate Impact Threshold Level	Streetcar Project Generated Line Operation Noise Level	Build Alternative Noise (without train horns)
		Feet	mph	L_{dn} (dBA)	L_{dn} (dBA)	L_{dn} (dBA)	Impact Assessment
R1	2409 Clifton Avenue	24	10	61	59	50	No Impact
R2	2148 Clifton Avenue	25	10	62	59	50	No Impact
R3	2216 Vine Street	25	10	68	63	50	No Impact
R4	1900 Race Street	32	10	65	61	48	No Impact
R5	1211 Elm Street	34	10	64	61	48	No Impact
R6	1201 West 12th Street	19	10	63	60	52	No Impact
R7	722 Main Street	33	10	67	63	48	No Impact
R8	641 Walnut Street	30	10	69	64	49	No Impact

1. Existing L_{dn} noise levels are derived from day and night time 20 minute noise measurements collected at each representative monitoring location identified on Figure 2-1.
2. Headways of 20 minutes (7 PM to 12 midnight, 6 AM to 8 AM, and 10 AM to 5 PM), 10 minutes (8 AM to 10 AM and 5 PM to 7 PM) were used for the impact assessment, with no service assumed from 12 Midnight to 6 AM.
3. Land use at each site is residential.

3.1.2 Maintenance and Storage Facilities

The principal sources of noise that are likely to cause annoyance to residences living adjacent to transit MSF include: moving transit cars with auxiliary equipment, trains negotiating tight curves (wheel squeal noise), car wash facilities, shop repair work and pings and bangs emanating from train car coupling and train wheels passing through switches and joints in the special track work included in the MSF. These types of activities are expected to take place at varying times of the day.

A summary of the existing and future day-night noise level estimates due to noise generated from MSF activities is provided in Table 3-2**.** Noise generated at the two Henry Street MOF facilities are expected to be 2 to 3 dBA below the FTA minimum impact threshold and those at generated from the proposed CBD facility are projected to be 9 dBA below. As a result, therefore no noise mitigation measures are required at any of the proposed MOF facilities.

Table 3-2.Projected Noise Exposure Levels and Impact Assessment using FTA Criteria Associated with Maintenance and Storage Facilities

Site #	Receptor Site Address	Maintenance and Storage Facility (MSF) Location	Existing Day-Night Noise Level Ldn (dBA)	FTA Moderate Impact Threshold Level Ldn (dBA)	Projected Day-Night Noise Level (Ldn dBA) FTA Impact Assessment
R9	Residential property located at 1941 Race Street, Cincinnati, OH	Location 1 (South side of Henry Street Between Elm & Race Streets)	59	58	56 No Impact
R9	Residential property located at 1941 Race Street, Cincinnati, OH	Location 2 (North side of Henry Street Between Elm & Race Streets	59	58	55 No Impact
R10	Residential property located at 405 Broadway Street, Cincinnati, OH	Location 3 (South west corner of E 3rd & Broadway Streets)	67	63	54 No Impact

3.2 Vibration Impact Assessment

The major source of streetcar vibration is the rolling interaction of the car wheels on the track; the vibration resulting from this interaction increases with greater speeds. Factors that influence the amplitudes of ground-vibration include car suspension parameters, condition of the wheels and rails, type of track, track support system, type of building foundation, and the properties of the soil and rock layers through which the vibration propagates. Use of continuously welded rail eliminates wheel impacts at rail joints and results in significantly lower vibration levels than with jointed track. Adequate wheel and rail maintenance also is an important preventive measure in controlling levels of ground-borne vibration. Further reductions in ground-borne vibration levels typically involve special track support systems, vehicle modifications, building modifications, operational changes, or adjustments to the vibration transmission path. To be effective, many of these measures must be optimized or tuned for the frequency spectrum of the vibration. A general rule of thumb is that the lower the vibration frequency the harder it is to mitigate excessive ground-borne vibration levels using standard approaches and vibrations below about 20 Hz are difficult to control in a cost-effective manner.

3.2.1 Ground Vibration Impacts from Streetcar Operations

Estimated vibration levels and impact assessment from streetcar line operations were determined by following the methodology described in Chapter 10 of the *Transit Noise and Vibration Impact Assessment* Manual (FTA, May 2006). Vibration-sensitive land uses within 100 feet of the study area corridor are primarily residential properties. If the vibration impact criteria are exceeded the potential long-term vibration impacts at these locations include structural damage and annoyance to building occupants.

3.2.2 Vibration Analysis Findings

The results of the vibration impact analysis completed along the streetcar Build Alternatives are presented in Table 3-3. Vibration levels at all locations are significantly below the minimum impact threshold of 72 V dB. Based on the results of the vibration impact analysis, vibration levels throughout the proposed transit corridor are expected to remain below the vibration impact threshold. The highest estimated vibration level is project to occur at site R6 a residential property located at 1201 West 12th Street where the vibration level will reach 65 V dB. Activities at a maintenance and storage facility location are not the type of activities which generate vibration levels that would travel beyond any of the facility locations. Vibration levels generated by the maintenance and storage facility would be similar to that generated by street traffic.

The vibration impact assessment was completed at the closest representative properties identified within the study area. Historic or other vibration sensitive structures would need to be located within a centerline distance of five feet or less to approach or exceed the FTA 72 V dB impact threshold. There are no building facades located within a five-foot centerline distance of the proposed alignment and therefore no vibration impacts are expected to occur to sensitive properties.

The No Build Alternative would not result in vibration impacts.

Table 3-3. Estimated Vibration Levels From Streetcar Operations

Site	Description	Distance to Receptor from Tracks	Streetcar Travel Speeds	Estimated Vibration Levels	FTA Vibration Criteria	Impact Yes/No
		mph	Feet	VdB	VdB	
R1	2409 Clifton Avenue	24	10	64	72	No
R2	2148 Clifton Avenue	25	10	64	72	No
R3	2216 Vine Street	25	10	64	72	No
R4	1900 Race Street	32	10	62	72	No
R5	1211 Elm Street	34	10	61	72	No
R6	1201 West 12th Street	19	10	65	72	No
R7	722 Main Street	33	10	62	72	No
R8	641 Walnut Street	30	10	63	72	No

3.3 Noise and Vibration Mitigation

FTA requires that mitigation be evaluated for all areas where an impact is expected to occur, although consideration of factors such as cost-effectiveness can be incorporated into the decision regarding whether to specific mitigation for a particular location. Mitigation normally would be specified for areas expected to experience severe impact, unless there is no practical method of achieving a reduction in noise level.

The projected noise levels associated with operation of the streetcar under the Build Alternatives would not exceed the FTA criteria for a “moderate impact” or “severe impact” at any of the representative sites evaluated. The analysis findings indicate that noise generated from MSF locations is expected to be below the FTA impact threshold at the nearest noise sensitive properties adjacent to each of the three MSF locations. Therefore, no noise mitigation measures associated with streetcar operations are required.

FTA requires that mitigation be evaluated for all areas where an impact is expected to occur, although consideration of factors such as cost-effectiveness can be incorporated into the decision regarding whether to specific mitigation for a particular location. Mitigation normally would be specified for areas expected to experience severe impact, unless there is no practical method of achieving a reduction in vibration levels. The projected ground vibration levels generated from streetcar line operations were found to be below the minimum vibration impact threshold of 72 V dB at all representative sites. Therefore, no vibration mitigation measures are required for this project.

4.0 Construction Noise and Vibration

The control of noise and vibration during the construction of the Cincinnati Streetcar project it is important to minimize potential adverse impacts on the neighboring communities. Potential noise and vibration from short-term construction activities will be controlled by including construction noise and vibration criteria in construction contract documents. Specifications will require the construction contractor to comply with any state or local ordinances and regulations.

Construction activities associated with the Build Alternatives would have short-term noise impacts on receptors in the immediate vicinity of the construction site including the proposed maintenance facilities, track beds and streetcar stops. Potential construction activities which could cause annoyance on the adjacent residential communities during construction phase include: noise from the operation of construction equipment; and noise from construction and delivery vehicles traveling to and from the site. The level of impact of these noise sources depends upon the noise characteristics of the equipment, activities involved, the construction schedule, and the distance of equipment from sensitive receptors.

Typical noise levels of construction equipment expected to be used during construction are presented in Table 4-1. In general, the noise levels would be highest during the early phases of construction, when excavation and heavy daily truck traffic would occur. Average noise levels for typical construction equipment, measured at 50 feet from the construction site, range from 81 dBA for generators and pumps to 89 dBA for asphalt spreaders to 101 dBA for pile drivers. The total hourly energy average dBA noise level, L_{eq} (1-hour), at a distance of 50 feet from the construction site boundary usually is on the order of 85 dBA.

4.1 Preliminary Construction Noise Assessment

Construction noise generated by the Streetcar project would be similar to the noise generated by typical construction projects in urban areas. Preliminary analysis of construction noise assumes an hourly L_{eq} noise level of 85 dBA at a distance of 50 feet from the construction site boundary. This noise level has been found to be consistent with noise levels from roadway construction activities where maximum instantaneous noise level from individual construction equipment is limited to 86 dBA. Noise levels at noise sensitive properties located at known distances from the construction site boundary can be estimated by assuming a 6 dBA drop-off for every doubling of distance from the site boundary.

In general, construction-related noise would occur during weekday daytime hours when people can tolerate higher levels of noise. Depending on the type of construction activity, however, some construction activities may need to occur during weekend or nighttime periods. For example, this could occur if construction activities require complete closure of traffic lanes on roadways that are extremely congested during weekdays. Nighttime construction activities could result in adverse noise impacts, especially to sensitive properties such as adjacent residences where people would be sleeping.

During final design when construction methods, staging, type and number of equipment and duration at a specific location would be known, an accurate assessment of potential impacts associated with construction activities at nearby noise sensitive properties will be determined.

4.2 Construction Vibration Impact Assessment

The major sources of vibration in the study area corridor include automobiles, trucks, and buses. As indicated in Figure 1-2, typical velocity levels generated by these types of vehicles range from 50 to 60 V dB and are below the threshold of perception. FTA vibration criteria do not require baseline measurement of existing vibration levels to access potential damage from transit construction operations (FTA, 2006). However, damage risk criteria would be developed during the construction phase of the project, after which they would be applicable to the project. Construction of the streetcar and its components could result in short-term increases in vibration levels at properties in the immediate vicinity of construction activities. Common vibration-producing equipment includes jackhammers, pavement breakers, hoe rams, augur drills, bulldozers, and backhoes. Typical vibration source levels for construction equipment range from 58 to 104 VdB (Table 4-1). Pavement breaking and soil compaction would probably produce the highest levels of construction-related vibration. Generally, annoyance effects may be expected during construction near sensitive sites within approximately 200 feet of the construction activity. Actual distances at which effects would occur will depend on the type of construction equipment used and soil characteristics in the area. Construction of a streetcar line in an existing street usually does not require an extended construction period that would make construction vibration a serious concern.

Table 4-1. Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level (dBA) 50 Feet From Source
Air Compressor	81
Backhoe	80
Ballast Equalizer	82
Ballast Tamper	83
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane, Derrick	88
Crane, Mobile	83
Dozer	85
Generator	81
Grader	85
Impact Wrench	85
Jack Hammer	88
Loader	85
Paver	89

Equipment	Typical Noise Level (dBA) 50 Feet From Source
Pile Driver (Impact)	101
Sonic	96
Pneumatic Tool	85
Pump	76
Rail Saw	90
Rock Drill	98
Roller	74
Saw	76
Scarifier	83
Scraper	89
Shovel	82
Spike Driver	77
Tie Cutter	84
Tie Handler	80
Tie Inserter	85
Truck	88

Source: FTA, 2006.

4.2.1 Vibration Control Requirements

Notwithstanding the specific vibration levels specified herein, the vibration control measures listed below could be utilized to minimize to the greatest extent feasible the vibration levels in all areas outside the construction limits:

- Specify realistic vibration limits in contract documents.

- Monitor vibrations at nearest sensitive locations throughout the construction period.
- Inform people living and working in the vicinity about construction method, possible effects, quality control measures and precautions to be used and the channels of communication available to them
- Use of vibratory pile drivers or auguring for setting piles in lieu of impact pile drivers would minimize impacts.