Federal Transit Administration

Madison Street Corridor Bus Rapid Transit (BRT)

Noise and Vibration Discipline Report

Prepared for

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SDOT

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1 Introduction

The purpose of this discipline report is to present the results of noise and vibration assessment for the Madison Street Corridor Bus Rapid Transit (Madison BRT) Project in Seattle, Washington. The project corridor is primarily on Madison Street between 1st Avenue and Martin Luther King Jr. Way E (MLK Jr. Way E) (Figure 1). The Federal Transit Administration (FTA) is the federal agency responsible for reviewing the proposal for compliance with the National Environmental Policy Act (NEPA).

2 Project Description

2.1 Background

The City of Seattle’s Department of Transportation (SDOT) proposes to provide new Bus Rapid Transit (BRT) service on Madison Street between 1st Avenue and Martin Luther King, Jr. Way East (MLK Jr. Way E.), Spring Street between 1st Avenue and 9th Avenue, and 1st Avenue and 9th Avenue between Madison Street and Spring Street as part of the Madison Street Corridor Bus Rapid Transit (Madison BRT) Project.

The Madison BRT Project is located in a dense and rapidly developing area that includes portions of Madison Valley, the Central District, Capitol Hill, First Hill, and Downtown Seattle. These areas are among the densest residential neighborhoods in the City and are sizable employment centers due to the presence of two major medical centers and Seattle University. Providing BRT service along this 2.4-mile corridor is identified in the Seattle Transit Master Plan and listed as a near-term action in the 2016 Move Seattle Strategic Vision. This project would improve transit capacity, travel time, reliability, and connectivity in an area that is highly urbanized and has a lower rate of automobile ownership than other parts of the city.

The Madison BRT Project would connect with dozens of bus routes, the Center City Connector Streetcar, the South Lake Union Street Car, and First Hill Streetcar, and would improve access to ferry service at the Colman Dock Ferry Terminal, First Hill medical institutions and housing, Seattle University, and Link light rail. As part of the project, pedestrian and bicycle access along the corridor would also be improved and enhancements would be made to the streetscape and public realm to increase comfort, visibility, and legibility in the Madison Street corridor.

2.2 Project Location

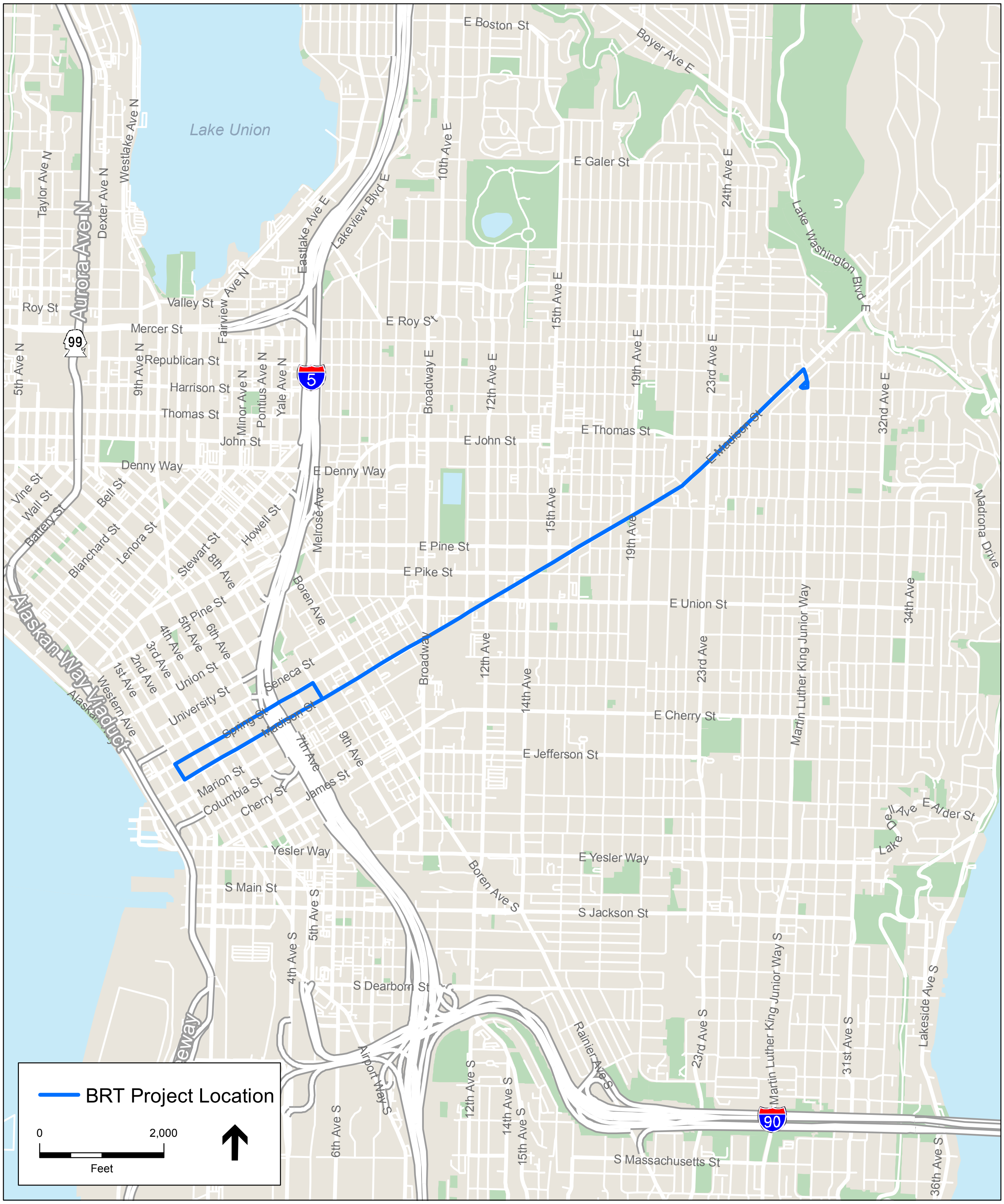
The project site is located in Seattle, Washington (Figure 1). The 4.6-mile roundtrip route would begin and end at MLK Jr. Way E in the east. Figure 2 shows that from MLK Jr. Way E the Madison BRT Project would head west on Madison Street for 2.26 miles to 1st Avenue, head north on 1st Avenue for 290 feet, head east on Spring Street for 0.43 mile, south on 9th Avenue for 290 feet, and head east on Madison Street for 1.78 miles.

The project corridor traverses several Seattle neighborhoods: Downtown, First Hill, Capitol Hill, Central Area, and Madison Valley.

SOURCE:
Wa. Dept. of Ecology 2016; ESA 2016; OSM 2015.

SDOT Madison BRT Design . 150820

Figure 1
Project Vicinity



SOURCE:
Wa. Dept. of Ecology 2016; ESA 2016; OSM 2015.

SDOT Madison BRT Design . 150820

Figure 2

Project Alignment

Downtown

The Downtown neighborhood is located at the westernmost end of the project corridor from 1st Avenue to the Interstate 5 (I-5) crossing. Downtown Seattle is primarily commercial, including large office towers in the city center, and is the largest employment center in the city.

First Hill

Moving east to First Hill, from I-5 to Broadway Avenue, the density decreases and there is a greater mixture of mid- and low-rise buildings with mixed residential-commercial uses. On the summit of First Hill, and heading east toward Broadway, institutional uses line the south side of Madison and commercial uses line the north. Virginia Mason Hospital and Swedish Hospital both have several large medical facility buildings adjacent to, or within, one block of the Madison Street corridor.

Capitol Hill

North of the project corridor, the Capitol Hill neighborhood runs from Broadway Avenue to 26th Avenue. The Pike-Pine corridor, Madison Valley, and Broadway areas are located along the Madison Street corridor. It includes mid-rise development, transitioning into low-rise and mixed commercial and residential development.

The Central Area

South of the project corridor, the Central Area neighborhood also runs from Broadway Avenue to 26th Avenue. It includes mid-rise development, transitioning into low-rise and mixed commercial and residential development. The Seattle University campus is adjacent to the Madison Street corridor.

Madison Valley

The Madison Valley neighborhood is located between 26th Avenue to MLK Jr. Way and east of the project corridor to Madison Park. Low-rise and mixed commercial and residential development dominates the corridor in this neighborhood.

2.3 Description of Proposed Work

The Project would create a new BRT line along the Madison Street corridor. It would include approximately 11 BRT station areas with 21 directional platforms along the project corridor, new Transit Only Lanes (TOLs) and Business Access & Transit (BAT) lanes, pedestrian and bicycle improvements, and signal and utility upgrades along the corridor. The Madison BRT Project would replace portions of the King County Metro Route 12 where they would otherwise overlap. Metro anticipates they will revise Route 12 to compliment the BRT and continue to serve the east Capitol Hill areas as it currently does.

The Madison BRT Project would use nine new buses, seven of which would be on the road at any one time. The buses would be 60-foot articulated low-floor vehicles with three doors on the right side and two on the left. The BRT would operate Monday through Saturday from 5 a.m. to 1 a.m. and on Sundays and holidays from 6 a.m. to 11 p.m. They would run every six minutes between 6 a.m. and 7 p.m. on weekdays and every 15 minutes during all other hours of operation.

Construction would start in 2018 and conclude in the fall of 2019.

Stations

There would be a total of approximately 11 BRT station areas with 21 directional platforms.

- Martin Luther King Jr. Way Station: eastbound and westbound curbside stops, shared with Metro Routes 8 and 11;
- 24th Avenue Station: eastbound and westbound curbside stops, shared with Metro Route 11;
- 22nd Avenue Station: eastbound and westbound curbside stops, shared with Metro Route 11;
- 17th Avenue Station: eastbound and westbound curbside stops, shared with Metro Route 11;
- 12th Avenue Station: eastbound and westbound stops on shared center island platform (Metro Route 2 would continue to have eastbound and westbound curbside stops in this vicinity);
- Boylston Avenue Station: eastbound and westbound stops on shared center island platform. Transfer to First Hill Streetcar;
- Terry Station: eastbound and westbound stops on shared center island platform (Metro Route 60 would continue to have eastbound and westbound curbside stops in this vicinity);
- 8th Avenue Stations: eastbound curbside stop on Spring Street, westbound center island stop on Madison;
- 5th Avenue Stations: eastbound curbside stop on Spring Street shared with Metro Route 2, westbound curbside stop on Madison;
- 3rd Avenue Stations: eastbound curbside stop on Spring Street, westbound curbside stop on Madison; and
- 1st Avenue Station: northbound stop on center island platform, shared with the Center City Connector streetcar.

What is a Sidewalk Station?

A sidewalk station is a station that would be located at the curb. They are typically 60 feet long.

What is an Island Station?

An island station is a platform in the center median of the street. Island stations are at least 60 feet long and approximately 9 feet wide.

Each stop would typically have a shelter (except the 1st Avenue stop), off-board fare payment machines, and real-time arrival information. The level-boarding platforms would be approximately 13 inches in height (1st Avenue stop would have 10-inch platform to accommodate the streetcar) and ADA-accessible to the maximum extent feasible.

Right-of-Way Improvements

Reconfiguration of Lanes

As part of the project, new TOLs and BAT lanes would be provided. TOLs can be located anywhere within the right-of-way and only allow transit use. They are typically painted red to inform all corridor users that this lane is for transit only. BAT lanes are a type of bus lane located on the curbside and permit general traffic use for accessing driveways or crossing streets (but not for through travel).

For the Madison BRT Project, 1.98 miles of new TOLs would be provided. Between 5th Avenue and 9th Avenue there would be 0.24 mile of center, unidirectional TOL. Between 9th Avenue and 15th Avenue there would be 0.80 mile of center TOLs heading in both directions (1.60 miles total). TOLs would also be provided throughout the corridor (about another 0.14 mile cumulatively) to ensure adequate transit flow. This would include TOLs being placed in front of transit stops, to keep them from being blocked, and on 9th Avenue to ensure buses can easily make the transition from Spring Street to Madison Street.

Approximately 0.82 mile of BAT lanes would be provided under the project. Unidirectional BAT lanes would be provided on Spring Street between 1st Avenue and 6th Avenue (0.3 mile heading east) and on Madison Street between 1st Avenue and 5th Avenue (0.24 mile heading west) and between 15th Avenue and 17th Avenue (0.14 heading east). BAT lanes would be provided for both directions on Madison Street between 17th Avenue and 18th Avenue (0.14 mile total).

Parking

Bus lanes must be at least 10.5 feet, and preferably 12 feet wide, according to American Public Transportation Association (APTA) standards (APTA, 2010). Many of the existing rights-of-way within the corridor would not allow for the addition of a new 10.5–foot-wide bus lane without the removal of on-street parking. The Madison BRT Project would remove 222 on-street parking spaces within the corridor, 10 of which would be passenger or delivery loading spaces, 113 would be street parking spaces, and 99 would be spaces that are restricted (currently allowing parking during non-peak hours only).

Paving

Approximately 10 acres of roadway and sidewalk pavement would be replaced under the project. The TOL pavement would be replaced with Portland cement concrete pavement (PCCP) to increase the life of the BRT travel lanes.

Alterations to Existing Street Corridor

According to APTA standards, bus lanes must be at least 10.5 feet wide (APTA, 2010). Many of the existing rights-of-way within the corridor would not allow for the addition of a new 10.5–foot-wide bus lane without the narrowing of other existing lanes. In certain sections of the roadway, existing general purpose lanes may need to be converted for BRT use. A list of the changes to the existing street corridor is provided below:

- Roadway curb widening on seven blocks of Madison Street;
- Full depth PCCP roadway restoration under proposed BRT travel lanes corridor wide;
- Sidewalk restoration and repairs impacting approximately 75 block faces;
- Storm water detention system construction underneath Madison Street (up to 72” detention pipe diameter);
- Corridor wide roadway restriping;
- Remove north/south crossing of Madison Street via Terry Avenue; and
- Remove left turn lanes on Madison Street to Minor Avenue, Summit Avenue, and Boylston Avenue.

Signal and Utility Improvements

As part of the Madison BRT Project, Transit Signal Priority (TSP) would be provided at most signalized corridor intersections between 7th Avenue and MLK Jr Way. Signal priority would be used to hold lights green for approaching BRT vehicles and shorten red times for BRT vehicles at intersections. Separate “queue jump” transit only phases would be employed where BRT vehicles need to go in advance of general purpose traffic. In addition, two new signals would be provided on Spring Street: one at the 8th Avenue intersection and one at the 9th Avenue intersection.

The vehicles would be electrically powered using either electric trolleybus (ETB) technology requiring overhead contact systems (OCS) or some combination of ETB/OCS and emerging battery-powered technology allowing for substantial “off wire” operation. In order to power the line, new overhead wires would need to be installed in the following areas:

- 1st Avenue from Madison Street to Spring Street (approximately 300 feet)
- Spring Street from 1st Avenue to 3rd Avenue, and from 7th Avenue to 9th Avenue (approximately 0.5 mile);
- 9th Avenue from Spring Street to Madison Street (approximately 300 feet);
- Madison Street from 19th Avenue to MLK Jr. Way E (approximately 0.7 miles); and
- MLK Jr. Way E from Madison Street to E Harrison Street (approximately 800 feet).

In addition, a new traction-powered substation (TPSS) would be needed somewhere near the eastern end of the project, where the existing overhead catenary system would need to be extended.

Pedestrian and Bicycle Improvements

The Project would include a number of improvements for pedestrians and bicyclists.

Where the project is impacting the existing sidewalks along the corridor, repairs or replacements would be completed to restore them to ADA standards. Corner bulb-out sidewalk extensions would be provided at a number of locations, which reduce street crossing distance and increase visibility of pedestrians. At Boren Avenue, Broadway Avenue, and Union Street sidewalks would be narrowed slightly to accommodate left turn lanes.

Protected Bicycle Lanes (PBLs) would remain on Spring Street between 2nd Avenue and 4th Avenue and added on Union Street between 12th Avenue and 14th Avenue. A sharrow situation would be created in the left lane on Spring Street from 1st Avenue to 2nd Avenue.

Additional crosswalk and bicycle crossings would be provided at the intersection of 12th Avenue and Union Street, in accordance with the Seattle Bike Transportation Plan. As part of the project, a wide crosswalk would be constructed on Madison Street on the east side of the intersection, enabling transitions between the bike facilities on Union Street, to the east across Madison Street, and 12th Avenue.

A short segment of bicycle lane would be striped through the intersection of 24th Avenue and John Street and improvements to the sidewalk on Madison Street west of the intersection would be included in the project in order to facilitate through movements on the 24th Avenue greenway.

Landscaping Improvements

In order to complete construction of the stations, lane widening, utility relocations, and sidewalk and other frontage improvements, approximately 70 street trees may be removed; however, this number would be refined during final design. All trees removed would be replaced in accordance with the City of Seattle's Tree Replacement Standards (SMC 15.43) and in coordination with SDOT Urban Forestry.

As part of the project, SDOT would be installing a new 2,600 square-foot Pocket Plaza with sidewalk and landscaping at the intersection of Madison Street, E Pike Street and 14th Avenue.

Stormwater Improvements

The project would replace existing stormwater infrastructure impacted by the Madison BRT Project. The majority of storm drainage impacts would be from proposed curbside bus stations.

The Project would address the City's stormwater code, improving stormwater quality and detention where required. The project passes through three basins and each would be addressed appropriately. The project is required to provide flow control for two of the five stormwater basins. The basins that require flow control are the Combined Sewer West basin and the Combined Sewer East basin. Combined Sewer West basin is in the downtown area on Spring Street and Madison Street from 1st Avenue to Interstate 5. The Combined Sewer East basin is from 17th Avenue to the end of the project at MLK Jr. Way E. The project would evaluate stormwater BMPs including rain gardens and pervious surfaces to meet requirements of the City of Seattle 2016 Stormwater Manual.

Utility Relocations

Utilities are anticipated to be relocated where the roadway would be widened to accommodate BRT bus lanes and stations. There are approximately eight blocks that are proposed for widening. Utilities that would be relocated include roadway lighting, overhead contact systems, signals, storm drainage, overhead and underground power, and overhead and underground telecommunications. There are conflicts with proposed bus station amenities and existing utility systems that would require utility modifications and relocations.

Art

The City has committed to contributing 1% of City funds to add public art (1% for Art Program); federal and state funds do not apply to this program. These funds are combined with other project art contributions to fund larger art installations which may or may not be located on the Madison Street corridor; this decision is made by the City's Art Council.

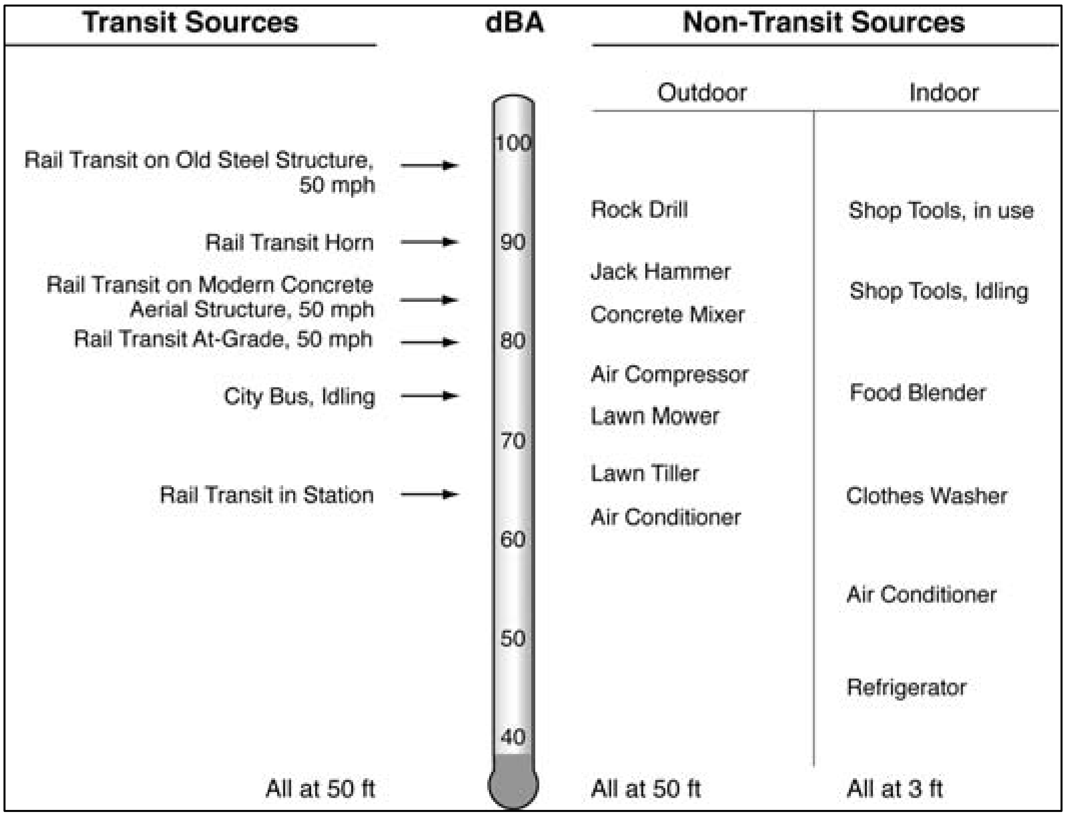
3 Fundamentals of Noise and Vibration

3.1 Noise

Noise is defined as unwanted sound. The manner in which people respond to noise depends on its composition, intensity, frequency, and duration. The loudness of sound as interpreted by the human ear depends on fluctuations in air pressure. Sound is highly variable from the quietest to loudest sounds perceived. Noise impacts to humans are measured in terms of air pressure expressed in decibels or dB. Because of the variability in the loudness of sound, changes in sound (noise) are measured on a logarithmic scale. Since noise is measured on a logarithmic scale, an increase in noise of 10 dB would be considered twice as loud. A 3 dB change is considered to be barely perceivable difference for the human ear.

When considering the effects noise has on an individual, it is important to take into account the frequency response of the human ear, which has increased sensitivity to certain frequencies of sound - particularly lower frequencies. In order to account for the human ear sensitivity, the A-weighting scale, which best estimates the way in which the human ear responds, is commonly used. A decibel (dB) on the A-weighted scale is referred to as dBA. Figure 3 illustrates typical A-weighted sound levels for transit and non-transit sources. It describes a receiver's noise at any moment in time.

Figure 3 Typical A-weighted Sound Levels



Source: FTA 2006

Noise level measurements of traffic and/or transit sources are described as follows:

- The *Maximum Sound Level (L_{max})* during a single noise event.
- The *Hourly Equivalent Sound Level ($L_{eq}(h)$)*, which describes a receiver's cumulative noise exposure from all events over a one-hour period.
- The *Day-Night Average Sound Level (L_{dn})*, which describes a receiver's cumulative noise exposure from all events over a full 24 hours, with events between 10pm and 7am increased by 10 decibels to account for greater nighttime sensitivity to noise.

These descriptors of transit noise and how they are used to measure noise impacts are described in section 4.

3.2 Vibration

As described in the FTA's Transit Noise and Vibration Impact Assessment (FTA, 2006), ground-borne vibration can be a serious concern for nearby neighbors of a transit system route or maintenance facility, causing buildings to shake and rumbling sounds to be heard. In contrast to airborne noise, ground-borne vibration is not a common environmental problem. It is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. Ground-borne vibration is more likely to occur during construction from activities such as blasting, pile driving, and the operation of heavy earthmoving equipment.

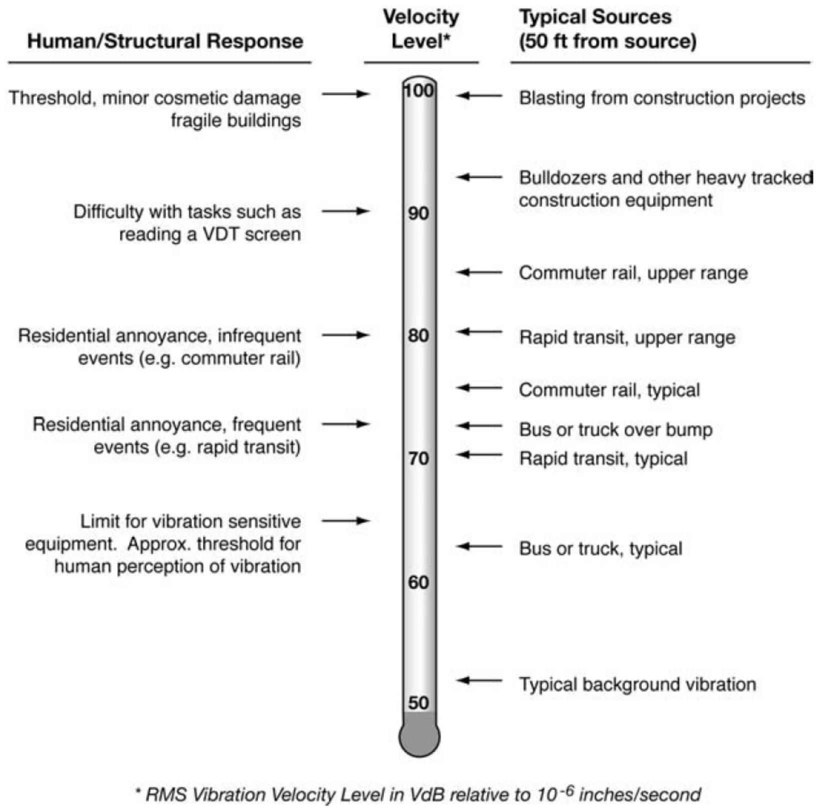
There are several descriptors of ground-borne vibration used when measuring vibration impacts:

- The peak particle velocity (PPV) measures rapidly fluctuating motions and is defined as the maximum instantaneous peak of the vibration signal. The PPV is most frequently used to describe vibration impacts to buildings.
- The root mean square (RMS) amplitude is most frequently used to describe the effect of vibration on the human body. The RMS amplitude is defined as the average of the squared amplitude of the signal.

PPV and RMS are normally described in inches per second. However, FTA 'compresses the range of numbers' used to describe vibration into a simpler unit called vibration decibels (VdB). Typically, ground-borne vibration generated by man-made activities attenuates rapidly with distance from the source of the vibration. Sensitive receptors for vibration include structures (especially older masonry structures), people (especially residents, students, the elderly, and the sick), and vibration-sensitive equipment.

The effects of ground-borne vibration include movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings. Building damage is not a factor for most projects, with the occasional exception of blasting and pile driving during construction. Ground-borne vibration can also cause annoyance to humans at a certain threshold. Figure 4 illustrates common vibration sources and the human and structural response to ground-borne vibration.

Figure 4 Typical Levels of Ground-Borne Vibration



Source: FTA 2006

4 Regulatory Framework

Because this project is funded by the FTA, the impact determination is based on the guidance in the Transit Noise and Vibration Impact Assessment (FTA, May 2006)[1] as well as the City of Seattle Noise Control Ordinance (SMC 25.08).

The FTA guidance manual establishes procedures, criteria, and modeling tools for predicting and assessing noise impacts of proposed transit projects. Consideration of established criteria and methods such as the FTA methodology in evaluating and assessing potential impacts is consistent with NEPA. The FTA methodology, as well as relevant state, and local noise regulations are described below.

4.1 Federal Transit Administration

The noise assessment presented in this report follows the methodologies and procedures established by FTA as specified in the Transit Noise and Vibration Impact Assessment (FTA Manual, May 2006).

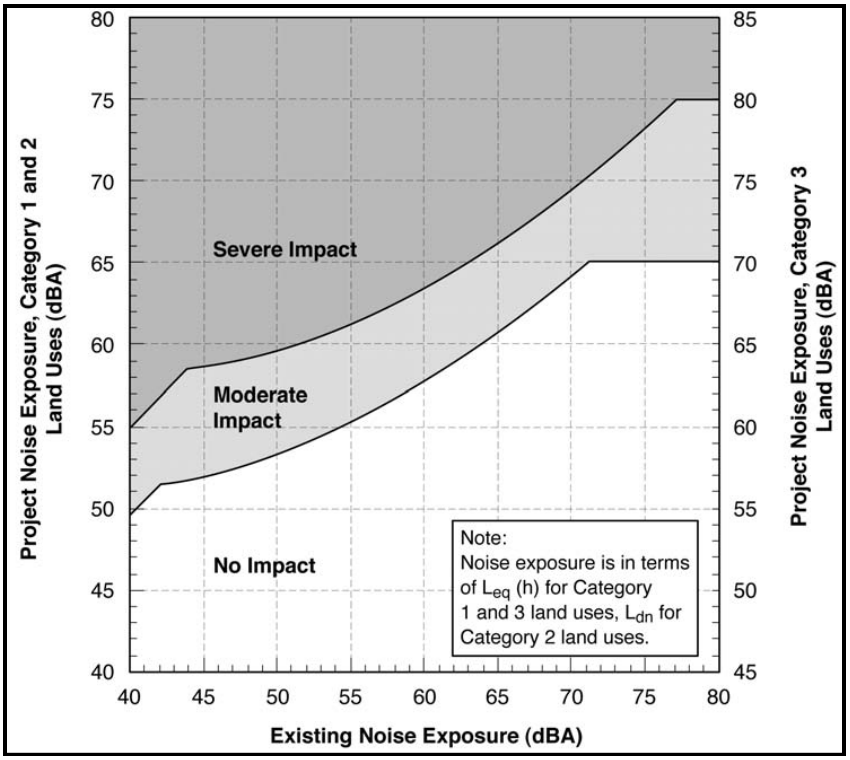
[1] Federal Highway Administration (FHWA) methods are not applicable to this project because the proposed Madison BRT Project improvements will not increase roadway capacity, construct new through-traffic lanes, or significantly alter the horizontal or vertical alignments of existing roadways.

Noise

- The General Assessment approach described in Chapter 5 of the FTA Manual provides procedures for determining the estimated severity of potential noise impacts at the noise sensitive receivers. Noise sensitive receivers are locations (land use categories defined by FTA) that may have sensitivities to project generated noise. FTA-defined sensitive receptors/land uses are described below. **Land Use Category 1**: 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 uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls. The noise metric used for this category is outdoor hourly L_{eq} (the noisiest hour of transit-related activity during hours of noise sensitivity).
- **Land Use Category 2**: 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. The noise metric used for this category is L_{dn}.
- **Land Use Category 3**: Institutional land use with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included. The noise metric used for this category is outdoor hourly L_{eq} (the noisiest hour of transit-related activity during hours of noise sensitivity).

Impacts to sensitive receptors are determined based on noise impact criteria shown in Figure 5: No Impact, Moderate Impact, and Severe Impact. The criterion for each degree of impact is on a sliding scale dependent on the existing noise exposure and the project noise exposure.

Figure 5 Noise Impact Criteria for Transit Projects



Source: FTA, 2006

As an example of impact evaluation, consider the FTA's sliding impact criterion for Category 2 receivers. An existing environment of 45 dBA L_{dn} would be moderately impacted if the project created a noise level of 52 dBA to 59 dBA L_{dn}. An existing environment of 60 dBA L_{dn} would be moderately impacted if the project created a noise level of 58 dBA to 63 dBA L_{dn}. Those same "existing" environments (45 or 60 dBA L_{dn}) would be severely impacted (or "significantly impacted" according to NEPA) if the project created noise levels greater than 59 dBA and 63 dBA L_{dn}, respectively.

If noise from the project exceeds the FTA criterion curve for "impact", then noise abatement actions are considered. Noise from the project that is expected to exceed the FTA criterion curve for "severe impact" results in a significant adverse effect pursuant to NEPA, and feasible/effective noise mitigation measures would need to be considered and incorporated into the project design. If feasible/effective mitigation actions are not available, then unavoidable adverse impacts would occur if the particular alternative is selected. It should be noted that moderate impact can be considered as "significant adverse impact or effect" when the conditions described in Chapter 3.2.5 of the FTA Manual are met.

Vibration

The FTA has adopted vibration standards that can be used to evaluate potential building damage impacts related to construction activities. The vibration damage criteria adopted by the FTA are shown in Table 1.

Table 1 Construction Vibration Damage Criteria

Building Category	PPV (in/sec)
I. Reinforced-concrete, steel or timber (no plaster)	0.5
II. Engineered concrete and masonry (no plaster)	0.3
III. Non-engineered timber and masonry buildings	0.2
IV. Buildings extremely susceptible to vibration damage	0.12

Source: FTA 2006

The FTA has also adopted standards associated with human annoyance for groundborne vibration impacts for three sensitive receptor/ use categories:

- Vibration Category 1, High Sensitivity – buildings where vibration would interfere with operations within the building, including vibration-sensitive research and manufacturing facilities, hospitals with vibration-sensitive equipment, and university research operations. Vibration-sensitive equipment includes, but is not limited to, electron microscopes, high-resolution lithographic equipment, and normal optical microscopes.
- Vibration Category 2, Residential – refers to all residential land uses and any buildings where people sleep, such as hotels and hospitals. This is primarily because ground-borne vibration and noise are experienced indoors and building occupants have practically no means to reduce their exposure.
- Vibration Category 3, Institutional – refers to institutional land uses such as schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment but still have the potential for activity interference.

The human annoyance criteria adopted by the FTA are shown in Table 2. Note that no thresholds have been adopted or recommended for commercial and office uses. Due to the nature of the construction activities, the criteria under “Infrequent Events” are used for the impact assessment.

Table 2 Construction Vibration Human Annoyance Criteria

Land Use Category	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch / sec)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB

Source: FTA 2006

[1] “Frequent Events” is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.

[2] “Occasional Events” is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.

[3] “Infrequent Events” is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.

[4] 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 HVAC systems and stiffened floors.

In addition to the human annoyance criteria by use categories, there are some sensitive buildings, such as concert halls, TV and recording studios, and theaters that are not categorized in Table 2. Table 3 includes the acceptable vibration levels for special buildings. Due to the nature of the construction activities, the criteria under “Occasional or Infrequent Events” are used for the impact assessment.

Table 3 Vibration Impact Criteria for Special Buildings

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch / sec)	
	Frequent Events[1]	Occasional or Infrequent Events[2]
Concert Halls	65 VdB	65 VdB
TV Studios	65 VdB	65 VdB
Recording Studios	65 VdB	65 VdB
Auditoriums	72 VdB	80 VdB
Theaters	72 VdB	83 VdB

Source: FTA 2006

Notes:

[1] “Frequent Events” is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

[2] “Occasional or Infrequent Events” is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.

4.2 City of Seattle Noise Control Ordinance

The City of Seattle’s Municipal Code (SMC), Chapter 25.08 – Noise Control, defines noise limits due to the project construction. Table 4 includes the exterior sound level limits described in SMC Chapter 25.08.410A.

Table 4 City of Seattle Exterior Sound Level Limits (dBA)

Zoning District of Sound Source	Zoning District of Receiving Property		
	Residential Day / Night	Commercial	Industrial
Residential	55 / 45	57	60
Commercial	57 / 47	60	65
Industrial	60 / 50	65	70

Source: City of Seattle 1977

Notes:

- Noise levels are based on the Leq during the measurement interval, using a minimum measurement interval of 1 minute for a constant sound source, or a one-hour measurement for a non-continuous sound source.
- Daytime represents the hours between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekdays and legal holidays.
- Nighttime noise levels are based on SMC Chapter 25.08.420A.

SMC Chapter 25.05.425 describes the sounds created by construction and maintenance equipment. Table 5 summarizes construction noise limits.

Table 5 City of Seattle Construction Sound Level Limits (dBA)

Zoning District of Sound Source	Zoning District of Receiving Property		
	Residential	Commercial	Industrial
Daytime Construction Noise Limits for **equipment on construction sites** (crawlers, tractors, dozers, rotary drills and augers, loaders, power shovels, cranes, derricks, graders, off-highway trucks, ditchers, trenchers, compactors, compressors, and pneumatic-powered equipment.)			
Residential	80	82	85
Commercial	82	85	90
Industrial	85	90	95
Daytime Construction Noise Limits for **portable powered equipment** (powered hand tools).			
Residential	75	77	80
Commercial	77	80	85
Industrial	80	85	90
Daytime Construction Noise Limits for **impact types of equipment** (pavement breakers, pile drivers, jackhammers) – may exceed the exterior sound level limits in any one hour period between the hours of 8 a.m. and 5 p.m. on weekdays and 9 a.m. and 5 p.m. on weekends and legal holidays, but in no event may the sound level exceed the following: Leq (1 hour): 90 dBA Leq (30 min): 93 dBA Leq (15 min): 96 dBA Leq (7.5 min): 99 dBA			

Source: City of Seattle 1977

Notes:

- Noise levels based on the Leq for a minimum measurement interval of 1 minute for a constant sound source, or a one-hour for a non-continuous sound source.
- Daytime represents the hours between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekdays and legal holidays.
- All noise levels are as measured at the property line or 50 feet from the equipment, whichever is greater.

SMC Chapter 25.08, Subchapter VII describes variances. A noise variance could be obtained from the Administrator to permit construction sound levels in excess of the limits described above during daytime and nighttime hours.

5 Methodologies

Potential noise and vibration impacts from the project were evaluated using the General Assessment described in the FTA Manual (FTA 2006).

5.1 Noise

Existing Noise Levels

Existing noise levels were estimated based on existing traffic volumes provided in the Madison Corridor BRT Study Traffic Analysis Report (SDOT 2016A) and following the methodology described in Chapter 5.2.2 of the FTA Manual.

The following assumptions were used:

- All vehicles are automobiles. While there would be truck and bus use along the corridor, consideration of all traffic as automobile traffic would result in a conservative (lower) existing noise condition.
- Speed: 30 miles per hour (mph) was used for all vehicles.

Operational Noise Levels

Chapter 5.2.2 of the FTA Manual was used to assess project noise impacts to the Land Use Categories 1, 2, and 3 along the corridor. . The noise assessment analyzes project specific information, such as type of bus, the number of bus operations by hour, and bus speed. The assumptions used for this project are listed below:

- Bus volumes: 6-minute headway between the hours of 6:00 a.m. and 7:00 p.m. This makes 20 passbys on 2-way roadway segments or 10 passbys on 1-way roadway segment. 15-minute headway between the hours of 5:00 a.m. and 6:00 a.m. and the hours of 7:00 p.m. and 1:00 a.m. This makes 8 passbys on 2-way roadway segments or 4 passbys on 1-way roadway segment.
- Speed: 30 miles per hour (mph) was used for the bus operation based on the information provided in Route 48 & Madison Corridor Electrification Computer Load Flow Simulation Report (SDOT 2016B).
- Bus Type: Electric

Construction Noise Levels

For construction noise assessment, the general assessment methodology described in Chapter 12.1.1 of the FTA Manual is used. It should be noted that the City of Seattle has the municipal code (SMC) that enforces construction noise. Therefore, the construction impact threshold is based on SMC described in Section 4.2.

Impact Assessment

To determine the impacts of the project, existing noise levels were compared to predicted operational noise levels by roadway segment. Land Use Categories 1, 2, and 3 were assessed for each roadway segment. If moderate or severe impacts were identified in any land use categories at any roadway segment, the specific land use would be identified for the further assessment. This is shown in Tables 12 - 14.

5.2 Vibration

The FTA Manual states that it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. This is because the rubber tires and suspension systems of buses provide vibration isolation. Most problems with bus-related vibration can be directly related to a pothole, bump, expansion joint, or other discontinuity in the road surface. Because the project corridor already has bus operations, the vibration assessment for long-term impacts (bus operations) was not conducted for this project.

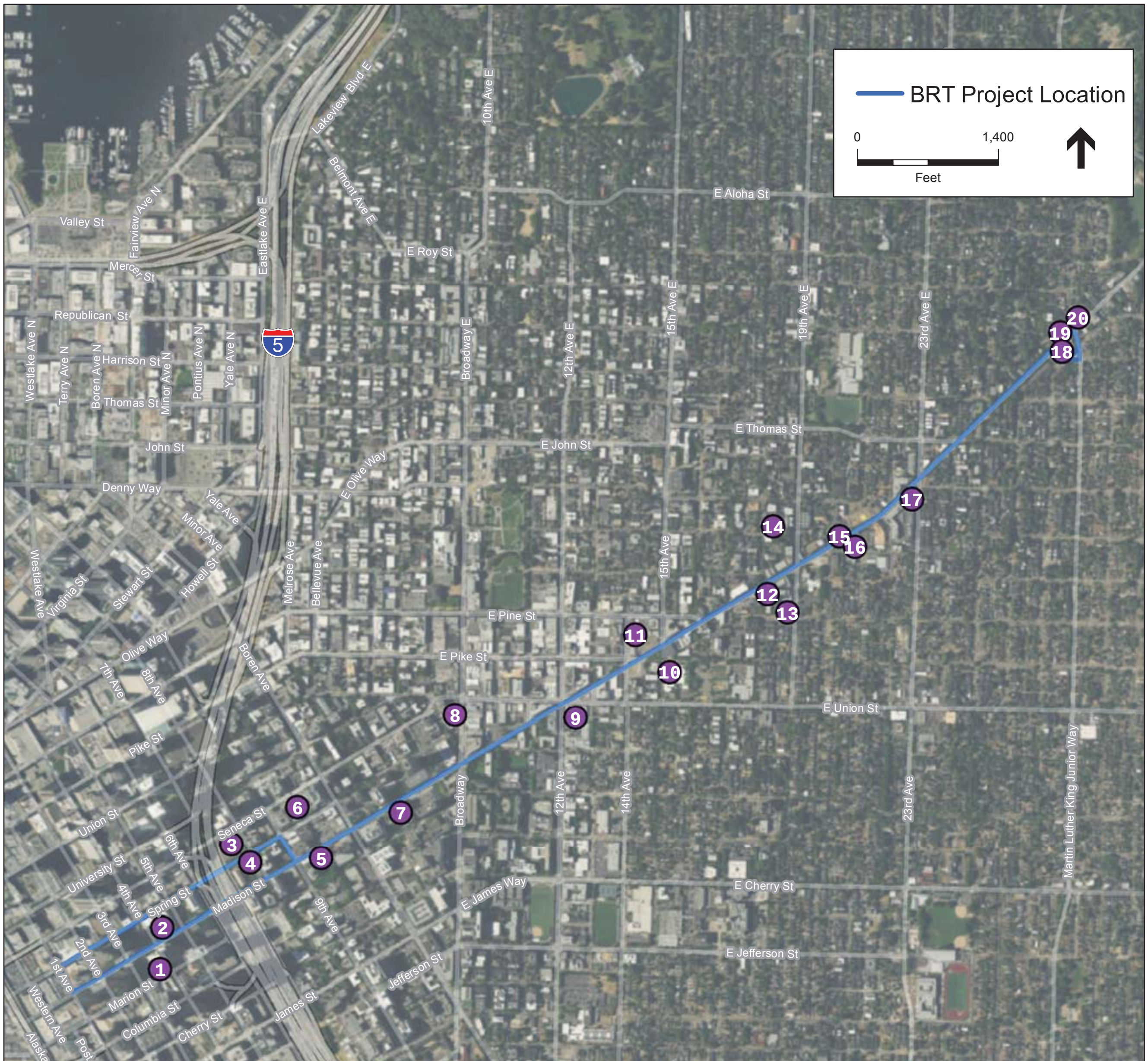
With regard to the vibration assessment due to the construction activities, Chapter 12.2 of the FTA Manual is used. Impact thresholds are included in Section 4.1.2 of this report.

6 Affected Environment

6.1 Noise- and Vibration-Sensitive Receptors

The land uses along the project corridor is mixed mostly with high intensity commercial and residential uses. Much of the residential development along the alignment is vertical mixed use, with retail uses on the first floor and residential uses above. Notable residential receptors include the single-family homes located to the east of the proposed bus layover site at the intersection of E Arthur Place, E Harrison Street, and MLK Jr. Way E.

Figure 6 shows notable non-residential sensitive receptors. This figure is intended to provide an overview of some of the sensitive receptors that exist presently along the project corridor. However, land uses are often in flux as business move and redevelopment occurs.



Notable Non-Residential Sensitive Receptors

1. Downtown YMCA
2. Seattle Public Library
3. Town Hall Seattle
4. Seattle First Presbyterian
5. Puget Sound Blood Center
6. Virginia Mason Seattle Main Campus
7. Swedish Medical Center
8. The Polyclinic
9. Pioneer Human Services
10. Seattle Academy of Arts and Sciences
11. First AME Church and Child Development Center
12. Powerful Voices
13. Peace for the Streets by Kids from the Streets
14. Sanctuary Church – Capitol Hill
15. Pride Foundation
16. Planned Parenthood
17. Madison Temple Church of God
18. Loving The Self Therapeutic Services
19. Bailey-Boushay House
20. At Indaba

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SOURCE:
Wa. Dept. of Ecology 2016; ESA 2016; OSM 2015.

SDOT Madison BRT Design . 150820

Figure 6
Notable Non-Residential Sensitive Receptors

6.2 Existing Noise Environment

The predominant noise source along the project corridor is vehicular traffic. The traffic analysis report for this project includes the PM peak hour intersection analysis. The PM peak hour traffic volumes by roadway segments are presented in Table 6.

Table 6 presents the existing noise levels per roadway segment.

Table 6 Existing Noise Levels

Roadway Segment			PM Peak Hour Traffic Volume	Distance between Roadway Centerline and Receiver Facade	Peak Hour Leq (dBA) at Receiver Facade
Roadway	From	To			
Madison	1st	2nd	442	33	60
	2nd	3rd	523	33	61
	3rd	4th	530	33	61
	4th	5th	615	33	61
	5th	6th	783	33	62
	6th	7th	1731	28	67
	7th	8th	1316	33	65
	8th	9th	1315	33	65
	9th	Terry	1382	33	65
	Terry	Boren	1327	33	65
	Boren	Minor	1442	33	65
	Minor	Summit	1430	33	65
	Summit	Bolston	1366	33	65
	Boylston	Broadway	1370	33	65
	Broadway	Broadway Ct	1360	33	65
	Broadway Ct	10th	1359	33	65
	10th	Seneca	1344	33	65
	Seneca	11th	1358	33	65
	11th	12th	1549	33	65
	12th	13th	1389	33	65
	13th	14th	1174	33	64
	14th	15th	1244	33	65
	15th	16th	1167	33	64
	16th	17th	1602	33	66
	17th	18th	1579	33	66
	18th	19th	1511	33	65
	19th	20th	1414	33	65
	20th	Denny	1251	33	65
	Denny	22nd	1258	33	65
	22nd	23rd	1251	33	65
	23rd	John	707	33	62
	John	25th	679	33	62
	25th	26th	1036	33	64
	26th	27th	985	33	63
	27th	MLK	945	33	63
MLK	Madison	Harrison	789	33	63
9th	Madison	Spring	328	33	59
Spring	9th	8th	179	33	56
	8th	7th	198	33	57
	7th	6th	221	37.5	56
	6th	5th	1131	33	64
	5th	4th	660	33	62

Roadway Segment			PM Peak Hour Traffic Volume	Distance between Roadway Centerline and Receiver Facade	Peak Hour Leq (dBA) at Receiver Facade
Roadway	From	To			
	4th	3rd	730	33	62
	3rd	2nd	633	33	62
	2nd	1st	430	33	60
1st	Madison	Spring	1293	41	64

7 Project Impacts

7.1 Construction Noise

During construction there would be temporary increases in sound levels near active areas of construction and along roadways used for construction vehicles. The increase in noise levels would depend on the type of equipment used and the amount of time it is in use. Typical construction equipment could include bulldozers, graders, pavers, concrete and haul trucks. Approximate sound levels for these and other types of equipment are shown in Table 7, as well as attenuated levels at distance. The typical attenuation of sound over distance for stationary noise sources is 6 dBA per doubling of distance (FTA, 2006).

Table 7 Typical Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level (dBA) 50 ft from Source
Air Compressor	81
Backhoe	80
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane, Mobile	83
Dozer	85
Generator	81
Grader	85
Jack Hammer	88
Loader	85
Paver	89
Pneumatic Tool	85
Pump	76
Roller	74
Saw	76
Truck	88

Source: FTA 2006

FTA's General Assessment methodology is used to identify construction noise impacts. Two noisiest pieces of construction equipment from Table 7 would be a paver and a truck/jack hammer. When that equipment is operated together for an hour, the noise level would be 92 dBA at 50 feet. As shown in

Table 6, the distance between construction equipment (center of the corridor) and potential noise sensitive receivers would be less than 50 feet for all project roadway segments.

When construction occurs, construction noise levels could be as high as 92 dBA at 50 feet, which would exceed City of Seattle daytime thresholds of 82 dBA for residential receivers and 85 dBA for commercial receivers (which include institutional uses) and would exceed the nighttime thresholds of 77 dBA for residential receivers and 80 dBA for commercial receivers. The Madison BRT Project would be required to obtain a noise variance for nighttime work from the City of Seattle prior to construction. Because construction noise impacts would be temporary, and the project would be required to adhere to the conditions of the noise variance and other permit requirements, they would not be significant.

7.2 Construction Vibration

A vibration impact assessment was conducted based on the methodology described in Section 5.2 of this report. Table 8 includes vibration source levels for typical construction equipment derived from FTA Manual.

Table 8 Vibration Source Levels for Construction Equipment

Equipment	PPV at 25 ft (in/sec)	Approximate L_v* at 25 ft
Vibratory Roller	0.210	94
Large Bulldozer	0.089	87
Loaded Trucks	0.076	86
Jackhammer	0.035	79
Small Bulldozer	0.003	58

Source: FTA 2006
*RMS velocity in decibels (VdB) re 1 micro in/sec.

Impacts to Buildings

Potential damage to buildings and structures along the alignment was assessed based on how the structures are built. FTA criteria for building and structural damage is listed below. To be conservative, it was assumed that all structures along the project corridor would fall into Building Category 3, non-engineered timber and masonry buildings. The impact threshold would be 0.2 in/sec PPV.

Table 9 Construction Vibration Damage Criteria

Building Category	PPV (in/sec)	Approximate Lv †
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

† RMS velocity in decibels (VdB) re 1 micro-inch/second

Minimum distances from construction equipment where PPV levels would be less than 0.2 in/sec are shown in Table 10. When construction equipment is within these distances the PPV level would exceed 0.2 in/sec, and could have a vibratory impact on buildings. Due to the close proximity to the receiving structures, construction equipment would be located within those distances. See Section 8 for potential mitigation measures.

Table 10 Minimum Distances for Structural Damage

Equipment	Distance (feet)
Vibratory Roller	30
Large Bulldozer	15
Loaded Trucks	15
Jackhammer	10
Small Bulldozer	5

Human Annoyance

The threshold for vibration impacts to humans is dependent on the sensitive receptor/land use category defined by FTA. These thresholds are listed in Table 2, above. Table 3 includes the threshold for special buildings. The sensitive receptors are shown on Figure 6.

Table 11 includes minimum distances from construction equipment that VdB levels would be less than appropriate thresholds.

Table 9 Minimum Distances for Human Annoyance

Equipment	Distance (feet)		
	Land Use Category 1	Land Use Category 2	Land Use Category 3
Vibratory Roller	250	80	65
Large Bulldozer	145	45	40
Loaded Trucks	135	45	35
Jackhammer	80	25	20
Small Bulldozer	20	5	5

Town Hall Seattle is approximately 150 feet from the curb of Spring St. If a vibratory roller is used during an event, it would be considered an impact. Vibration from construction equipment could annoy people within residential and non-residential buildings along Madison and Spring Streets as construction equipment could be located as close as 10 to 20 feet from the building. See Section 8 for potential mitigation measures.

7.3 Project Operation Noise

Noise levels from transit sources (e.g., buses) were predicted using the methodology described in Section 5.1 of this report. Tables 12 to 14 presents the impact summaries of each land use category. As indicated in the tables. Impacts are expected to be less than significant due to project operation.

There is currently no bus activity at the east end of the alignment on MLK Jr. Way/E Harrison Street where a new bus layover area is proposed as part of the Project. Buses operating in this location would be considered a new noise source; however, as the analysis below shows, the noise levels would remain below the impact thresholds for all land uses in this neighborhood.

Table 12 Land Use Category 1 Impact Summary

Roadway Segment			PM Peak Hour Traffic Volume	Peak Hour Leq (dBA)	Moderate Impact Threshold	Project Noise Level (Leq dBA)	Impact
Roadway	From	To					
Madison	1st	2nd	442	60	58	52	No
	2nd	3rd	523	61	59	52	No
	3rd	4th	530	61	59	52	No
	4th	5th	615	61	59	52	No
	5th	6th	783	62	59	51	No
	6th	7th	1731	67	63	50	No
	7th	8th	1316	65	61	51	No
	8th	9th	1315	65	61	50	No
	9th	Terry	1382	65	61	52	No
	Terry	Boren	1327	65	61	52	No
	Boren	Minor	1442	65	61	52	No
	Minor	Summit	1430	65	61	52	No
	Summit	Bolston	1366	65	61	52	No
	Boylston	Broadway	1370	65	61	53	No
	Broadway	Broadway Ct	1360	65	61	53	No
	Broadway Ct	10th	1359	65	61	53	No
	10th	Seneca	1344	65	61	53	No
	Seneca	11th	1358	65	61	53	No
	11th	12th	1549	65	61	53	No
	12th	13th	1389	65	61	53	No
	13th	14th	1174	64	61	52	No
	14th	15th	1250	65	61	52	No
	15th	16th	1177	64	61	55	No
	16th	17th	1602	66	62	55	No
	17th	18th	1579	66	62	55	No
	18th	19th	1511	65	61	55	No
	19th	20th	1414	65	61	55	No
	20th	Denny	1251	65	61	55	No
	Denny	22nd	1258	65	61	54	No
	22nd	23rd	1251	65	61	54	No
	23rd	John	707	62	59	54	No
	John	25th	679	62	59	54	No
	25th	26th	1036	64	61	54	No
	26th	27th	985	63	60	54	No
	27th	MLK	945	63	60	54	No
MLK	Madison	Harrison	798	63	60	48	No
9th	Madison	Spring	328	59	58	50	No
Spring	9th	8th	179	56	56	51	No
	8th	7th	198	57	57	51	No
	7th	6th	221	56	56	50	No
	6th	5th	1131	64	61	51	No
	5th	4th	660	62	59	52	No
	4th	3rd	730	62	59	52	No
	3rd	2nd	633	62	59	52	No
	2nd	1st	430	60	58	52	No
1st	Madison	Spring	1293	64	61	50	No

Note: Noise levels are hourly Leq.

Table 10 Land Use Category 2 Impact Summary

Roadway Segment			PM Peak Hour Traffic Volume	Peak Hour Leq (dBA)	Moderate Impact Threshold	Project Noise Level (Ldn dBA)	Impact
Roadway	From	To					
Madison	1st	2nd	442	60	58	57	No
	2nd	3rd	523	61	59	57	No
	3rd	4th	530	61	59	57	No
	4th	5th	615	61	59	57	No
	5th	6th	783	62	59	55	No
	6th	7th	1731	67	63	55	No
	7th	8th	1316	65	61	55	No
	8th	9th	1315	65	61	55	No
	9th	Terry	1382	65	61	57	No
	Terry	Boren	1327	65	61	57	No
	Boren	Minor	1442	65	61	57	No
	Minor	Summit	1430	65	61	57	No
	Summit	Bolston	1366	65	61	57	No
	Boylston	Broadway	1370	65	61	57	No
	Broadway	Broadway Ct	1360	65	61	57	No
	Broadway Ct	10th	1359	65	61	57	No
	10th	Seneca	1344	65	61	57	No
	Seneca	11th	1358	65	61	57	No
	11th	12th	1549	65	61	57	No
	12th	13th	1389	65	61	57	No
	13th	14th	1174	64	61	57	No
	14th	15th	1250	65	61	57	No
	15th	16th	1177	64	61	60	No
	16th	17th	1602	66	62	60	No
	17th	18th	1579	66	62	60	No
	18th	19th	1511	65	61	60	No
	19th	20th	1414	65	61	60	No
	20th	Denny	1251	65	61	60	No
	Denny	22nd	1258	65	61	59	No
	22nd	23rd	1251	65	61	59	No
	23rd	John	707	62	59	59*	No
	John	25th	679	62	59	59*	No
	25th	26th	1036	64	61	59	No
	26th	27th	985	63	60	59	No
	27th	MLK	945	63	60	59	No
MLK	Madison	Harrison	798	63	60	53	No
9th	Madison	Spring	328	59	58	55	No
Spring	9th	8th	179	56	56	55	No
	8th	7th	198	57	57	55	No
	7th	6th	221	56	56	55	No
	6th	5th	1131	64	61	56	No
	5th	4th	660	62	59	57	No
	4th	3rd	730	62	59	57	No
	3rd	2nd	633	62	59	57	No
	2nd	1st	430	60	58	57	No
1st	Madison	Spring	1293	64	61	54	No

Note: Noise levels are Ldn.

*Actual project noise level is 58.7 dBA.

Table 11 Land Use Category 3 Impact Summary

Roadway Segment			PM Peak Hour Traffic Volume	Peak Hour Leq (dBA)	Moderate Impact Threshold	Project Noise Level (Ldn dBA)	Impact
Roadway	From	To					
Madison	1st	2nd	442	60	63	52	No
	2nd	3rd	523	61	64	52	No
	3rd	4th	530	61	64	52	No
	4th	5th	615	61	64	52	No
	5th	6th	783	62	64	51	No
	6th	7th	1731	67	68	50	No
	7th	8th	1316	65	66	51	No
	8th	9th	1315	65	66	50	No
	9th	Terry	1382	65	66	52	No
	Terry	Boren	1327	65	66	52	No
	Boren	Minor	1442	65	66	52	No
	Minor	Summit	1430	65	66	52	No
	Summit	Bolston	1366	65	66	52	No
	Boylston	Broadway	1370	65	66	53	No
	Broadway	Broadway Ct	1360	65	66	53	No
	Broadway Ct	10th	1359	65	66	53	No
	10th	Seneca	1344	65	66	53	No
	Seneca	11th	1358	65	66	53	No
	11th	12th	1549	65	66	53	No
	12th	13th	1389	65	66	53	No
	13th	14th	1174	64	66	52	No
	14th	15th	1250	65	66	52	No
	15th	16th	1177	64	66	55	No
	16th	17th	1602	66	67	55	No
	17th	18th	1579	66	67	55	No
	18th	19th	1511	65	66	55	No
	19th	20th	1414	65	66	55	No
	20th	Denny	1251	65	66	55	No
	Denny	22nd	1258	65	66	54	No
	22nd	23rd	1251	65	66	54	No
	23rd	John	707	62	64	54	No
	John	25th	679	62	64	54	No
	25th	26th	1036	64	66	54	No
	26th	27th	985	63	65	54	No
	27th	MLK	945	63	65	54	No
MLK	Madison	Harrison	798	63	65	48	No
9th	Madison	Spring	328	59	63	50	No
Spring	9th	8th	179	56	61	51	No
	8th	7th	198	57	62	51	No
	7th	6th	221	56	61	50	No
	6th	5th	1131	64	66	51	No
	5th	4th	660	62	64	52	No
	4th	3rd	730	62	64	52	No
	3rd	2nd	633	62	64	52	No
	2nd	1st	430	60	63	52	No
1st	Madison	Spring	1293	64	66	50	No

Note: Noise levels are hourly Leq.

7.4 Project Operation Vibration

The FTA Manual states that it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads, as described in Section 5.2 of this report. The Madison BRT Project would, in the areas with island stations, move the bus station further away from potential sensitive receptors. In other areas, the road right-of-way, and thus the stations, is moving closer to the surrounding land uses. Changes in vibration from these location changes are expected to be imperceptible. Vibration impacts due to project operation would not be expected.

8 Mitigation Measures

8.1 Construction Noise

To satisfy the Seattle Noise Ordinance, a noise control plan will be implemented to reduce noise impacts to the community. Night-time noise will require a Noise Variance from the Seattle Department of Construction and Inspections.

8.2 Construction Vibration

To reduce construction vibration impacts, a vibration control plan will be developed by the Contractor and approved by SDOT. Contractors will phase in construction activity, use low-impact construction technologies, and avoid the use of vibrating equipment where possible to avoid construction vibration impacts. Contractors will use smaller and lower impact construction technologies to avoid impacts to vibration sensitive receivers, where these structures are located within the distances presented in Tables 7-3 and 7-4. Contractors will avoid the use of driving piles and will drill piles instead wherever practicable. The construction contractor is responsible for implementing this measure during the construction phase.

8.3 Operations

The Madison BRT project would not result in operational noise impacts; as such, no mitigation is recommended.

9 References

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