9.9 NOISE AND VIBRATION TECHNICAL REPORT

KMC REPORT NO. 020302 KM CHNG ENVIRONMENTAL INC.

CENTRAL CORRIDOR TRANSIT AA/EIS STUDY

- NOISE AND VIBRATION TECHNICAL REPORT

RAMSEY COUNTY RAILROAD AUTHORITY

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2.0 Noise

This chapter includes an introduction to basic noise concepts including noise descriptors, the prediction methodologies and modeling assumptions, the results of the ambient noise monitoring program, and the evaluation of potential impacts along the Central Corridor.

.1 Human Perception of Noise

The characteristics and properties of noise are explained in the following subsections.

.1.1 Describing Noise

Noise is "unwanted sound" and, by this very definition, the perception of noise is a subjective process. Several factors affect the actual level and quality of sound (or noise) as perceived by the human ear and can generally be described in terms of loudness, pitch (or frequency), and time variation.

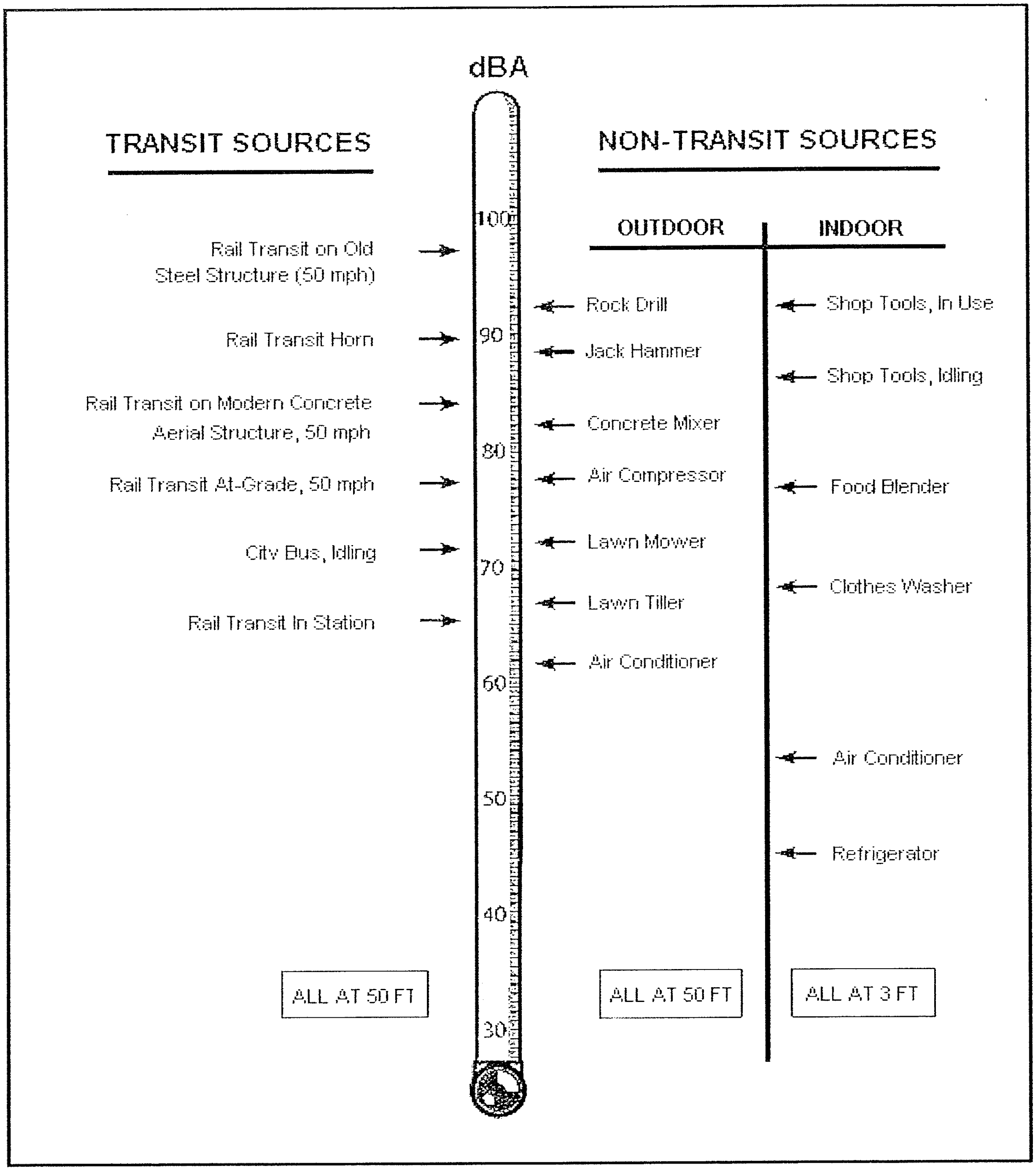
Loudness. The loudness, or magnitude, of noise determines its intensity and is measured in decibels (dB). The noise decibel is used to describe a large range of sound levels. For example, ambient noise ranges from 40 decibels from the rustling of leaves to over 70 decibels from a truck passby to over 100 decibels from a rock concert.

Pitch. Pitch describes the character and frequency content of noise. Measured in Hertz (Hz), frequency is typically used to identify the annoying characteristics of noise and thereby identify the proper mitigation to help eliminate or minimize its magnitude. The human ear is typically sensitive to noise frequencies between 20 Hz (low-pitched noise) and 20,000 Hz (high-pitched noise). For example, noise may range from very low-pitched "rumbling" noise from stereo sub-woofers to mid-range traffic noise to very high-pitched whistle noise.

Time Variation. The time variation of some noise sources can be characterized as continuous, such as a building ventilation fan, intermittent, such as for a train passby, or impulsive, like a car backfire.

.1.2 Description of Noise Levels

Various levels are used to quantify noise from transit sources including a sound's loudness, duration, and tonal character. For example, the A-weighted decibel (dBA) is commonly used to describe the overall noise level. Because the decibel is based on a logarithmic scale, a 10-decibel increase in noise level is generally perceived as a doubling of loudness, while a 3-decibel increase in noise is just barely perceptible to the human ear. The A-weighting is an attempt to take into account the human ear's response to audible frequencies. Typical A-weighted sound levels from transit and other common sources are shown in **Figure 1-1**. The following A-weighted noise descriptors are typically used to determine impacts from transit-related sources:



Source: *Transit Noise and Vibration Impact Assessment - Final Report*. Federal Transit Administration. Washington. D.C.. April 1995.

Figure 1-1: Typical A-weighted Noise Levels

- **Lmax** represents the maximum noise level that occurs during an event or train passby and is the noise level actually heard during the event or passby.

- **Leq** represents a level of constant noise with the same acoustical energy as the fluctuating noise levels (e.g., highway traffic) observed during a given interval such as one hour. For transit projects the Leq noise level is commonly used to describe levels at non-residential places (such as offices, schools, and churches) with primarily daytime uses. Leq(h) is a noise level averaged over one hour.

- **Ldn**, the day-night noise level, represents the average noise level evaluated over a 24-hour period. A 10-decibel penalty is added to events that occur during the nighttime hours (10:00 p.m. to 7:00 a.m.) to account for people's increased sensitivity to noise while they are sleeping. For transit projects the Ldn is commonly used to describe noise at residences.

- **SEL** is the sound exposure level typically used to predict overall transit source levels. The SEL converts the time period of the Leq to one second allowing for the direct comparison of events or passbys with different time durations.

Unlike the Lmax level, the hourly Leq noise level describes noise over a longer time duration than just a single event. For example, a single six-car train passby at 50 mph has an Lmax of 88 dBA but a Leq(h) level of only 54 dBA. This is due to the concept of time averaging whereby the overall average noise level (Leq) during the one-hour period is much less than the short-duration passby level of the event (Lmax). The Lmax and the hourly Leq levels are theoretically equivalent for constant noise sources such as a transformers or rooftop ventilation units.

.2 Evaluation Criteria

The criteria used to evaluate noise impacts are described in the following subsections. Criteria used to evaluate operational and construction impacts are discussed separately.

.2.1 Operational Noise

Operational criteria are used to assess noise impacts from the project alternatives when they are fully operational. These criteria are, therefore, typically evaluated against the project operations that occur in the design year.

.2.1.1 Federal Noise Guidelines

The Federal Transit Administration's *Transit Noise and Vibration Impact Assessment* guidance manual (DOT-95-16, April 1995) presents the basic concepts, methods, and procedures for evaluating the extent and severity of noise impacts from transit projects. Transit noise impacts are assessed based on land-use categories and sensitivity to noise from transit sources under the FTA guidelines. The FTA noise impact criteria are defined by two curves that allow increasing project noise levels as existing noise increases up to a point, beyond which impact is determined based on project noise alone. The FTA land-use categories and required noise metrics are described in Table 1-1.

Table 1-1

FTA LAND-USE CATEGORIES AND NOISE METRICS

Land-use Category	Noise Metric	Description
1	Leq(h)	Tracts of land set aside for serenity and quiet, such as outdoor amphitheaters, concert pavilions, and historic landmarks.
2	Ldn	Buildings used for sleeping such as residences, hospitals, hotels, and other areas where nighttime sensitivity to noise is of utmost importance.
3	Leq(h)	Institutional land-uses with primarily daytime and evening uses including schools, libraries, churches, museums, cemeteries, historic sites, and parks, and certain recreational facilities used for study or meditation.

Source: *Transit Noise and Vibration Impact Assessment - Final Report*, Federal Transit Administration, Washington, D.C., April 1995.

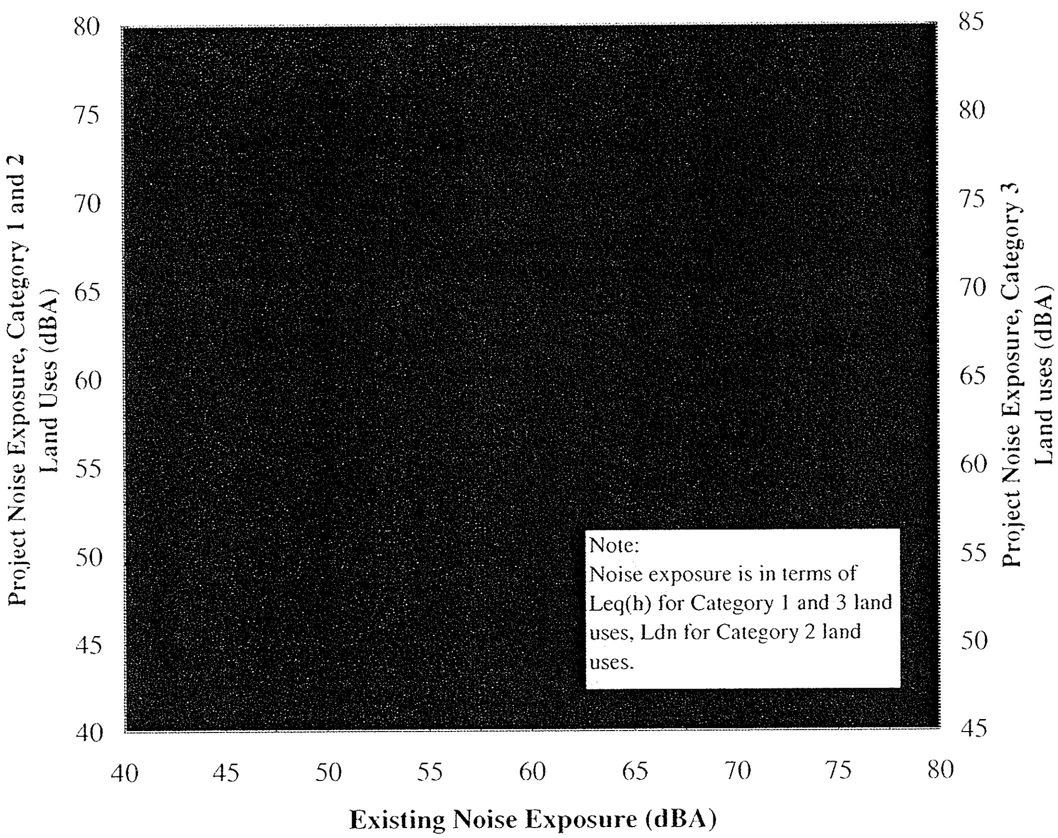
The FTA noise criteria are delineated into two categories: *impact* and *severe impact*. The *impact* threshold defines areas where the change in noise is noticeable but may not be sufficient to cause a strong, adverse community reaction. The *severe impact* threshold defines the noise limits above which a significant percentage of the population would be highly annoyed by new noise. The level of impact at any specific site can be established by comparing the predicted project noise level at the site to the existing noise level at the site. The FTA noise impact criteria for all three land-use categories are shown in **Figure 1-2**.

.2.1.2 APTA Noise Criteria

In addition to FTA noise guidance, the Central Corridor Transit AA/EIS Study is evaluating the proposed Build Alternative using the American Public Transit Association's (APTA) design criteria[1].

Unlike the FTA noise impact criteria, which are based on cumulative exposure to predicted transit noise (e.g., 24-hour day-night noise levels), the APTA criteria are based on single event maximum vehicle passby noise levels. As shown in Table 1-2, maximum noise levels (or Lmax) from transit vehicle passbys are applicable to single and multi-family residences as well as commercial receptors located in various communities ranging from low-density residential to industrial. The APTA maximum passby noise levels will be applied to all modes of transit, including bus rapid transit (BRT) and light rail transit (LRT) passbys.

[1] "Noise and Vibration", *Guidelines and Principles for Design of Rapid Transit Facilities*, Section 2.7, APTA, Washington, DC, 1979.



Source: *Transit Noise and Vibration Impact Assessment - Final Report*, Federal Transit Administration, Washington, D.C., April 1995.

Figure 1-2: FTA Noise Impact Criteria for Transit Projects

Table 1-2

APTA CRITERIA FOR SINGLE EVENT MAXIMUM AIRBORNE NOISE LEVELS (LMAX) FROM TRAIN OPERATIONS (dBA)

Community Area Category[1]		Receptor Category[2]		
		Single Family	Multi-Family	Commercial
I	Low Density Residential	70	75	80
II	Average Residential	75	75	80
III	High Density Residential	75	80	85
IV	Commercial	80	80	85
V	Industrial/Highway	80	85	85
Specific Receptor Categories				
Amphitheaters			60	
"Quiet" Outdoor Recreation Areas			65	
Concert Halls, Radio and TV Studios			70	
Churches, Theaters, Schools, Hospitals, Museums, and Libraries			75	

1. Community categories include: Low Density urban residential, open space park, suburban residential or quiet recreation area with no nearby highways; Average urban residential, quite apartment and hotels, open space, suburban residential, or occupied outdoor area near busy streets; High Density urban residential, average semi-residential/commercial areas, parks, museum and non-commercial public building areas; Commercial areas with office buildings, retail stores, etc., primary daytime occupancy (Central Business District); and Industrial areas or highway corridors.
2. Receptor categories include Single Family dwellings, Multi-Family dwellings and Commercial buildings.

Note: The APTA criteria are generally referenced to or applied at a point 50 feet or farther from the track centerline.

.2.2 Construction Noise

Noise limits placed on construction activities from the FTA as well as local ordinances are described in the following subsections.

.2.2.1 Federal Design Guidelines

During the preliminary engineering/environmental analysis phase of a project, construction details are limited; therefore, the FTA guidelines suggest evaluating proposed construction scenarios against the one-hour Leq thresholds shown in Table 1-3. These design guidelines are evaluated against noise levels from the two loudest pieces of equipment that, under worst-case conditions, are assumed to operate continuously for one hour during both the daytime (7:00 a.m. to 10:00 p.m.) and nighttime (10:00 p.m. to 7:00 a.m.) periods.

Table 1-3

RECOMMENDED FTA CONSTRUCTION NOISE LIMITS (dBA)

Land-use Category	Construction Period	
	Daytime	Nighttime
Residential	90	80
Commercial	100	100
Industrial	100	100

Source: *Transit Noise and Vibration Impact Assessment - Final Report*. Federal Transit Administration. Washington. D.C.. April 1995.

.2.2.2 Local Ordinances

In addition to the FTA criteria, an inventory of local and county noise ordinances was compiled for all municipalities along the proposed Project Corridor. Local noise ordinances generally do not set limits on transit operations but rather on construction and other nuisance noises. Additionally, construction activities are limited almost everywhere to the daytime hours when noise disturbance and interference are minimized. Table 1-4 shows all applicable local noise ordinances along the Project Corridor.

In order to evaluate other noise criteria using the FTA modeling methodology, the St. Paul noise limit of 85 dBA L10 was converted to 82 dBA Leq using the Federal Highway Administration's (FHWA) relationship between the L10 and the Leq noise criteria of 3-dBA.

Table 1-4

INVENTORY OF LOCAL NOISE ORDINANCES ALONG THE CENTRAL CORRIDOR

Criteria	Municipality	
Description	Minneapolis[1]	St. Paul[2]
Noise Limit Threshold at 50 feet	90 dBA (Lmax)	85 dBA (L10)[3]
Construction Period Limits	7 a.m. – 6 p.m. (weekdays only)	None specified
Nuisance Restrictions	Yes	Yes
Other Construction Noise Regulations	Special permit required for variances.	Special permit required for variances.

1 Minneapolis "Code of Ordinance", Title 15, Chapter 389, Article I, Section 389.65 and 389.70.
2 St. Paul "Legislative Code", Chapter 293, Section 293.09.
3 In order to evaluate other noise criteria using the FTA modeling methodology, the St. Paul noise limit of 85 dBA L10 was converted to 82 dBA Leq using the Federal Highway Administration's (FHWA) relationship between the L10 and the Leq noise criteria of 3-dBA.

.3 Modeling Methodology and Assumptions

A detailed description of the modeling methodologies and the types of noise sources included in the modeling prediction are included in the following sub-sections.

.3.1 Modeling Methodology

A description of the FTA modeling methodologies for both operations and construction is included in the following sub-sections.

.3.1.1 Operations

The impact assessment from future transit noise sources along the project corridor was determined according to the FTA guidelines and includes a screening procedure, general assessment, and detailed analysis, as described below:

- **Screening Procedure** – Identifies existing noise-sensitive land-uses along the proposed project corridor and whether or not impact is likely. Further analysis is required if noise-sensitive receptors fall within FTA "screening" distances for various sources.

- **General Assessment** – Estimates the severity of noise impacts in the study area selected during the Screening Procedure analysis. When detailed project data of existing background noise levels are not available, conservative assumptions are used to identify the noise levels at which potential impact could result.

- **Detailed Analysis** – Quantifies impacts through an in-depth analysis that includes ambient noise monitoring and a delineation of site-specific impacts and mitigation measures for each of the proposed project alternatives.

The Screening Procedure considered a screening distance of 1,000 feet to determine the number, location, and land-use types of noise-sensitive receptors along the project corridor.

Because precise alignment and operations data were available, a Detailed Analysis was conducted to quantify the overall noise level at receptors identified during the screening procedure. The noise prediction modeling included all new sources of noise proposed along the project corridor, including LRT train passbys, rail auxiliary equipment at stations, BRT passbys, and BRT idle at stations. Operations data were adjusted based on the existing topography, such as acoustically hard or soft ground, and terrain cuts. Project noise levels from facilities, such as rail yards and the BRT maintenance facility, were predicted using the FTA General Assessment guidelines.

Based on the screening distances shown in Table 1-5, over 3,600 receptor locations were identified along the project corridor and included in the modeling analysis. These receptor locations include single- and multi-family residences, hotels, schools, churches, commercial offices, parks, and historic resources.

Project noise levels were described for the two Build Alternatives: The University Avenue Busway/BRT Alternative operating on a dedicated Right-Of-Way (ROW) along the median of University Avenue, except in the downtown areas of Minneapolis and St. Paul where BRT buses run along existing roadways in mixed traffic; and the University Avenue LRT Alternative operating on a dedicated ROW along the median of University Avenue for the entire length of the corridor. The BRT Alignment will include a total of 25 passenger stations, while the LRT Alignment will include a total of 21 passenger stations.

Operations data, such as volumes, speeds, consist sizes for LRT trains, and other operations input data are described in the Appendix.

Table 1-5

FTA SCREENING DISTANCES FOR NOISE ASSESSMENTS

Project Type	Description	Screening Distance (feet)	
		Unobstructed	Intervening Buildings
Fixed Guideway System	Rail Transit Guideway	700	350
	Rail Transit Station	200	100
	Rail Yard	2,000	1,000
Bus Systems	Busway	500	250
	Bus Storage & Maintenance Facilities	1,000	500

.3.1.2 Construction

Construction noise expected along the Central Corridor was estimated according to the procedures outlined in the FTA guidelines. Construction equipment operates as either a stationary or mobile source. Stationary equipment operates in one location for an extended period of time and produces either continuous noise (e.g., from pumps, generators, and compressors) or intermittent noise (e.g., from pile drivers and pavement breakers). Mobile equipment moves around the construction site, with engine power varying as needed (e.g., bulldozers and loaders) or to and from the construction site (e.g., trucks). Construction noise is highly dependent on variations in equipment power setting and activity. Mobile noise sources typically do not operate at full power continuously.

The construction noise prediction methodology is based on the following assumptions:

- The construction equipment operates at full power for a one-hour period;
- Free field conditions, ignoring ground effects;
- Equipment's full power reference emission level;
- All construction equipment operates at the center of the project site or track centerline;
- The two noisiest pieces of equipment expected to be utilized during each construction phase; and,
- Noise attenuation resulting only from energy dissipation (i.e., 6 dBA for each doubling of distance).

Based on the results of the screening procedure, whereby potential noise-sensitive receptors were identified along the project corridor, a general assessment was conducted according to the FTA construction noise guidelines. Predicted levels that exceeded the FTA construction noise guidelines indicated potential construction noise impacts. For these impact locations, a detailed construction noise impact assessment should be completed during the project final design with mitigation recommendations included in the construction specification documents.

The impact assessment is based on the types of equipment that are typically used for each construction activity. Noise levels from typical construction equipment types are provided in the FTA guidelines at a reference distance of 50 feet. These levels were used to estimate the onset of impact at nearby sensitive receptors for each of the different construction activities. The noise predictions included the two loudest pieces of equipment that could be utilized for each construction activity. This assessment is preliminary only and will be updated during final design to reflect more precise construction scenarios, equipment types, and operating schedules. The following construction scenarios were selected to be representative of the types of activities expected during construction of the Central Corridor:

- Track-Laying (At Grade);
- Passenger Station Construction;
- Bridge Renovation; and,
- Rail and Bus Maintenance Facilities.

The equipment types and the maximum FTA reference noise levels are shown in Table 1-6 for each of the selected prototypical construction scenarios. Although numerous equipment types would eventually be used during each scenario, the FTA guidelines suggest using only the two loudest pieces during the preliminary noise impact assessment.

Table 1-6

FTA NOISE REFERENCE LMAX LEVELS FOR ALL CONSTRUCTION EQUIPMENT BY SCENARIO (dBA)

Construction Equipment Type	Construction Scenario			
	Track Laying (At Grade)	Passenger Stations	Bridge Renovation	Rail & Bus Facilities
Grader	85	85	85	--[1]
Jack Hammer	--	--	88	--
Loader	--	--	--	85
Tie Inserter	85	--	--	--
Truck	--	88	--	88

1. Equipment type not included in the prediction modeling for selected construction scenario.

.3.2 LRT Passbys

The LRT cars proposed along the Central Corridor are to be provided by Bombardier. These vehicles consist of 94-foot electrically powered railcars that operate on continuously welded rail tracks. Adjustments to the predicted noise levels for each passby included the following:

- Track type: at-grade (ballast) vs. aerial (concrete slab);
- Train speed;
- Consist size; and;
- Period volumes.

Reference data, such as Lmax and SEL noise levels and average acoustical source height, are shown in Table 1-7 for LRT passby noise sources.

Table 1-7

SUMMARY OF NOISE SOURCE REFERENCE DATA

Noise Source		Duration	Height	Noise Level (dBA)	
Name	Description	(seconds)	(feet)	Lmax	SEL
LRT	Train passbys	--[1]	2	80	82
Auxiliary Equipment	Stations	30	10	65	101
BRT	Bus passbys	--	8	85	88
BRT Idle	Stations	20	8	74	110
Rail Yard/Layover Facility	Rail Yard	--	2	82	118
BRT Maintenance Yard	BRT Facility	--	8	75	111
Wheel Squeal-LRT	Curves with Radius <82 ft	4	0	100	136

1. Not applicable. Passby and facility noise prediction equations do not require a duration time.
Note: All noise levels are based on a reference distance of 50 feet and a speed of 50 mph (for mobile sources).

Using the peak- and 24-hour LRT volumes listed in the Appendix, passby noise levels from LRT vehicles were predicted at each of the identified receptor locations along the project corridor using the FTA methodology.

.3.3 BRT Passbys

The BRT vehicles proposed along the Project Corridor would be specially designed vehicles that could accommodate additional passengers and provide access to center platform stations on the left side of the vehicle. These vehicles consist of 60-foot diesel-powered articulated buses with three axles that would travel primarily on the dedicated BRT ROW along the Central Corridor. Adjustments to the predicted noise levels for each passby included BRT travel speed and period volumes. A maximum speed of 30 mph was used everywhere along the Project Corridor.

Reference data, such as Lmax and SEL noise levels and average acoustical source height, are shown in Table 1-7 for BRT passby noise sources. Default FTA reference noise data for commuter buses, including noise level and source height, were used for the proposed articulated BRT vehicles.

Using the peak- and 24-hour BRT volumes listed in the Appendix, passby noise levels from BRT vehicles were predicted at each of the identified receptor locations along the project corridor using the FTA methodology.

.3.4 Stationary Sources

In addition to LRT and BRT passbys, several stationary sources were also included in the modeling prediction analysis including:

- LRT auxiliary equipment at stations;
- BRT vehicle idling at passenger stations; and,
- LRT wheel squeal along tight-radius curves.

All reference data, such as Lmax and SEL source noise levels and average acoustical source height, are shown in Table 1-7 for each of the stationary sources.

Using the peak- and 24-hour period volumes listed in the Appendix, event noise levels from each stationary source were predicted at each of the identified receptor locations along the project corridor using the FTA methodology.

.3.4.1 Wheel Squeal

Wheel squeal occurs from train passbys in tight-radius curves. The LRT vehicles that are proposed along the Central Corridor are to be provided by Bombardier. Based on manufacturer's specifications, wheel squeal from these vehicles is not expected to occur at curves with a radius above 82 feet.[2]

.3.4.2 Auxiliary Equipment

LRT auxiliary equipment, such as rooftop heating and ventilation units, were also included in the noise modeling analysis at stations. Although the auxiliary equipment is included in the cumulative LRT passby noise level, it is the dominant train noise source when the LRT trains are stopped at the station and is, therefore, modeled separately. As shown in Table 1-7, an average delay time in the station of 20 seconds and an LRT rooftop source height of 10 feet was used to predict project noise levels from auxiliary equipment.

.3.4.3 Bus Idling

Idling noise from BRT vehicles near stations were also included in the modeling prediction analysis. Although each source type has different reference idling noise levels, as shown in Table 1-7, overall idling noise predicted from BRT buses is based on average idling times of 20 seconds with an average acoustical source height of 10 feet. This average acoustical height is based on a rooftop exhaust location.

.3.5 Facilities

In addition to LRT and the BRT operations, several ancillary facilities were also included in the modeling prediction analysis including:

- Rail Yards; and,
- BRT Maintenance Facility.

All reference data, such as Lmax and SEL source noise levels and average acoustical source height, are shown in Table 1-7 for each of the facility noise sources.

Using the peak- and 24-hour period volumes listed in the Appendix, event noise levels from each facility noise source were predicted at each of the identified receptor locations along the project corridor using the FTA methodology.

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[2] Email correspondence from John Crawford (URS) on 18 January 2002.

.3.5.1 Rail Yards

Noise from activities at rail yards includes train movements through switches (which is normally associated with the clickety-clack sounds), and maintenance work. Overall yard noise was predicted at nearby receptor locations from the following facilities:

- LRT maintenance facility on Franklin Avenue (Minneapolis), and;
- LRT layover facility near Gillette factory (St. Paul).

As shown in Table 1-7, rail yard noise levels from general train activities are based on the FTA reference levels.

All volumes used to predict the overall noise levels from the rail yards, including the peak- and 24-hour periods, are described in the Appendix.

.3.5.2 BRT Maintenance Facility

Noise from activities at the BRT maintenance facility on Snelling Avenue were also predicted at nearby receptors based on default FTA operations. The BRT Maintenance Facility was included under the BRT Alternative only

As shown in Table 1-7, BRT Maintenance Facility noise from general bus servicing and cleaning activities is based on the FTA reference levels. All volumes used to predict the overall noise levels from the BRT Maintenance Facility, including the peak- and 24-hour periods, are described in the Appendix.

.3.6 24-Hour Ldn Noise Level

At residential receptors identified along the project corridor, including residences and hotels, the 24-hour Ldn noise level was used to assess impact against the FTA impact criteria. Using Equation 1, average hourly Leq noise levels during the daytime (from 7 a.m. to 10 p.m.) and the nighttime (from 10 p.m. to 7 a.m.) periods were used to develop an overall 24-hour Ldn noise level.

$$Ldn_{50} = 10\log\left[15\times10^{\left(\frac{LeqD_{50}}{10}\right)} + 9\times10^{\left(\frac{LeqN_{50}+10}{10}\right)}\right] - 10\log(24) \qquad \text{[Eq. 1]}$$

<u>where:</u>

Ldn_{50}	= 24-hour Ldn noise level at 50 feet (in dBA);
$LeqD_{50}$	= average <u>daytime</u> hourly Leq(h) noise level at 50 feet between 7 a.m. and 10 p.m. (in dBA);
$LeqN_{50}$	= average <u>nighttime</u> hourly Leq(h) noise level at 50 feet with 10-dBA penalty applied for nighttime events between 10 p.m. and 7 a.m. (in dBA); and,
-10log(24)	= Ldn adjustment factor based on the number of hours in a day (in dBA).

.3.7 Attenuation and Shielding Effects

In areas along the project corridor with intervening structures, such as buildings, or terrain features that affect the noise propagation path between the transit source and receptor, noise attenuation was determined on a receptor-by-receptor basis. The following shielding and attenuation factors were included in the modeling analysis:

- Ground attenuation effects;
- Terrain Cut shielding effects;
- Building shielding effects; and,
- Atmospheric divergence or distance attenuation.

All methodologies are based on the FTA modeling guidelines.

.4 Existing Conditions

Existing noise along the project corridor was measured to characterize ambient background levels in the community. The scope and the results of the noise measurement program are described in the following subsections.

.4.1 Background Ambient Noise Levels

In accordance with FTA noise guidelines, a noise-monitoring program was conducted along the study area from downtown Minneapolis to downtown St. Paul along University Avenue to (1) establish the existing ambient background levels within the project area and (2) develop project criteria noise limits.

As shown in **Figure 1-3**, noise measurements were obtained at 10 receptor locations along the Central Corridor. Three measurements were obtained for a 24-hour period, and seven measurements were conducted for the peak, off-peak and nighttime periods. The results were used to establish baseline noise levels for both residential and non-residential receptors. The existing noise environment was characterized according to the FTA land-use categories shown in Table 1-1.

Existing land-uses along the Central Corridor are exposed to a variety of noise sources ranging from vehicular traffic to cross streets and arterials. Noise measurements were conducted at noise-sensitive locations along the corridor as described in the Central Corridor Transit Study *Noise and Vibration Measurement Protocol* (October 2001). The monitoring locations shown in **Figure 1-3** were selected to be representative of the types of neighborhoods and land-uses found along the corridor. The results of the community noise-monitoring program were used to establish the existing background noise levels and to develop the allowable project criteria using the FTA guidelines. The noise-monitoring program was conducted in November 2001 at 10 receptor locations to establish existing peak-hour Leq noise levels at non-residential locations and 24-hour Ldn noise levels at residences. The results of the noise-monitoring program, including measurement date, time, and noise levels, are summarized in Table 1-8 for each of the 10 discrete receptors.

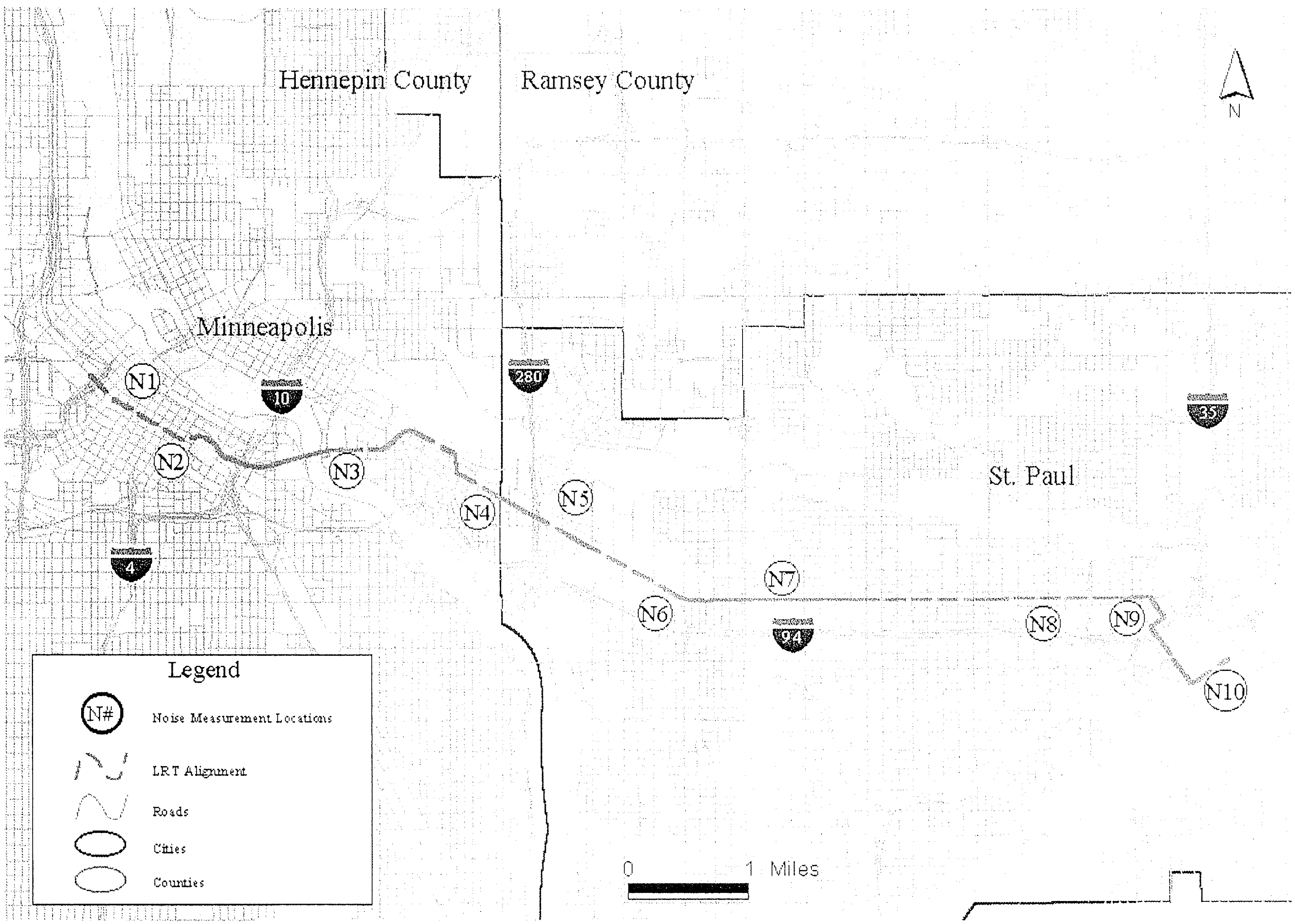


Figure 1-3: Community Noise Monitoring Locations along the Central Corridor

Table 1-8

SUMMARY OF NOISE MEASUREMENT PROGRAM ALONG THE CENTRAL CORRIDOR

Noise Measurement Location		FTA L.U. Cat.	Noise Measurement Period											
			Peak-Hour			Off-Peak (9 a.m. – 4 p.m.)			Latenight (12-4 a.m.)			24-hour Ldn		
No.	Description		Date	Time	Leq[1]	Date	Time	Leq[1]	Date	Time	Leq[1]	Date	Time	Ldn[1]
N1	Residence, Senior Home, Minneapolis, N 4th St. and Hennepin Ave.	2	11/14/01	13:03	69.2	11/13/01	14:51	68.5	11/14/01	00:19	60.7	--[2]	--	67.5
N2	Hospital, Minneapolis, Hennepin County Medical Center, 6th St.	2	11/12/01	17:40	61.9	11/13/01	14:12	64.1	11/14/01	00:53	57.9	--	--	63.8
N3	Hospital, Campus Area, Boynton Health Service, Church & Wash.	2	11/09/01	10:05	72.8	11/12/01	15:18	69.7	11/14/01	01:37	58.8	--	--	68.0
N4	Residence, University Area, 79 SE Clarence Ave.	2	11/14/01	07:26	56.9	--	--	--	--	--	--	11/14/01	10:26	53.9
N5	Residence, University Area, 808 Seal St. near Raymond Ave.	2	11/14/01	13:27	61.7	11/15/01	10:57	61.1	11/14/01	15:32	50.0	--	--	58.8
N6	Residence, University Area, 499 Lynhurst Ave.	2	11/14/01	13:50	53.9	11/14/01	12:40	55.2	11/14/01	15:08	45.1	--	--	53.0
N7	Residence, University Area, 1414 Sherbourne Ave.	2	11/14/01	07:31	59.3	--	--	--	--	--	--	11/14/01	11:31	61.0
N8	Residence, University Area, 386 Aurora Ave.	2	11/15/01	07:22	62.6	--	--	--	--	--	--	11/15/01	12:22	64.7
N9	Institution, St. Paul, State Capitol	3	11/09/01	16:07	67.5	--	--	--	--	--	--	--	--	51.7
N10	Residence, St. Paul, 4th St. and Robert St.	2	11/09/01	13:00	67.5	11/13/01	05:30	67.4	11/14/01	14:22	57.9	--	--	65.6

1. All Leq and Ldn noise levels are reported in A-weighted decibels.
2. '--' = Not applicable. No noise measurements were conducted during the selected period.

.4.2 Estimate 24-Hour Ldn Noise Levels from Continuous Measurements

At several residences, continuous 24-hour noise measurements were conducted to establish the existing background Ldn noise levels. At each location, 24 hourly Leq noise measurements were collected during one continuous 24-hour period. To compute the Ldn noise level, the hourly Leq noise levels were summed logarithmically, with a 10-dBA penalty applied to all measurements conducted between 10 p.m. and 7 a.m. The results of these calculations are summarized Table 1-8.

.4.3 Estimate 24-Hour Ldn Noise Levels from Short-term Measurements

At those receptor locations where 24-hour continuous noise measurements were not collected, short-term noise measurements were conducted during various periods of the day as a substitute. Following the FTA guidelines, short-term noise measurements were conducted during the each of the following periods:

- a.m. or p.m. peak-hour period (7-9 a.m. or 4-6 p.m.);
- Midday or off-peak period (9 a.m.-4 p.m.); and,
- Late night period (12-4 a.m.).

To account for the reduced measurement period, a 2-dBA penalty is applied to all measured Leq noise levels resulting in a slightly conservative estimate of the actual 24-hour Ldn noise level.

The final results of the noise-monitoring program are summarized in Table 1-9. These finalized Leq and Ldn levels were used in the modeling analysis to establish background noise levels at all other identified receptors along the project corridor. Where noise measurements were not conducted, an equivalent background level was estimated based on its similarity to one of the 10 discrete receptors. This equivalencing evaluated land-use, location to cross streets or other major ambient noise sources, and vicinity to the discrete 10 receptors.

Table 1-9

SUMMARY OF EXISTING AMBIENT NOISE LEVELS (dBA)

Receptor		Area	Type[1]	Land-use Cat.[2]		Noise Level	
No.	Description and Location			FTA	APTA	Leq	Ldn
N1	Senior Home. N 4th St. and Hennepin Ave.	Minneapolis	Res.	2	MF IV	--	68
N2	Hennepin County Medical Center. 6th St.	Minneapolis	Oth.	2	HOS	--	64
N3	Boynton Health Service, Church & Washington	Campus	Oth.	2	HOS	--	68
N4	Residence, 79 SE Clarence Ave.	University	Res.	2	SF III	--	54
N5	Residence, 808 Seal St. near Raymond Ave.	University	Res.	2	MF V	--	59
N6	Residence, 499 Lynhurst Ave.	University	Res.	2	MF III	--	53
N7	Residence, 1414 Sherbourne Ave.	University	Res.	2	SF III	--	61
N8	Residence, 386 Aurora Ave.	University	Res.	2	SF III	--	65
N9	Institution, State Capitol	St. Paul	NR	3	COM IV	68	--
N10	Residence, 4th St. and Robert St.	St. Paul	Res.	2	COM IV	--	66

1. Receptor types include residential (Res.), non-residential (NR), and other receptor types (e.g., hotels and parks).

2. The APTA land-use categories include single- (SFAM) and multi-family (MFAM) residences, commercial properties (COM), and several other specific land-use types, such as outdoor amphitheaters (Park). For each receptor type, a corresponding community area category, such as low-density (I) or industrial (V), are also required to select the proper APTA evaluation criteria.

An existing peak-hour equivalent noise level, or Leq(h), measured at the State Capitol was 68 dBA. Similarly, 24-hour noise measurements conducted to establish residential day-night noise levels, or Ldn, ranged from 53 dBA at location N6 (a residence along Lynhurst Avenue) to 68 dBA at N1 (a senior home in downtown Minneapolis). The measured noise levels are fairly typical for both urban areas and community developments along highway corridors.

.5 Long-Term Effects

A noise assessment was completed to determine the potential noise related impacts at various sensitive receptor locations along the Central Corridor. The noise levels predicted at the discrete receptors for each of the Build Alternatives were determined using the FTA guidelines and methodologies. These levels were then compared to both the FTA and APTA criteria. Corridor-wide impacts from operations were then evaluated at noise-sensitive receptors within approximately 1,000 feet of the proposed corridor alignments.

The results of the noise impact assessment for each of the project alternatives are described in the following subsections.

.5.1 Baseline

In accordance with FTA guidelines, noise impacts from the future Build Alternatives are not compared to the No-Build condition to determine impact. Instead, the FTA analysis methodology establishes project criteria noise limits based on existing measured noise levels along the proposed project corridor. Exceedances of the FTA noise criteria limits under the Build Alternatives are considered impacts of the project. Therefore, FTA guidelines do not require a noise assessment for the future No-Build Alternative.

.5.2 BRT

Under the BRT Alternative, transit operations along the Central Corridor would consist of low-floor, sixty-foot articulated transit buses.

.5.2.1 Federal Criteria

As shown in Table 1-10, the peak-hour Leq noise level from BRT operations along the Central Corridor is predicted to be 54 dBA at R9 (State Capitol in St. Paul). The peak hour Leq(h) noise level is not expected to exceed the FTA Land-use Category 3 *impact* or *severe impact* criteria at the selected discrete receptor under the BRT Alternative.

Table 1-10

FTA NOISE IMPACT SUMMARY AT DISCRETE RECEPTORS FROM TRANSIT OPERATIONS (dBA)

Receptor		FTA Land-use Category	Existing BKGD Level	Alternative		Impact Criteria	
No.	Description			BRT	LRT	IMP	SEV
R1	Senior Home. N 4th St. and Hennepin Ave.	2	68 Ldn	**67**	53	*63*	*68*
R2	Hennepin County Medical Center. 6th St.	2	64 Ldn	40	39	*60*	*66*
R3	Hospital. Boynton Health Service	2	68 Ldn	63	27	*63*	*68*
R4	Residence. 79 SE Clarence Ave.	2	54 Ldn	48	41	*55*	*61*
R5	Residence. 808 Seal St. near Raymond Ave.	2	59 Ldn	44	37	*57*	*63*
R6	Residence. 499 Lynhurst Ave.	2	53 Ldn	53	46	*54*	*61*
R7	Residence. 1414 Sherbourne Ave.	2	61 Ldn	56	50	*58*	*64*
R8	Residence. 386 Aurora Ave.	2	65 Ldn	53	47	*61*	*66*
R9	Institution. State Capitol	3	68 Leq	54	45	*68*	*73*
R10	Residence. 4th St. and Robert St.	2	66 Ldn	59	50	*61*	*67*

Note: Assessment of impact is determined as follows: No Impact and **Impact**

At residential receptors (Category 2), 24-hour Ldn levels from BRT operations are predicted to range from 40 dBA at R2 (Hennepin County Medical Center) to 67 dBA at R1 (Senior Home on Hennepin Avenue in Minneapolis). As shown in Table 1-10, except for receptor R1, none of the predicted Ldn levels are expected to exceed the FTA Land-use Category 2 *impact* or *severe impact* criteria at the selected receptor locations under the BRT Alternative. The predicted Ldn noise level of 67 dBA at receptor R1 is, however, predicted to exceed the FTA *impact* criterion of 63 dBA under the BRT Alternative.

As shown in Table 1-11, corridor-wide project noise levels are predicted to exceed the FTA Category 2 land-use *impact* criteria at 94 locations and the *severe impact* criteria at an additional 11 locations under the BRT Alternative. Similarly, exceedances of the FTA Category 3 land-use *impact* criteria are also predicted at an additional 19 locations. No exceedances of the FTA Category 1 Land-Use criteria are predicted under the BRT Alternative. The corridor-wide impact assessment evaluated impacts at noise-sensitive locations, such as residences, offices, and parks. The number of impacted Category 2 receptors includes buildings and structures such as single- and multi-family dwellings. The receptor locations, where exceedances of the FTA *impact* and *severe impact* criteria under the BRT Alternative are predicted to occur, are shown in Appendix Figure A-1.

Table 1-11

SUMMARY OF FTA NOISE IMPACT COUNTS

Corridor Section	Impact Criteria Category	Alternative			
		BRT		LRT	
		Cat. 2	Cat. 3	Cat. 2	Cat. 3
Downtown Minneapolis	*Impact*	1	0	0	0
	Severe Impact	0	0	0	0
	Sum	1	0	0	0
Campus	*Impact*	5	1	0	1
	Severe Impact	1	0	0	0
	Sum	6	1	0	1
University Avenue	*Impact*	86	18	11	0
	Severe Impact	10	0	0	0
	Sum	96	18	11	0
Downtown St. Paul	*Impact*	2	0	0	0
	Severe Impact	0	0	0	0
	Sum	2	0	0	0
Totals	*Impact*	94	19	11	1
	Severe Impact	11	0	0	0
	Sum	105	19	11	1

Note: FTA land-use categories include residential (Cat. 2) and institutional (Cat. 3) receptors.

.5.2.2 APTA Criteria

Unlike the FTA criteria, which assess impact based on cumulative noise levels, the APTA criteria evaluate impacts based on maximum passby noise levels. As shown in Table 1-12, Lmax noise levels from bus operations under the BRT Alternative are predicted to range from 57 dBA at R2 (Hennepin County Medical Center in Minneapolis) to 84 dBA at R1 (Senior Home on Hennepin Avenue in Minneapolis). Except for receptors R1 and R3, none of the predicted Lmax noise levels at the discrete receptors are expected to exceed the APTA design criteria under the BRT Alternative. The predicted Lmax noise levels at receptors R1 (84 dBA) and R3 (81 dBA) under the BRT Alternative are, however, predicted to exceed the APTA impact criteria of 80 dBA at R1 and 75 dBA at R3, respectively.

Table 1-12

APTA NOISE IMPACT SUMMARY AT DISCRETE RECEPTORS FROM TRANSIT OPERATIONS (dBA)

Receptor		APTA Land-use Category	Alternative		Impact Criteria
			BRT	LRT	
No.	Description				
R1	Senior Home, N 4th St. and Hennepin Ave.	MF IV	**84**	71	*80*
R2	Hospital, Hennepin County Medical Center	HOS	57	57	*75*
R3	Hospital, Boynton Health Service	HOS	**81**	28	*75*
R4	Residence, 79 SE Clarence Ave.	SF III	65	60	*75*
R5	Residence, 808 Seal St. near Raymond Ave.	MF V	61	55	*85*
R6	Residence, 499 Lynhurst Ave.	MF III	70	65	*80*
R7	Residence, 1414 Sherbourne Ave.	SF III	73	68	*75*
R8	Residence, 386 Aurora Ave.	SF III	71	65	*75*
R9	Institution, State Capitol	COM IV	75	67	*85*
R10	Residence, 4th St. and Robert St.	COM IV	79	71	*85*

Note: Assessment of impact is determined as follows: No Impact and **Impact**.

As shown in Table 1-13, corridor-wide single event Lmax noise levels under the BRT Alternative are predicted to exceed the APTA design criteria at up to 59 locations (31 residential and 28 commercial). The receptor locations, where exceedances of the APTA impact criteria are predicted under the BRT Alternative, are shown in Appendix Figure A-2.

Table 1-13

SUMMARY OF APTA NOISE IMPACT COUNTS

Corridor Section	Alternative					
	BRT			LRT		
	Res.	Com.	Other	Res.	Com.	Other
Downtown Minneapolis	1	1	0	0	0	0
Campus	1	8	0	0	2	0
University Avenue	27	11	0	3	4	0
Downtown St. Paul	2	8	0	0	0	0
Totals	31	28	0	3	6	0

Note: Residential (Res.) land-uses include all single- and multi-family buildings while commercial (Com.) receptors include all non-residential receptors such as offices. Other specific receptor types (Other) include schools and amphitheaters.

.5.2.3 Historic Resources

As shown in Table 1-14, peak-hour Leq noise levels are expected to range from 34 dBA at H22 (Municipal Building at 290 5th Street in St. Paul) to 48 dBA at H1 (United Way of St. Paul Charitable Institute in St. Paul) and H3 (Commercial Building on 4th Street in St. Paul). Similarly, 24-hour Ldn noise levels are predicted to range from 37 dBA at H17 (Apartment Building at 300 Broadway Street in St. Paul) and H20 (Apartment Building at 308 Prince Street in St. Paul) to 47 dBA at H5 (Apartment Building at 198 6th Street in St. Paul). Project noise levels under the BRT Alternative are, therefore, not predicted to exceed the FTA Land-Use Categories 1, 2, or 3 at any historic resources identified along the project corridor.

Table 1-14

FTA NOISE IMPACT SUMMARY FROM TRANSIT OPERATIONS AT HISTORIC RESOURCES (dBA)

Receptor		FTA Category	Existing Background	Alternative		Impact Criteria	
No.	**Description**			**BRT**	**LRT**	**IMP**	**SEV**
H1	United Way of St. Paul Charitable Institute, 172 4th Street (St. Paul)	3	68 Leq	48	53	68	73
H2	Union Depot Commercial Building, 214 4th Street (St. Paul)	3	68 Leq	39	50	68	73
H3	Commercial Building, 4th Street (St. Paul)	3	68 Leq	48	54	68	73
H4	Sibley Park Operating Association, 400 Sibley Street (St. Paul)	3	68 Leq	39	42	68	73
H5	Galtier Plaza Apartments, 198 6th Street (St. Paul)	2	66 Ldn	47	40	61	67
H6	US Postal Service, 180 Kellogg Blvd (St. Paul)	3	68 Leq	36	43	68	73
H7	US Postal Service, 162 Kellogg Blvd (St. Paul)	3	68 Leq	46	42	68	73
H8	L A Venaglia Commercial Building, 241 Kellogg Blvd (St. Paul)	3	68 Leq	37	48	68	73
H9	Lowertown Lofts Cooperative Residences, 255 Kellogg Blvd (St. Paul)	2	66 Ldn	40	50	61	67
H10	Army Corps Center Commercial Building, 333 Sibley Street (St. Paul)	3	68 Leq	40	54	68	73
H11	Apartment Building, 262 4th Street (St. Paul)	2	66 Ldn	39	51	61	67
H12	Union Station, 352 Sibley Street (St. Paul)	3	68 Leq	39	54	68	73
H13	Commercial Building, 4th Street (St. Paul)	3	68 Leq	36	51	68	73
H14	Port of Authority of St. Paul Municipal Bldg, 230 5th Street (St. Paul)	3	68 Leq	38	48	68	73
H15	James Steele Construction Company, 352 Wacouta Street (St. Paul)	3	68 Leq	36	50	68	73
H16	PMA Limited Partnership Commercial Bldg, 281 Kellogg Blvd (St. Paul)	3	68 Leq	38	53	68	73
H17	Tilsner Apartment Building, 300 Broadway Street (St. Paul)	2	66 Ldn	37	53	61	67
H18	Commercial Building, 275 4th Street (St. Paul)	3	68 Leq	35	53	68	73
H19	Parkside Apartments, 242 5th Street (St. Paul)	2	66 Ldn	39	49	61	67
H20	Apartment Building, 308 Prince Street (St. Paul)	2	66 Ldn	37	58	61	67
H21	City of St. Paul Mears Park, 220 6th Street (St. Paul)	3	68 Leq	38	43	68	73

H22	City of St. Paul Municipal Building. 290 5th Street (St. Paul)	3	68 Leq	34	60	68	73
H23	City of St. Paul Municipal Building. 290 5th Street (St. Paul)	3	68 Leq	35	56	68	73

Note: Assessment of impact is determined as follows: No Impact: **Impact**: and **[Severe Impact]**.

.5.3 LRT

The LRT Alternative would operate along a dedicated Right-Of-Way (ROW) running in the median along the Central Corridor.

.5.3.1 Federal Criteria

Similar to the BRT Alternative, the peak-hour Leq noise level, shown in Table 1-10, is predicted to be 45 dBA at R9 (State Capitol in St. Paul). The peak hour Leq(h) noise level is not expected to exceed the FTA Land-Use Category 3 *impact* or *severe impact* criteria at the selected discrete receptor.

At residential receptors (Category 2), 24-hour Ldn levels from LRT operations are predicted to range from 27 dBA at R3 (Boynton Health Service in Campus) to 53 dBA at R1 (Senior Home on Hennepin Avenue in Minneapolis). As shown in Table 1-10, none of the predicted Ldn levels are expected to exceed the FTA Land-use Category 2 *impact* or *severe impact* criteria at the discrete receptor locations under the LRT Alternative.

As shown in Table 1-11, corridor-wide project noise levels under the LRT Alternative are predicted to exceed the FTA Category 2 Land-Use *impact* criteria at 11 locations. Project noise levels are not predicted to exceed the *severe impact* criteria anywhere along the project corridor. Similarly, project noise levels are also predicted to exceed the Category 3 Land-Use *impact* criteria at one additional location under the LRT Alternative. No exceedances of the FTA Category 1 Land-Use criteria are predicted under the LRT Alternative. The impact assessment includes impacts at structures only. The receptor locations, where exceedance of the FTA *impact* and *severe impact* criteria is predicted, are shown in Appendix **Figure A-3**.

.5.3.2 APTA Criteria

As shown in Table 1-12, Lmax noise levels from train passbys are predicted to range from 28 dBA at R3 (Boynton Health Service Center in Campus) to 71 dBA at R1 (Senior Home on Hennepin Avenue in Minneapolis) and R10 (Residence on 4th Street and Robert Street In St. Paul). No exceedances of the APTA design criteria are predicted under the LRT Alternative anywhere along the project corridor.

As shown in Table 1-13, single event Lmax noise levels under the LRT Alternative are predicted to exceed the APTA design criteria at nine locations (three residential and six commercial). The receptor locations, where exceedances of the APTA impact criteria are predicted, are shown in **Figure A-4**.

.5.3.3 Historic Resources

As shown in Table 1-14, peak-hour Leq noise levels are expected to range from 42 dBA at H4 (Commercial Building at 400 Sibley Street in St. Paul) and H7 (US Postal Service at 162 Kellogg Blvd in St. Paul) to 60 dBA at H22 (Municipal Building at 290 5th Street in St. Paul). Similarly, 24-hour Ldn noise levels are predicted to range from 40 dBA at H5 (Apartment Building at 198 6th Street in St. Paul) to 58 dBA at H20 (Apartment Building at 308 Prince Street in St. Paul). None of the project noise levels under the LRT Alternative are predicted to exceed the FTA Land-use Categories 1, 2, or 3 impact criteria at historic resources along the project corridor.

.6 Construction Effects

Noise levels from construction activities along the project corridor, although temporary in duration, may create a nuisance condition at nearby sensitive receptors. Exposure to excessive noise levels varies depending on the types of construction activity and the types of equipment used for each stage of work. Potential construction activities include track laying, station construction, and bridge rehabilitation. The following subsections describe the predicted noise levels and potential noise impacts associated with the project construction activities.

.6.1 BRT

Under the BRT Alternative, construction activities would primarily include passenger station construction, the renovation of an existing bus maintenance facility, and roadway re-alignments mainly along University Avenue.

As shown in Table 1-15, the noise levels from construction activities under the BRT Alternative are predicted to range from 31 dBA at R1 (Senior Home on Hennepin Avenue in Minneapolis) during Bus Facility construction to 88 dBA at R1 during Busway construction. As a result, construction activities are not predicted to exceed the FTA daytime noise limit of 90 dBA for residences or 100 dBA for commercial receptors at any of the discrete receptor locations under the BRT Alternative. Similarly, no exceedances of the local criteria of 90 dBA for Minneapolis and 82 dBA for St. Paul are predicted under the BRT Alternative for intermittent construction activities.

Table 1-15

SUMMARY OF CONSTRUCTION NOISE LEVELS AT DISCRETE RECEPTORS

Receptor		BRT Alternative				LRT Alternative				Criteria	
No.	Description	Bus-way	Station	Bridge	Bus Yard	Track Laying	Station	Bridge	Rail Yard	FTA	Local
R1	Senior Home, N 4th St. and Hennepin Ave.	88	67	43	31	84	72	43	42	90	90
R2	Hennepin County Medical Center, 6th St.	62	61	47	32	67	62	47	47	90	90
R3	Boynton Health, Church & Washington	83	60	58	35	84	64	58	46	90	90
R4	Residence, 79 SE Clarence Ave.	69	62	55	38	69	63	55	40	90	90
R5	Residence, 808 Seal St. near Raymond Ave	66	64	58	41	66	62	58	37	90	82

R6	Residence. 499 Lynhurst Ave.	70	61	46	48	70	62	46	35	90	82
R7	Residence. 1414 Sherbourne Ave.	74	56	41	55	74	56	41	34	90	82
R8	Residence. 386 Aurora Ave.	70	53	48	38	70	53	48	42	90	82
R9	Institution. State Capitol	76	64	57	36	79	59	57	46	100	82
R10	Residence. 4th St. and Robert St.	81	63	59	34	**[88]**	68	59	56	90	82

Note: Assessment of impact is determined as follows: No Impact; FTA **Impact**; and local criteria **[Impact]**.

As shown in Table 1-16, the distances at which an exceedance of the FTA daytime noise limits under the BRT Alternative are predicted to occur, range from 32 feet during station and yard construction to 40 feet during bridge construction at residential receptors, and from 10 feet to 13 feet at commercial receptors. As a result, exceedances of the FTA impact criteria are predicted to occur at 5 residential locations during BRT busway construction activities. Similarly, exceedances of the Minneapolis criterion of 90 dBA are predicted to occur at 5 receptor locations during busway construction. Under the St. Paul criterion of 82 dBA, exceedances are predicted at 193 locations during busway construction and 5 locations during station construction.

Table 1-16

SUMMARY OF CONSTRUCTION NOISE IMPACTS UNDER THE BRT AND THE LRT ALTERNATIVES

Scenario		Distances to Impact (in feet)				Impact Counts			
		Federal Criteria[1]		Local Criteria		Federal Criteria		Local Criteria	
		Res.	Com.	MN	St.P	Res.	Com.	MN	St.P
No.	Description	*90 dBA*	*100 dBA*	*90 dBA*	*82 dBA*	*90 dBA*	*100 dBA*	*90 dBA*	*82 dBA*
1	Busway/Track Construction	40	13	40	100	5	0	5	193
2	Stations Construction	32	10	32	81	0	0	0	5
3	Bridges Construction	40	13	40	100	0	0	0	0
4	Bus Yard Construction	32	10	32	81	0	0	0	0
5	Rail Yard Construction	32	10	32	81	0	0	0	0

1 The number of noise-sensitive receptors where maximum peak-hour construction noise levels are expected to exceed the FTA daytime residential (Res.) and commercial (Com.) construction limits is shown for each construction scenario.

.6.2 LRT

Under the LRT Alternative, construction activities would also include track laying along the entire length of the project corridor. Construction is also expected at two proposed LRT rail maintenance facilities, one on Franklin Avenue along the Hiawatha Line and the other near the Gillette factory in downtown St. Paul.

As shown in Table 1-15, the noise levels from construction activities under the LRT Alternative are predicted to range from 34 dBA at R7 (a residence on Sherbourne Avenue in St. Paul) during rail yard construction to 88 dBA at R10 (a residence on 4th and Robert Streets in St. Paul) during track laying. As a result, construction activities are not predicted to exceed the FTA daytime noise limit of 90 dBA for residences or 100 dBA for commercial receptors at any of the discrete receptor locations under the LRT Alternative. Except for receptor R10, no exceedances of the local criteria of 90 dBA for Minneapolis or 82 dBA for St. Paul are predicted under the LRT Alternative for intermittent construction activities.

As shown in Table 1-16, the distances at which an exceedance of the FTA daytime noise limits under the LRT Alternative are predicted to occur, range from 32 feet during station and yard construction to 40 feet during bridge construction and track laying at residential receptors, and from 10 feet to 13 feet at commercial receptors. As a result, exceedances of the FTA impact criteria are predicted to occur at 5 residential locations during LRT track laying activities. Similarly, exceedances of the Minneapolis criterion of 90 dBA are predicted to occur at 5 receptor locations during busway construction. Under the St. Paul criterion of 82 dBA, exceedances are predicted at 193 locations during busway construction and 5 locations during station construction.

.7 Mitigation

Mitigation measures to reduce the onset of noise impacts along the Central Corridor from BRT and LRT operations as well as during construction are described in the following subsections.

.7.1 BRT

The following recommended mitigation measures are specific to the BRT Alternative.

.7.1.1 BRT Operations

Although noise levels from on-road vehicles are regulated by federal and State agencies, several mitigation measures are recommended to minimize or eliminate noise impacts predicted along the project corridor. These mitigation measures may include:

- Operational limitations to reduce the overall cumulative noise (such as peak-hour Leq and 24-hour Ldn noise levels). Such operational limitations may include:
    - Travel speed reductions along particularly noise-sensitive areas;
    - Nighttime restrictions to minimize the impacts at residential and other FTA Land-use Category 2 receptors during the quietest period of the day; and,
    - Idle restrictions at stations closest to nearby noise-sensitive receptors.
- After-market noise silencers applied to the inside of the BRT engine compartment. According to the FTA guidance, noise silencers would reduce overall engine noise during both passbys and during idle at stations 6 to 10 dBA. Noise silencers for BRT engines would not, however, reduce rooftop exhaust noise; and,
- Although default FTA reference noise levels were used in the absence of more accurate data, vehicle-specific noise levels from the selected BRT manufacturer should be investigated further for more precise refinement of the modeling impact assessment.

Due to the elevated average source height of the BRT vehicles (i.e., 10-foot exhaust height) and the numerous cross streets, noise barriers are not recommended to mitigate the predicted impacts. Based on the location of predicted impacts, the excessive barrier height required to reduce the noise levels at nearby receptors, and the need for access from the numerous cross streets, barriers to reduce BRT noise levels are not expected to be feasible in adequately eliminating BRT passby noise levels.

.7.1.2 Construction Activity

The construction noise impact assessment is based on preliminary design information and will be updated during the final design to reflect more precise procedures and equipment. Noise control measures will be included in the construction specification documents to ensure compliance with all federal and state guidelines and noise limits. These specifications will require contractors to use properly maintained and operated equipment, including the use of exhaust mufflers according to the equipment manufacturer's specifications. Additional noise control measures will be incorporated into the construction specification documents as determined to be necessary during final design.

The FTA guidelines and procedures identify several areas of noise control including:

- Temporary noise barriers erected between noisy activities and noise-sensitive receptors;
- Use of sonic/vibratory pile-drivers rather than impact pile-driving near noise-sensitive receptors; and,
- Re-routing construction traffic along roadways that minimize noise impacts at nearby noise-sensitive receptors.

.7.2 LRT

The following recommended mitigation measures are specific to the LRT Alternative.

.7.2.1 LRT Operations

Noise impacts due to LRT train passbys were predicted at several locations under the LRT Alternative. Further investigation revealed that wayside barriers in various locations would eliminate the predicted impacts. As a result of the noise impact assessment, wayside barriers are recommended at the following approximate locations based on the evaluation criteria as shown in Table 1-17.

Table 1-17

RECOMMENDED NOISE MITIGATION ALONG THE LRT ALIGNMENT

Sta. No.		Corridor Location	Mitigation Description	
From	To		Type	Criteria
Westbound Side of LRT Corridor				
2230+00	2235+00	Campus	3-foot barrier	APTA
2248+00	2251+00	Campus	5-foot barrier	APTA
2324+00	2325+00	University	3-foot barrier	FTA
2326+00	2333+00	University	5-foot barrier	FTA
2514+00	2518+00	University	5-foot barrier	APTA
2541+00	2546+00	University	5-foot barrier	APTA

Eastbound Side of LRT Corridor				
2311+00	2313+00	Campus	3-foot barrier	FTA
2319+00	2321+00	University	3-foot barrier	FTA
2409+00	2412+00	University	3-foot barrier	FTA
2435+00	2437+00	University	5-foot barrier	FTA
2438+00	2441+00	University	5-foot barrier	FTA
2487+00	2491+00	University	5-foot barrier	APTA
2507+00	2513+00	University	5-foot barrier	APTA
2541+00	2546+00	University	3-foot barrier	APTA

At individual impact locations, an estimated minimum barrier length of approximately 200-300 feet is assumed in the above Sta. No. locations. The actual dimensions of the proposed barriers should be investigated further during final design using spectral data (i.e., octave band analysis) to provide a more detailed estimate of barrier insertion loss at impacted receptors.

In addition to noise barriers, several additional mitigation measures are recommended including:

- Operational limitations to reduce the overall cumulative noise (such as peak-hour Leq and 24-hour Ldn noise levels). Such operational limitations may include:
  - Travel speed reductions along particularly noise-sensitive areas; and,
  - Nighttime restrictions to minimize the impacts at residential and other FTA Land-Use Category 2 receptors during the quietest period of the day.
- Building insulation is effective in reducing transit noise inside the affected structure. Outdoor activities, however, would not benefit from sound insulation.

.7.2.2 Construction Activity

The recommended construction mitigation measures under the LRT Alternative are the same as was described under the BRT Alternative.

3.0 Vibration

This chapter introduces some basic ground-borne vibration and noise concepts including the prediction methodologies and modeling assumptions, the results of the existing source vibration measurement program, and the evaluation of impacts along the project corridor.

.1 Human Perception of Vibration

The characteristics and properties used to describe ground-borne vibration and noise are explained in the following subsections.

.1.1 Describing Vibration

Ground-borne vibration associated with vehicle movements is usually the result of uneven interactions between the wheel and the road or rail surfaces. Examples of such interactions (and subsequent vibrations) include train wheels over a jointed rail, an untrue railcar wheel with "flats", and motor vehicle wheels hitting a pothole or even a manhole cover.

Unlike noise, which travels in air, transit vibration typically travels along the surface of the ground. Depending on the geological properties of the surrounding ground and the type of building structure exposed to transit vibration, vibration propagation may be more or less efficient. Buildings with a solid foundation set in bedrock are "coupled" more efficiently to the surrounding ground and experience relatively higher vibration levels than those buildings located in sandier soil.

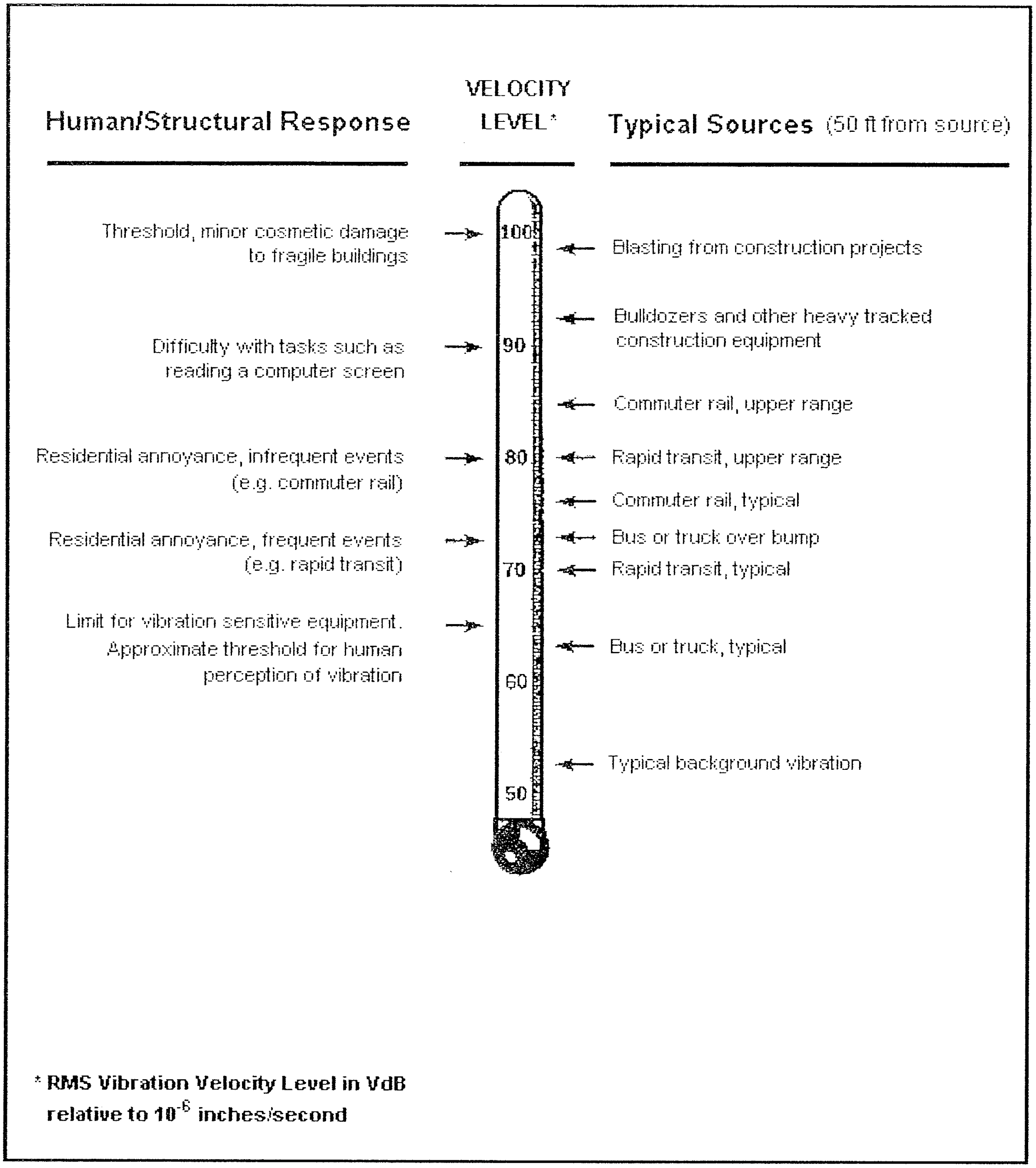
Similarly, ground-borne noise results from vibrating room surfaces located near a heavily traveled transit corridor, such as a subway line. As a result, annoyance due to the "rumbling" sound from ground-borne noise is only evaluated indoors and is described using the A-weighted decibel.

.1.2 Description of Vibration Levels

Vibration induced by vehicle passbys can generally be discussed in terms of displacement, velocity, or acceleration. However, human responses and responses by monitoring instruments and other objects are more accurately described with velocity. Therefore, the vibration velocity level is chosen to assess vibration impacts.

To more accurately describe the human response to vibration, the average vibration amplitude called the root mean square (RMS) amplitude, is used to assess impacts. The RMS velocity is expressed in inches per second (ips) or decibels (VdB). Vibration levels are referenced to 1 μips.

To evaluate the potential for damage to buildings, the peak particle velocity (PPV) is also used to characterize the vibration. Typically expressed in units of ips, PPV represents the maximum instantaneous vibration velocity observed during an event. Typical ground-borne vibration levels from transit and other common sources are shown in **Figure 2-1**.



Source: *Transit Noise and Vibration Impact Assessment - Final Report*. Federal Transit Administration, Washington, D.C., April 1995.

Figure 2-1: Typical Ground-Borne Vibration Levels

.2 Evaluation Criteria

As described in the following subsections, the FTA criteria will be used to assess annoyance due to vibration and ground-borne noise from single event transit operations.

.2.1 Operational Vibration

The FTA criteria are used to evaluate vibration from single-event transit passbys.

.2.1.1 Federal Criteria

The FTA vibration criteria for evaluating ground-borne vibration (and noise) impacts from train passbys at nearby sensitive receptors are shown in Table 2-1. These vibration criteria are related to ground-borne vibration levels that are expected to result in human annoyance, and are based on RMS velocity levels expressed in VdB relative to 1 μips. The FTA's experience with community response to ground-borne vibration indicates that when there are only a few train events per day, it would take higher vibration levels to evoke the same community response that would be expected from more frequent events. This is taken into account in the FTA criteria by distinguishing between projects with 'frequent' and 'infrequent' events, where the 'frequent'-events category is defined as more than 70 events per day. The vibration criteria levels shown in Table 2-1 are defined in terms of human annoyance for different land-use categories such as high sensitivity (Category 1), residential (Category 2), and institutional (Category 3). In general, the vibration threshold of human perceptibility is roughly 65 VdB.

The vibration levels shown in Table 2-1 are well below the damage criteria levels of approximately 95 to 100 VdB. It is extremely rare for vibration from train operations to cause any sort of building damage, including minor cosmetic damage. The potential for damage from vibratory or impact devices are discussed further under the construction criteria.

Table 2-1

FTA GROUND-BORNE VIBRATION IMPACT CRITERIA FOR ANNOYANCE (VdB)

Receptor Land-use		RMS Vibration Levels (VdB)		Ground-Borne Noise Levels (dBA)	
Category	**Description**	**Frequent Events**	**Infrequent Events**	**Frequent Events**	**Infrequent Events**
1	Buildings where low vibration is essential for interior operations	65	65	N/A	N/A
2	Residences and buildings where people normally sleep	72	80	35	43
3	Daytime institutional and office use	75	83	40	48
Specific Buildings	TV/Recording Studios/Concert Halls	65	65	25	25
	Auditoriums	72	80	30	38
	Theaters	72	80	35	43

Note: N/A = not applicable. Vibration-sensitive equipment, for example, is not sensitive to ground-borne noise.
Source: *Transit Noise and Vibration Impact Assessment - Final Report*, Federal Transit Administration, Washington, D.C., April 1995.

While vibration criteria are generally used to assess annoyance from transit sources at the exterior facade of receptors, ground-borne noise, or the rumbling sound due to vibrating room surfaces, is typically assessed indoors. In general, the relationship between vibration and ground-borne noise depends on the dominant frequency of the vibration and the acoustical absorption characteristics of the receiving room. Due to the limited data available regarding soil and ground propagation characteristics, average or typical soil conditions were assumed everywhere along the corridor for computing ground-borne noise.

.2.2 Construction Vibration

Vibration impacts due to construction activities were assessed using the FTA criteria to determine the onset of annoyance and as well as structural damage. These criteria are described in the following subsections.

.2.2.1 Federal Criteria

The vibration levels shown in Table 2-1 were also used to evaluate vibration annoyance from various construction scenarios expected along the project corridor. Additionally, depending on the construction activity, there is sometimes concern about damage to fragile or older historic buildings closest to heavy-duty construction activities. Even in these cases, damage is unlikely to occur except when the construction equipment is very close to the building structure. The recommended FTA criteria limits that were used to assess minor structural damage, such as small cracks in plaster walls, in PPV are 0.20 ips for fragile buildings and 0.12 ips for extremely fragile or older historic buildings.

.2.2.2 Local Ordinances

Vibration limits from Minneapolis, for example, are listed in terms of displacement, which cannot be compared with the FTA source levels, which are defined in terms of velocity. Therefore, there are currently no applicable vibration criteria related to construction activities using the FTA modeling methodology.

.3 Modeling Methodology and Assumptions

A description of the modeling methodologies and the types of vibration sources included in the modeling prediction are described in the following sub-sections.

.3.1 Modeling Methodology

Using the FTA's General Assessment methodology, vibration levels from LRT train passbys and from preliminary construction activities were predicted at receptors along the project corridor. Due to the complexity and cost associated with a Detailed Assessment, the General Assessment approach is fairly conservative. Impacts identified under the General Assessment approach should be investigated further during final design when details of the final track structure and construction activities are better known.

.3.1.1 Operations

Vibration levels from LRT passbys at sensitive receptors along the project corridor were determined using the FTA guidelines. Although BRT operations are also proposed, rubber-tired vehicles are typically not a major source of vibration annoyance, especially lighter-weight transit buses. Therefore, only railcar passbys along continuously welded rail and rail discontinuities such as switches and crossovers were included in the modeling analysis.

A vibration measurement program was conducted to better determine the extent of ground-borne vibration levels from existing LRT trains as well as to provide insight into the type of soil conditions found along the project corridor. The results of the measurement program are discussed in Section 2.4.

.3.1.2 Construction

Similar to the construction noise prediction analysis, vibration equipment was selected for each construction scenario with the highest reference level. The reference vibration levels were then adjusted for distance to determine the final level at the selected receptor. The maximum computed vibration level for each construction scenario was compared with the applicable criteria to establish its impact condition.

.3.2 LRT

Reference vibration levels from LRT passbys at 50 mph are based on the FTA ground-surface propagation curves as shown in **Figure 2-2**. Using the 'Rapid Transit' curve, a reference RMS vibration level could be determined at the distance for each identified receptor location. Depending on the receptor location, adjustments for speed and rail discontinuities were also taken into account.

.3.3 Construction Vibration - RMS

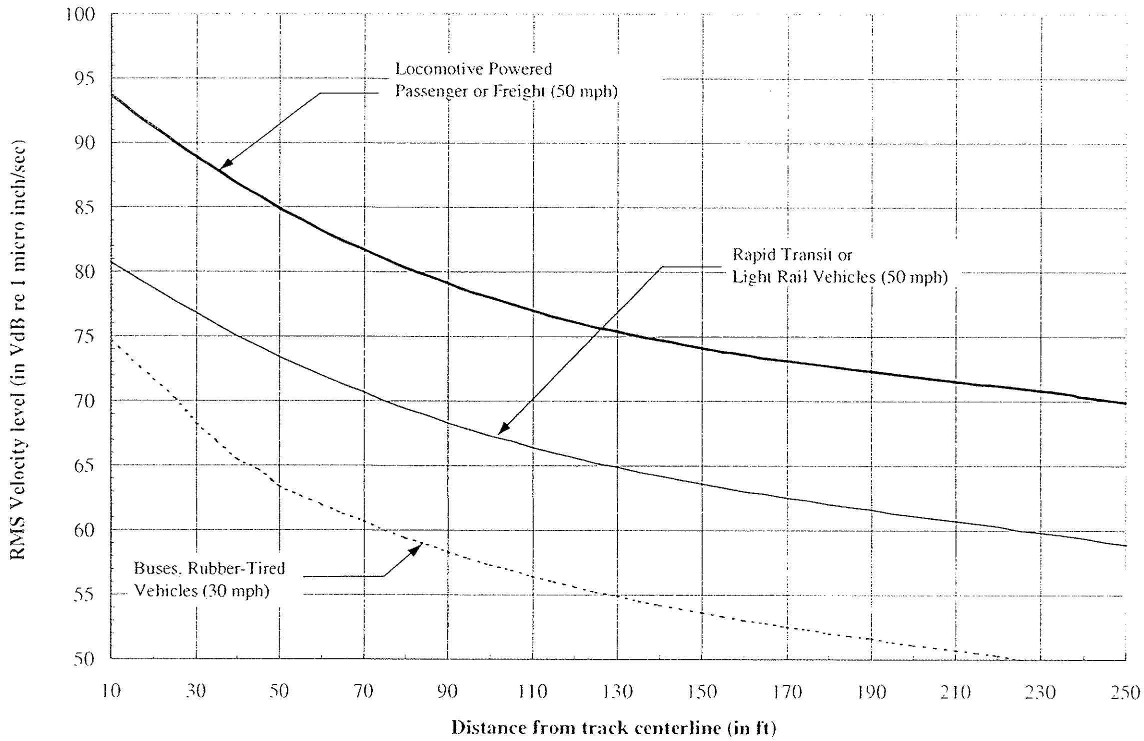
Using Equation 2, RMS vibration levels from construction equipment were used to predict project construction levels at each of the selected receptor locations.

$$RMS_{equip} = RMS_{ref} - 20\log\left(\frac{dS}{25}\right)$$

[Eq. 2: used to assess annoyance and interference (FTA)]

<u>where:</u>

RMS_{equip} = RMS vibration level at receptor from a <u>single</u> piece of equipment (in VdB);
RMS_{ref} = reference RMS vibration level at 25 feet from a <u>single</u> piece of equipment (in VdB); and,
dS = closest distance between the receptor and the equipment (in feet).



Source: *Transit Noise and Vibration Impact Assessment - Final Report*, Federal Transit Administration, Washington, D.C., April 1995.

Figure 2-2: FTA Generalized Ground Surface Vibration Curves

.3.4 Construction Vibration - PPV

Using Equation 3, PPV vibration levels from construction equipment were used to predict project construction levels at each of the selected receptor locations.

$$PPV_{equip} = PPV_{ref} \times \left(\frac{25}{dS} \right)^{1.5}$$ [Eq. 3: used to assess damage (FTA)]

where:

PPV_{equip} = PPV vibration level at receptor from a single piece of equipment (in ips);
PPV_{ref} = reference PPV vibration level at 25 feet from a single piece of equipment (in ips); and,
dS = closest distance between the receptor and the equipment (in feet).

.4 Existing Conditions

The scope and results of the vibration-monitoring program are described in the following section.

.4.1 Transit Source Levels

A vibration-monitoring program was conducted along the study area from downtown Minneapolis to downtown St. Paul along University Avenue to better define the existing vibration characteristics. As with noise, existing land-uses along the Central Corridor are exposed to a variety of vibration sources ranging from bus and truck passbys along roadways to freight and commuter rail passbys to ongoing construction activity. As shown in Figure 1-3, vibration measurements were obtained at the same 10 receptor locations included in the noise-monitoring program. The monitoring locations shown in Figure 1-3 were selected to be representative of the types of neighborhoods and land-uses found along the corridor. The results of the community vibration-monitoring program were used to establish the existing background noise levels and to adjust the ground propagation characteristics of the FTA default ground-surface vibration curve. The results of the vibration-monitoring program, including measurement date and observed ambient vibration levels, are summarized in Table 2-2 for each of the 10 discrete receptors.

The results of the vibration measurement program suggest that the project corridor exhibits ground propagation characteristics typical for urban transit corridors. Therefore, the default FTA ground-surface vibration curve was used to predict vibration levels from transit operations at nearby sensitive receptors without any adjustments.

Table 2-2

SUMMARY OF VIBRATION MEASUREMENT PROGRAM ALONG THE CENTRAL CORRIDOR (IN VdB)

Receptor		Area	Type[1]	FTA Cat.	Measurement Results[2]		
No.	Description and Location				Date	Avg.	Peak
N1	Senior Home, N 4th St. and Hennepin Ave.	Minneapolis	Res.	2	11/06/01	63	72
N2	Hennepin County Medical Center, 6th St.	Minneapolis	Oth.	2	11/06/01	54	63
N3	Boynton Health Service, Church & Washington	Campus	Oth.	2	11/08/01	56	64
N4	Residence, 79 SE Clarence Ave.	University	Res.	2	11/06/01	58	65
N5	Residence, 808 Seal St. near Raymond Ave.	University	Res.	2	11/06/01	55	58
N6	Residence, 499 Lynhurst Ave.	University	Res.	2	11/06/01	54	61
N7	Residence, 1414 Sherbourne Ave.	University	Res.	2	11/06/01	54	61
N8	Residence, 386 Aurora Ave.	University	Res.	2	11/06/01	55	62
N9	Institution, State Capitol	St. Paul	NR	3	11/07/01	52	59
N10	Residence, 4th St. and Robert St.	St. Paul	Res.	2	11/09/01	48	54

1. Receptor types include residential (Res.), non-residential (NR), and other receptor types (e.g., hotels and parks).
2. Average ambient vibration levels (Avg.) and maximum observed levels (Peak) are reported in VdB re 1μips.

.5 Long-Term Effects

Vibration impacts from LRT vehicles were evaluated at discrete receptors using the FTA criteria based on maximum single-event passbys as described in the following sections. Unlike the cumulative noise criteria, vibration criteria are evaluated based on single-event passbys. The results of the impact assessment are described in the following subsections.

.5.1 Baseline

In accordance with FTA guidelines, vibration impacts are only assessed from new proposed vibration sources such as LRT passbys. Under the Baseline Alternative, neither the BRT nor the LRT would be in service along the Central Corridor. Therefore, because no new sources of vibration are expected under the Baseline Alternative, a vibration impact assessment is not required.

.5.2 BRT

Due to their lighter weight, rubber-tired transit vehicles are typically not a significant source of vibration. Ground-borne vibration and noise levels from buses under the BRT Alternative are expected to be well below the ambient background and are, therefore, not expected to exceed the FTA impact criteria anywhere along the project corridor.

.5.3 LRT

The results of the vibration and ground-borne noise assessment are described in the following sub-sections.

.5.3.1 Federal Criteria

Under the LRT Alternative, new continuously welded rail is proposed at all sections of the alignment. Predicted vibration levels are expected to be well below the FTA impact criteria for frequent events at most of the FTA Land-use Category 1, 2, or 3 receptors identified along the project corridor. For example, as shown in Table 2-3, predicted vibration levels from LRT passbys are expected to range from below background levels at R2 (Hennepin County Medical Center in Minneapolis) and R5 (Residence at 808 Seal Street in University) to 69 VdB at R3 (Boynton Health Service Center in Campus). These levels are below the FTA impact criterion of 72 VdB for Category 2 Land-Uses.

Table 2-3

VIBRATION AND GROUND-BORNE NOISE IMPACT SUMMARY AT DISCRETE RECEPTORS (VdB)

Receptor		FTA Cat.	Dist. to Align.[1]	BRT		LRT		FTA	
No.	Description			VIB	GB-NZ	VIB	GB-NZ	VIB	GB-NZ
R1	Senior Home, N 4th St. and Hennepin	2	81	--[2]	--	65	30	*72*	*35*
R2	Hennepin County Medical Center	2	586	--	--	0	0	*72*	*35*
R3	Hospital, Boynton Health Service	2	81	--	--	69	34	*72*	*35*
R4	Residence, 79 SE Clarence Ave.	2	436	--	--	31	0	*72*	*35*
R5	Residence, 808 Seal St.	2	646	--	--	0	0	*72*	*35*
R6	Residence, 499 Lynhurst Ave.	2	418	--	--	36	1	*72*	*35*
R7	Residence, 1414 Sherbourne Ave.	2	259	--	--	55	20	*72*	*35*
R8	Residence, 386 Aurora Ave.	2	382	--	--	43	8	*72*	*35*
R9	Institution, State Capitol	3	137	--	--	56	21	*75*	*40*
R10	Residence, 4th St. and Robert St.	2	53	--	--	65	30	*72*	*35*

1 Closest distance between receptor and the proposed Build Alternative alignments.
2 '--' = below detection. Vibration (VIB) and Ground-Borne Noise (GB-NZ) levels from BRT passbys are expected to be well below the ambient background.

Similarly, maximum ground-borne noise levels due to LRT passbys, as shown in Table 2-3, are expected to range from less than background levels at several receptors including R2, R4, R5, R6, and R8 to 34 dBA at R3 (Boynton Health Service Center in Campus). No Exceedances of the FTA Land-Use Category 1, 2, and 3 ground-borne noise impact criteria are predicted at any of the discrete receptor locations under the LRT Alternative.

Corridorwide, exceedances of the FTA vibration impact criteria are predicted to occur at one FTA Category 2 receptor and 10 Category 3 receptors under the LRT Alternative. Similarly, exceedances of the FTA ground-borne noise impact criteria are predicted to occur at two FTA Category 2 receptors and 10 Category 3 receptors under the LRT Alternative.

.5.3.2 Project Facilities

Ground-borne vibration and ground-borne noise levels from activities at project facilities, such as the rail yard, are expected to be well below the ambient background levels. Therefore, no exceedances of the FTA impact criteria are expected under the LRT Alternative.

Table 2-4

SUMMARY OF VIBATION IMPACT COUNTS AT RESIDENCES

Corridor Section	Impact Criteria Type	Alternative			
		BRT		LRT	
		Cat. 2	Cat. 3	Cat. 2	Cat. 3
Downtown Minneapolis	RMS Vibration	NA	NA	0	1
	Ground-Borne Noise	NA	NA	0	1
	Sum	NA	NA	0	2
Campus	RMS Vibration	NA	NA	0	4
	Ground-Borne Noise	NA	NA	0	4
	Sum	NA	NA	0	8
University Avenue	RMS Vibration	NA	NA	1	5
	Ground-Borne Noise	NA	NA	2	5
	Sum	NA	NA	3	10
Downtown St. Paul	RMS Vibration	NA	NA	0	0
	Ground-Borne Noise	NA	NA	0	0
	Sum	NA	NA	0	0
Totals	RMS Vibration	NA	NA	1	10
	Ground-Borne Noise	NA	NA	2	10
	Sum	NA	NA	3	20

Note: NA means not applicable. A vibration impact assessment for the BRT Alternative was not determined.

.5.3.3 Historic Resources

As shown in Table 2-5, vibration levels from LRT passbys near historic resources are predicted to range from below ambient levels at several locations to 73 VdB at H12 (Union Station at Sibley Street in St. Paul). These levels are all well below the FTA Land-use Category 1, 2, and 3 impact criteria. Similarly, ground-borne noise levels at historic resources are also not predicted to exceed the FTA Land-use Categories 1, 2, or 3 impact criteria under the LRT Alternative. All of the predicted vibration levels are well below the threshold for minor cosmetic damage of 95 VdB.

Table 2-5

FTA VIBRATION IMPACT SUMMARY FROM OPERATIONS AT HISTORIC RESOURCES

Historic Resource		FTA Cat.	Dist. to Align.[1]	BRT	LRT			
No.	Description				RMS Vibration[2]	GB-Noise[3]	FTA VIB[2]	FTA GB-NZ[3]
H1	United Way of St. Paul Charitable Institute, 172 4th Street (St. Paul)	3	53	N/A[4]	65	30	75	40
H2	Union Depot Commercial Building, 214 4th Street (St. Paul)	3	157	N/A	64	29	75	40
H3	Commercial Building, 4th Street (St. Paul)	3	36	N/A	68	33	75	40
H4	Sibley Park Operating Association, 400 Sibley Street (St. Paul)	3	746	N/A	BD[5]	BD	75	40
H5	Galtier Plaza Apartments, 198 6th Street (St. Paul)	2	407	N/A	33	BD	72	35
H6	US Postal Service, 180 Kellogg Blvd (St. Paul)	3	726	N/A	BD	BD	75	40
H7	US Postal Service, 162 Kellogg Blvd (St. Paul)	3	404	N/A	34	BD	75	40
H8	L A Venaglia Commercial Building, 241 Kellogg Blvd (St. Paul)	3	285	N/A	58	23	75	40
H9	Lowertown Lofts Cooperative Residence, 255 Kellogg Blvd (St. Paul)	2	245	N/A	60	25	72	35
H10	Army Corps Center Commercial Bldg, 333 Sibley Street (St. Paul)	3	34	N/A	68	33	75	40
H11	Apartment Building, 262 4th Street (St. Paul)	2	227	N/A	60	25	72	35
H12	Union Station, 352 Sibley Street (St. Paul)	3	61	N/A	73	38	75	40
H13	Commercial Building, 4th Street (St. Paul)	3	141	N/A	64	29	75	40
H14	Port of Authority of St. Paul Municipal Bldg, 230 5th Street (St. Paul)	3	208	N/A	63	28	75	40
H15	James Steele Construction Company, 352 Wacouta Street (St. Paul)	3	222	N/A	61	26	75	40
H16	PMA Limited Partnership Commercial Bldg, 281 Kellogg Blvd (St. Paul)	3	465	N/A	18	BD	75	40
H17	Tilsner Apartment Building, 300 Broadway Street (St. Paul)	2	700	N/A	BD	BD	72	35
H18	Commercial Building, 275 4th Street (St. Paul)	3	314	N/A	51	16	75	40
H19	Parkside Apartments, 242 5th Street (St. Paul)	2	268	N/A	58	23	72	35
H20	Apartment Building, 308 Prince Street (St. Paul)	2	675	N/A	BD	BD	72	35
H21	City of St. Paul Mears Park, 220 6th Street (St. Paul)	3	594	N/A	BD	BD	75	40
H22	City of St. Paul Municipal Building, 290 5th Street (St. Paul)	3	493	N/A	8	BD	75	40
H23	City of St. Paul Municipal Building, 290 5th Street (St. Paul)	3	440	N/A	25	BD	75	40

1 Closest distance between receptor and the proposed Build Alternative alignments.
2 RMS Vibration levels are reported in VdB re 1 µips.
3 Ground-borne noise levels are reported in A-weighted decibels, or dBA.
4 NA = not applicable. Vibration levels along the BRT route are not expected to experience elevated vibration levels.

5 Vibration levels are predicted to be well below the background levels and are, therefore, not measurable.

.6 Construction Effects

Similar to noise, vibration levels from construction activities along the project corridor may create a nuisance condition at nearby sensitive receptors. However, in addition to a nuisance condition, the potential for minor structural damage was also analyzed. Based on the vibration-monitoring program, average ground propagation characteristics were assumed as part of the vibration modeling assessment. Vibration levels were determined for the same scenarios selected for the noise assessment including track-laying, and passenger station, bridge, and rail/bus yard construction. The following subsections describe the results of the construction impact assessment along the project corridor.

.6.1 Baseline

No construction activities are proposed under the Baseline Alternative. Therefore, a construction impact assessment was not conducted.

.6.2 BRT

Vibration impacts from proposed construction activities, although preliminary, are discussed for the BRT Alternative in the following sub-sections using the FTA impact criteria.

.6.2.1 Federal Criteria

Unlike noise levels, which are assessed using a cumulative exposure, vibration is event-based where the focus is on noticeability and damage. Typical activities under the BRT Alternative include passenger station and BRT maintenance facility construction. As shown in Table 2-6, maximum RMS vibration levels from construction activities are expected to range from 28 VdB at R1 (Senior Home on Hennepin Avenue in Minneapolis) during bus facility construction to 88 VdB at R1 during busway construction. As a result, exceedances of the FTA impact criteria are predicted at receptors R1, R3, and R10 during busway construction activities under the BRT Alternative. Similarly, as shown in Table 2-7, maximum PPV vibration levels from construction activities are expected to range from well below background to 0.043 ips at R1 during busway construction. No exceedances of the FTA PPV vibration impact criteria are predicted at any of the discrete receptor locations.

The distances at which exceedance of the FTA impact criteria are predicted range from 137 feet during bridge construction to 187 feet during busway, station, and BRT maintenance facility construction activities for residential receptors. As a result, exceedances of the FTA RMS vibration impact criteria are predicted at 59 residential and 25 commercial locations during busway construction and an additional 16 commercial locations during bridge construction. There are no exceedances of the FTA PPV vibration impact criteria predicted under the BRT Alternative.

Table 2-6

RMS VIBRATION IMPACT SUMMARY AT DISCRETE RECEPTORS FROM CONSTRUCTION ACTIVITIES

Discrete Receptor		Construction Activity RMS Vibration Levels (VdB)								
		BRT				LRT				
No.	Description	Bus-way	Station	Bridge	Bus Yard	Track	Station	Bridge	Rail Yard	FTA Imp. Crit.
R1	Senior Home. N 4th St. and Hennepin	**84**	64	36	28	**79**	69	36	39	72
R2	Hennepin County Medical Center	58	58	40	29	62	59	40	44	72
R3	Hospital, Boynton Health Service	**79**	57	51	32	**79**	62	50	43	72
R4	Residence, 79 SE Clarence Ave.	65	60	48	36	65	60	48	37	72
R5	Residence, 808 Seal St.	61	61	51	38	61	59	51	35	72
R6	Residence, 499 Lynhurst Ave.	65	58	39	45	65	59	39	33	72
R7	Residence, 1414 Sherbourne Ave.	69	53	34	53	69	53	34	32	72
R8	Residence, 386 Aurora Ave.	66	50	41	36	66	50	41	39	72
R9	Institution, State Capitol	71	62	50	33	75	56	50	43	75
R10	Residence, 4th St. and Robert St.	**77**	60	52	32	**83**	65	51	53	72

Table 2-7

PPV VIBRATION IMPACT SUMMARY AT DISCRETE RECEPTORS FROM CONSTRUCTION ACTIVITIES

Discrete Receptor		Construction Activity PPV Vibration Levels (ips)								
		BRT				LRT				
No.	Description	Bus-way	Station	Bridge	Bus Yard	Track	Station	Bridge	Rail Yard	FTA Imp. Crit.
R1	Senior Home. N 4th St. and Hennepin	0.043	0.001	ND	ND	0.020	0.003	ND	ND	0.2
R2	Hennepin County Medical Center	ND	ND	ND	ND	0.001	0.001	ND	ND	0.2
R3	Hospital, Boynton Health Service	0.018	ND	ND	ND	0.020	0.001	ND	ND	0.2
R4	Residence, 79 SE Clarence Ave.	0.002	0.001	ND	ND	0.002	0.001	ND	ND	0.2
R5	Residence, 808 Seal St.	0.001	0.001	ND	ND	0.001	0.001	ND	ND	0.2
R6	Residence, 499 Lynhurst Ave.	0.002	0.001	ND	ND	0.002	0.001	ND	ND	0.2
R7	Residence, 1414 Sherbourne Ave.	0.004	ND	ND	ND	0.004	ND	ND	ND	0.2
R8	Residence, 386 Aurora Ave.	0.002	ND	ND	ND	0.002	ND	ND	ND	0.2
R9	Institution, State Capitol	0.005	0.001	ND	ND	0.009	ND	ND	ND	0.2
R10	Residence, 4th St. and Robert St.	0.012	0.001	ND	ND	0.038	0.002	ND	ND	0.2

ND = non-detectable. The predicted vibration level is well below the ambient background.

.6.3 LRT

Vibration impacts from proposed construction activities, although preliminary, are discussed for the LRT Alternative in the following sub-sections using the FTA impact criteria.

.6.3.1 Federal Criteria

Typical activities under the LRT Alternative include passenger station construction and LRT track laying. As shown in Table 2-6, maximum RMS vibration levels from construction activities are expected to range from 32 VdB at R7 (a residence on Sherbourne Avenue in the University area) during LRT yard construction to 83 VdB at R10 (a residence on 4th and Robert Streets in St. Paul) during track laying. As a result, exceedances of the FTA impact criteria are predicted at receptors R1, R3, and R10 during track laying construction activities under the LRT Alternative. Similarly, as shown in Table 2-7, maximum PPV vibration levels from construction activities are expected to range from well below background to 0.038 ips at R10 during track laying. No exceedances of the FTA PPV vibration impact criteria are predicted at any of the discrete receptor locations.

The distances at which exceedance of the FTA impact criteria are predicted range from 137 feet during bridge construction to 187 feet during track laying, station, and LRT yard construction activities for residential receptors. As a result, exceedances of the FTA RMS vibration impact criteria are predicted at 56 residential and 26 commercial locations during busway construction and an additional 21 commercial locations during bridge construction. There are no exceedances of the FTA PPV vibration impact criteria predicted under the LRT Alternative.

.7 Mitigation

Mitigation measures to reduce the onset of vibration impacts along the Central Corridor from bus and rail operations and construction activities are described in the following subsections.

.7.1 BRT

No exceedance of the FTA impact criteria is expected anywhere from BRT operations. Therefore, no mitigation measures are currently recommended.

Because of the potential for adverse noise impacts during construction, a more detailed assessment and mitigation measures should be evaluated during project final design when the details of the construction stages and equipment use are better defined. The following candidate mitigation measures are recommended to eliminate or minimize adverse vibration impacts along the project corridor:

- Utilizing alternative construction methods including avoiding impact pile driving near vibration-sensitive receptors, such as residences, schools, and hospitals. Whenever possible, use of drilled piles or sonic/vibratory pile drivers to reduce excessive vibration is recommended.
- Re-routing truck traffic away from vibration-sensitive receptors; and,

- Using Best Available Control Technologies (BACT) to limit excessive vibration further.

.7.2 LRT

Exceedances of the FTA vibration impact criteria are predicted along the project corridor from LRT passbys. The impacts are predicted at residences directly adjacent to switches that result in elevated vibration and ground-borne noise levels from LRT train passbys.

Several mitigation measures are recommended to eliminate the predicted impacts including:

- Operating limitations such as speed reductions over the switches;
- Strategic placement of switches and crossovers away from vibration-sensitive receptors; and,
- The use of vibration dampening materials, such as ballast mats, under switches in vibration-sensitive locations.

The same construction mitigation measures described in Section 2.7.1 under the BRT Alternative are also recommended for the LRT Alternative.

4.0 Appendix

A list of the Appendix tables summarizing the input data used in the modeling prediction, such as BRT and LRT headway times, LRT consists sizes, BRT route, track separation distances, and vehicle speeds, are shown in Table A-1. A description of each Table and its contents is included under each sub-section.

Table A-1

CURRENT TABLES OF THE NOISE AND VIBRATION TECHNICAL REPORT APPENDIX

Appendix Table		
No.	**Section**	**Description**
A-2	A.1	Summary of Headway Times and Operations (in Minutes)
A-3	A.1	Summary of Operations Volumes at Facilities
A-4	A.2	Summary of West- and Eastbound Alignment Speeds (in mph)
A-5	A.3	Summary of Alignment Separation Distances (in feet)

.1 Vehicle Headway Times and Volumes

Vehicle volumes for BRT and LRT operations are based on the *Preliminary Operations Plan* report.[3] Vehicle volumes were developed from headway times for various periods of the day including peak-hour, daytime (7 a.m. to 10 p.m.), and nighttime (10 p.m. to 7 a.m.). Headway time represents the frequency or the amount of time between successive departures and is used to develop overall volumes (i.e., hourly volume = 60 minutes/headway time in minutes). As shown in Table A-2, BRT and LRT headway times range from 4 minutes during the peak-hours to 30 minutes during the latenight period.

As shown in Table A-2, total BRT and LRT volumes are summarized by period of the day (i.e., daytime, nighttime, peak-hour). Total vehicle volumes were separated into these three periods to facilitate the calculation of several cumulative noise metrics including the 24-hour Ldn noise level and the peak-hour Leq noise level.

Table A-2

SUMMARY OF HEADWAY TIMES AND OPERATIONS (IN MINUTES)

Transit		No. of Hours	FTA Period	Alternative					
				BRT			LRT		
Time	Period			Headway	Consist	Opns	Headway	Consist	Opns
4:00	Base – AM	3:00	Night	4	1	45	7.5	2	48
7:00	Base – AM	2:00	Day	4	1	30	7.5	2	32
9:00	Peak	6:30	Day	5.3	1	74	10	2	78
15:30	Base – PM	4:30	Day	4	1	67	7.5	2	72
20:00	Early PM	2:00	Day	8	1	15	15	2	16
22:00	Late PM	3:00	Night	16	1	11	30	2	12
1:00		21:00				242			258
Summary			Peak	7-9 a.m. & 4-6 p.m.		*15*			*16*
			Day	7 a.m. – 10 p.m.		*186*			*198*
			Night	10 p.m. - 7 a.m.		*56*			*60*

[3] *Preliminary Operations Plan*, Initial Draft, URS/LTK Engineering Services, February 13, 2002.

Table A-3

SUMMARY OF OPERATIONS VOLUMES AT FACILITIES

Description	Period[1]	Rail Yard Facility	BRT Maintenance Facility
Peak Hour Allocation[2]	Daytime	5.50	5.50
	Nighttime	1.00	1.00
	Peak-Hour	3.25	3.25
Transit Operations	Daytime	33.846	169.231
	Nighttime	6.154	30.769
	Peak-Hour	20.000[2]	100.000[2]
Auto Operations	Daytime	0.000	0.000
	Nighttime	0.000	0.000
	Peak-Hour	0.000	0.000

1 The total peak-hour periods were allocated between daytime (7a.m. to 10 p.m.) and nighttime (7 a.m. to 10 p.m.) periods as follows: daytime peak-hours (7:00-9:15 a.m. and 3:00-6:15 p.m.) and nighttime peak-hour (6:00-7:00 a.m.).

2 Peak-hour volumes are based on the FTA default operations.

.2 Alignment Speeds

Travel speeds for mobile sources, including BRT and LRT passbys, were also used to predict project noise and vibration levels at receptors identified along the project corridor. As shown in Table A-4, maximum travel speeds from BRT and LRT passbys vary by alternative and section of the project corridor. Average travel speeds were also applied to station locations to account for travel through the stations.

Table A-4

SUMMARY OF WEST- AND EASTBOUND ALIGNMENT SPEEDS (IN MPH)[1]

Corridor Area	BRT	LRT
Downtown Minneapolis	30/30	20/20
Campus	30/30	55/55
University	30/30	35/35
Downtown St. Paul	30/30	20/20

.3 Alignment Separation Distances

Alignment separation distances represent the distance between the near and far LRT tracks or the near and far BRT travel lanes. These distances were used in the modeling analysis to compute the cumulative noise level from BRT and LRT passbys in both directions. As shown in Table A-5, alignment separation distances between the westbound and the eastbound travel lanes/tracks are provided for both BRT and LRT sources by milepost or Sta. No. for each of the proposed Build Alternative-alignments. These separation distances are based on information provided by URS for the proposed BRT busway and the LRT track alignments.

Table A-5

SUMMARY OF ALIGNMENT SEPARATION DISTANCES (IN FEET)[1]

Corridor	Alternative-Alignment	
Sta. No.	BRT	LRT
2112.00	15	NA
2116.00	14	NA
2117.00	15	NA
2124.00	15	NA
2125.00	15	NA
2126.00	15	NA
2127.00	15	NA
2128.00	15	15
2135.00	12	15
2136.00	15	15
2139.00	15	22
2140.00	15	44
2141.00	15	45
2142.00	15	46
2143.00	15	47
2144.00	15	48
2145.00	15	15
2150.00	15	24
2151.00	15	42
2152.00	15	43
2154.00	15	44
2156.00	15	15
2189.00	0	15
2190.00	0	14
2190.17	0	14
2191.00	0	14
2196.00	51	14
2197.00	15	14
2213.00	15	15
2215.00	15	16
2218.00	15	17
2223.00	15	21
2224.00	15	28
2225.00	15	29
2230.00	15	24
2231.00	15	18
2232.00	15	17

Corridor	Alternative-Alignment	
Sta. No.	BRT	LRT
2247.00	15	20
2248.00	15	27
2249.00	15	31
2253.00	15	28
2254.00	15	19
2269.00	15	20
2270.00	15	26
2271.00	15	31
2272.00	15	36
2273.00	15	39
2278.00	15	30
2279.00	15	20
2280.00	15	14
2285.00	16	14
2287.00	15	14
2371.00	15	21
2372.00	15	29
2376.00	15	28
2377.00	15	15
2378.00	15	14
2428.00	15	15
2429.00	15	14
2607.00	15	16
2608.00	15	26
2609.00	15	27
2613.00	15	18
2614.00	15	14
2625.00	14	14
2631.00	15	14
2641.00	0	14
2659.00	0	13
2665.00	15	13
2673.00	15	13
2677.00	15	14
2678.00	15	15
2679.00	15	13
2684.00	15	13
2693.00	15	26
2694.00	15	29
2696.93	15	29
2697.00	15	NA
2709.00	14	NA
2710.00	15	NA
2716.00	15	NA

Note: NA means not applicable. The LRT alignment does not extend as far as the BRT alignment.

.4 Figures Identifying Receptor Locations Predicted to Exceed the Noise Impact Criteria

A list of the Appendix figures identifying the receptor locations predicted to exceed the project noise criteria is shown in Table A-6. A description of each Figure and its contents is included under each sub-section.

Table A-6

CURRENT TABLES OF THE NOISE AND VIBRATION TECHNICAL REPORT APPENDIX

Appendix Figures		
No.	**Section**	**Description**
A-1	A.4	Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the BRT Alternative
A-2	A.4	Receptors Predicted to Exceed the APTA Impact Criteria Under the BRT Alternative
A-3	A.4	Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the LRT Alternative
A-4	A.4	Receptors Predicted to Exceed the APTA Impact Criteria Under the LRT Alternative
A-5	A.4	Receptors Predicted to Exceed the FTA RMS Vibration Impact Criteria Under the LRT Alternative
A-6	A.4	Receptors Predicted to Exceed the FTA Ground-Borne Noise Impact Criteria Under the LRT Alternative

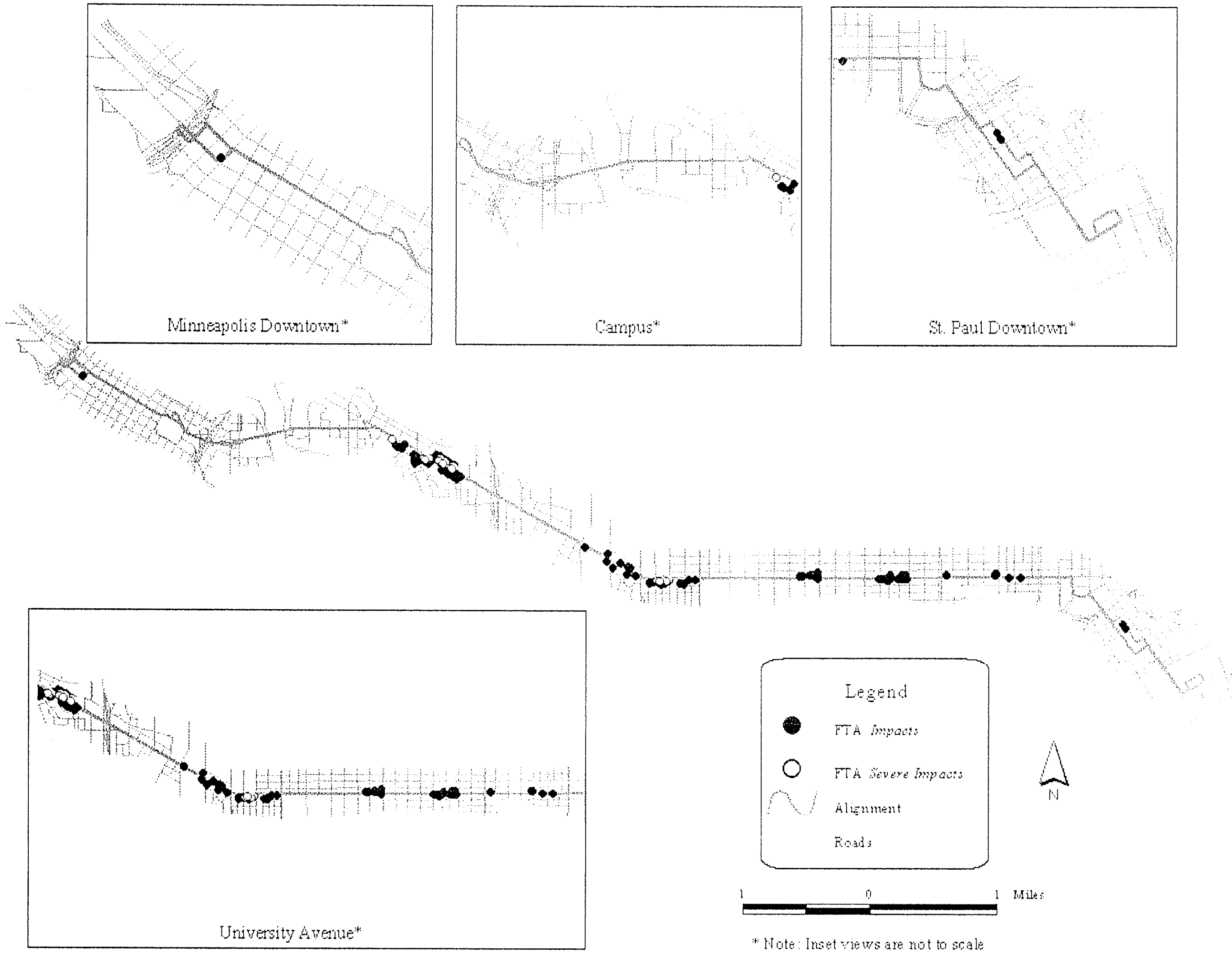


Figure A-1: Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the BRT Alternative

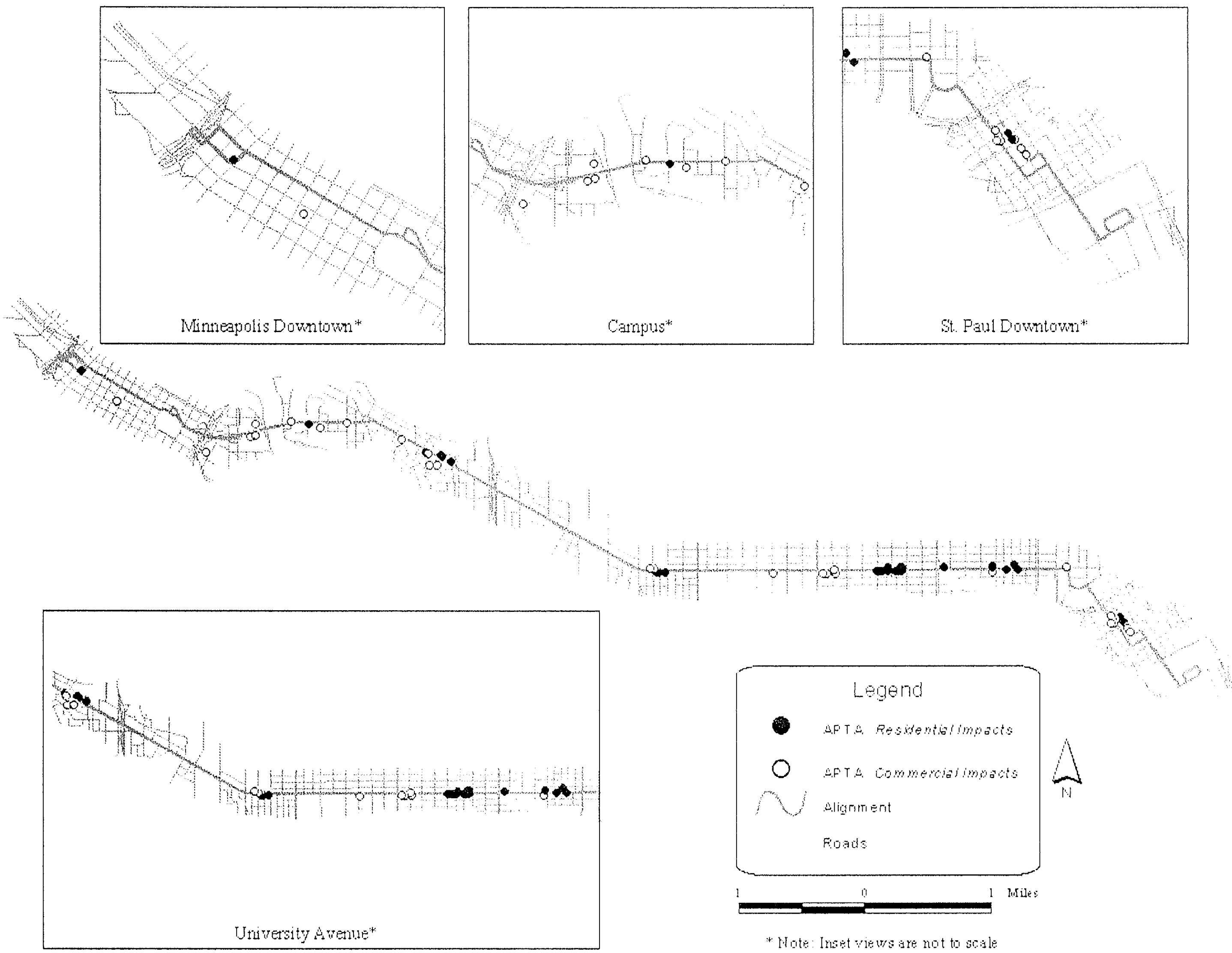


Figure A-2: Receptors Predicted to Exceed the APTA Operations Impact Criteria Under the BRT Alternative

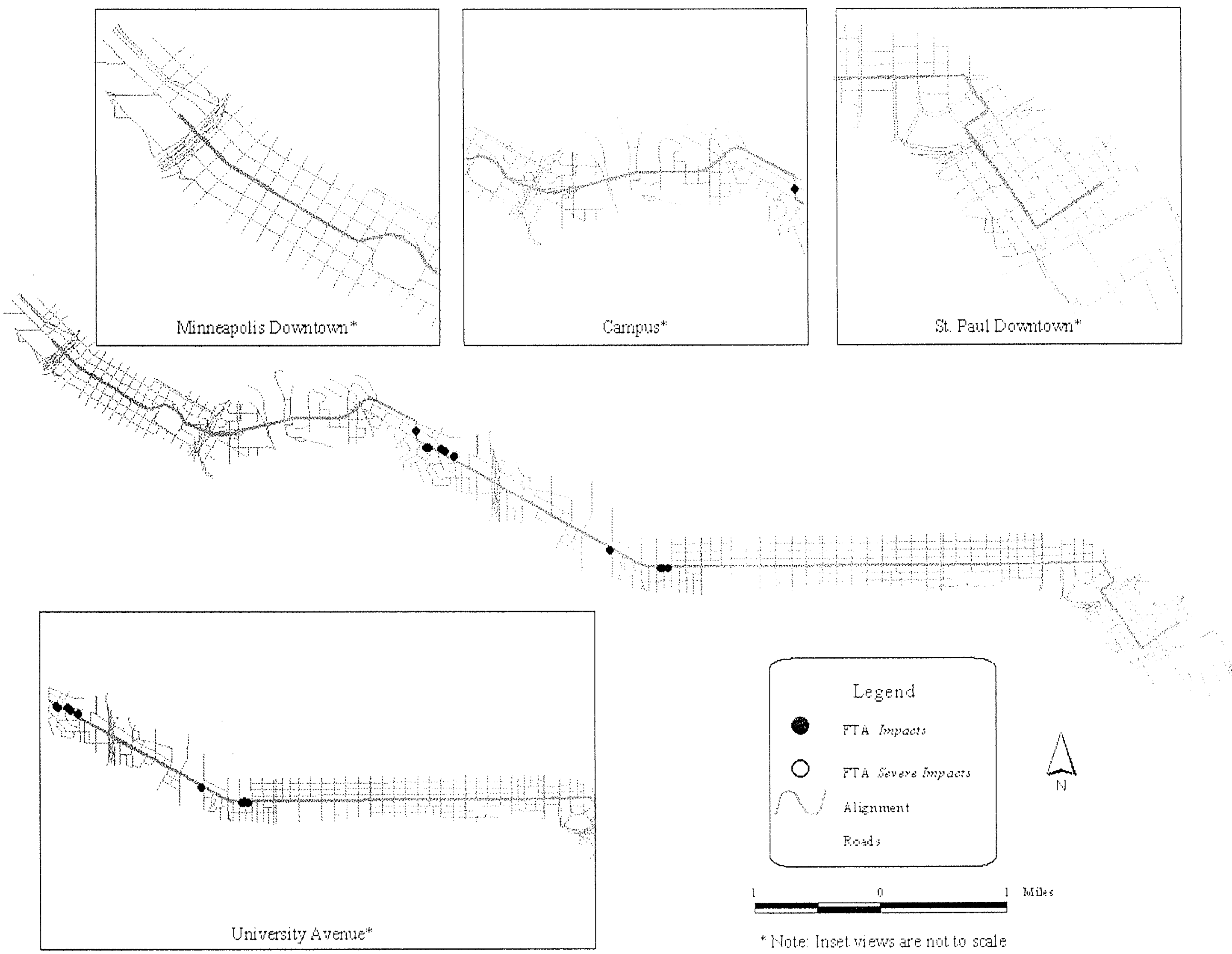


Figure A-3: Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the LRT Alternative

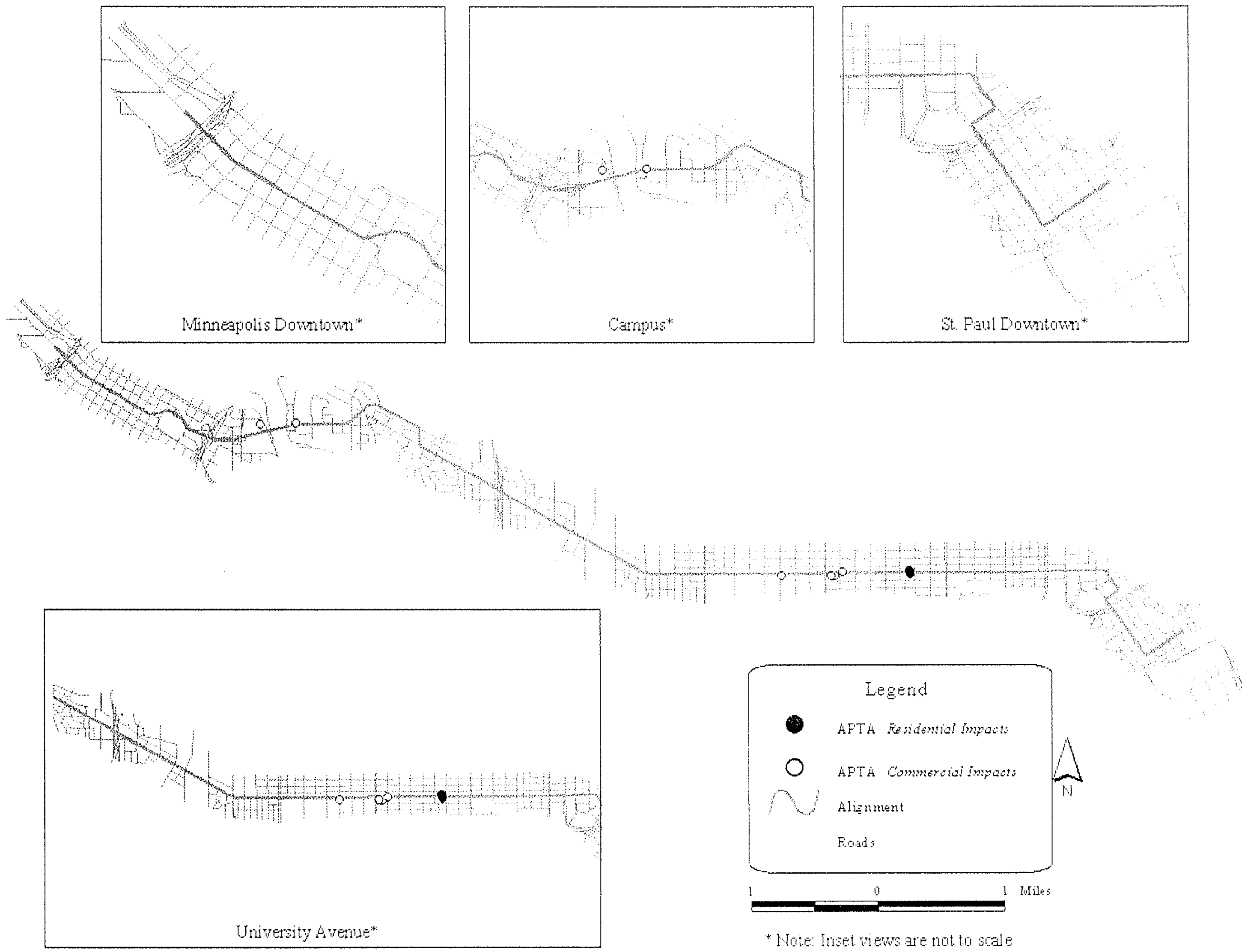


Figure A-4: Receptors Predicted to Exceed the APTA Operations Impact Criteria Under the LRT Alternative

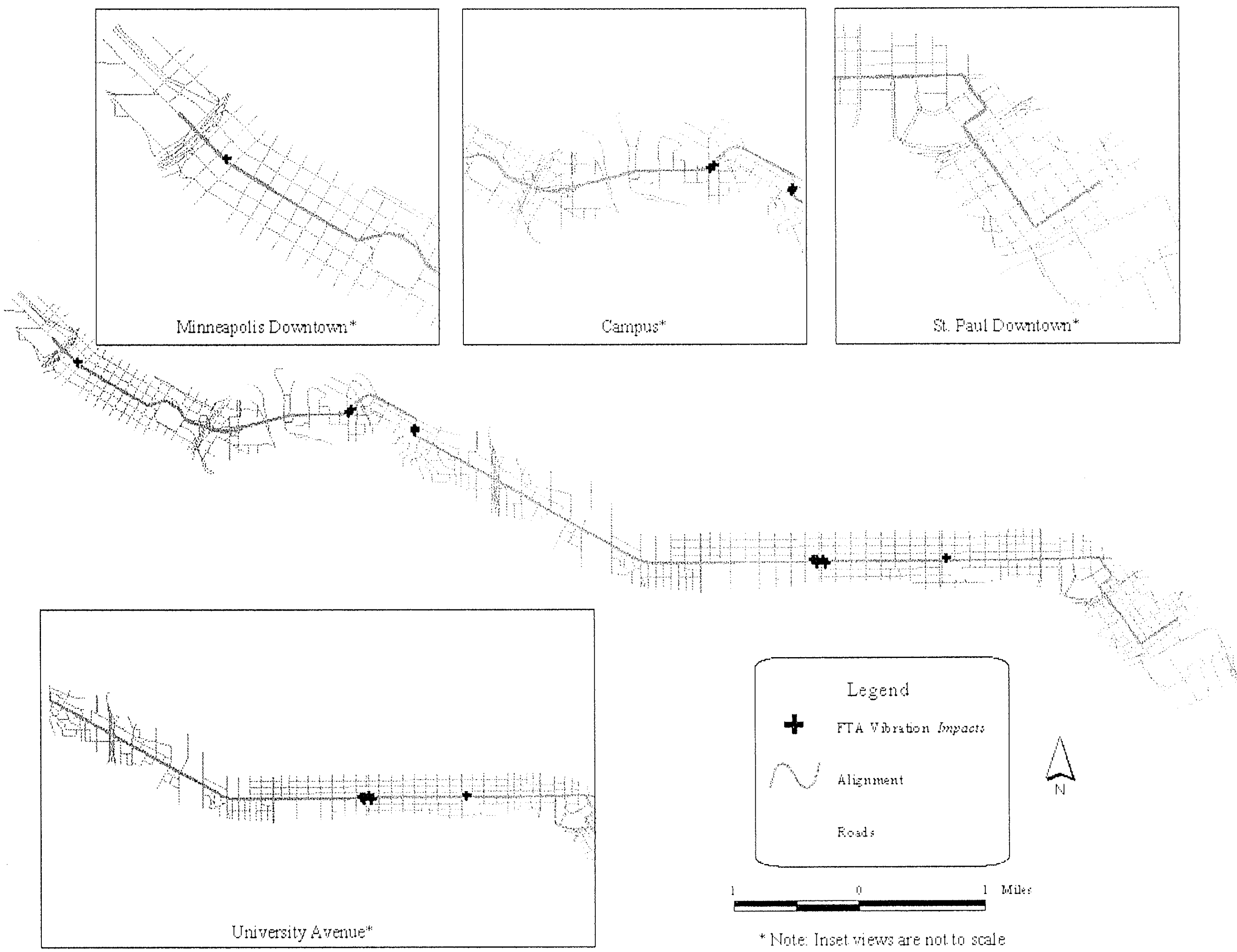


Figure A-5: Receptors Predicted to Exceed the FTA RMS Vibration Impact Criteria Under the LRT Alternative

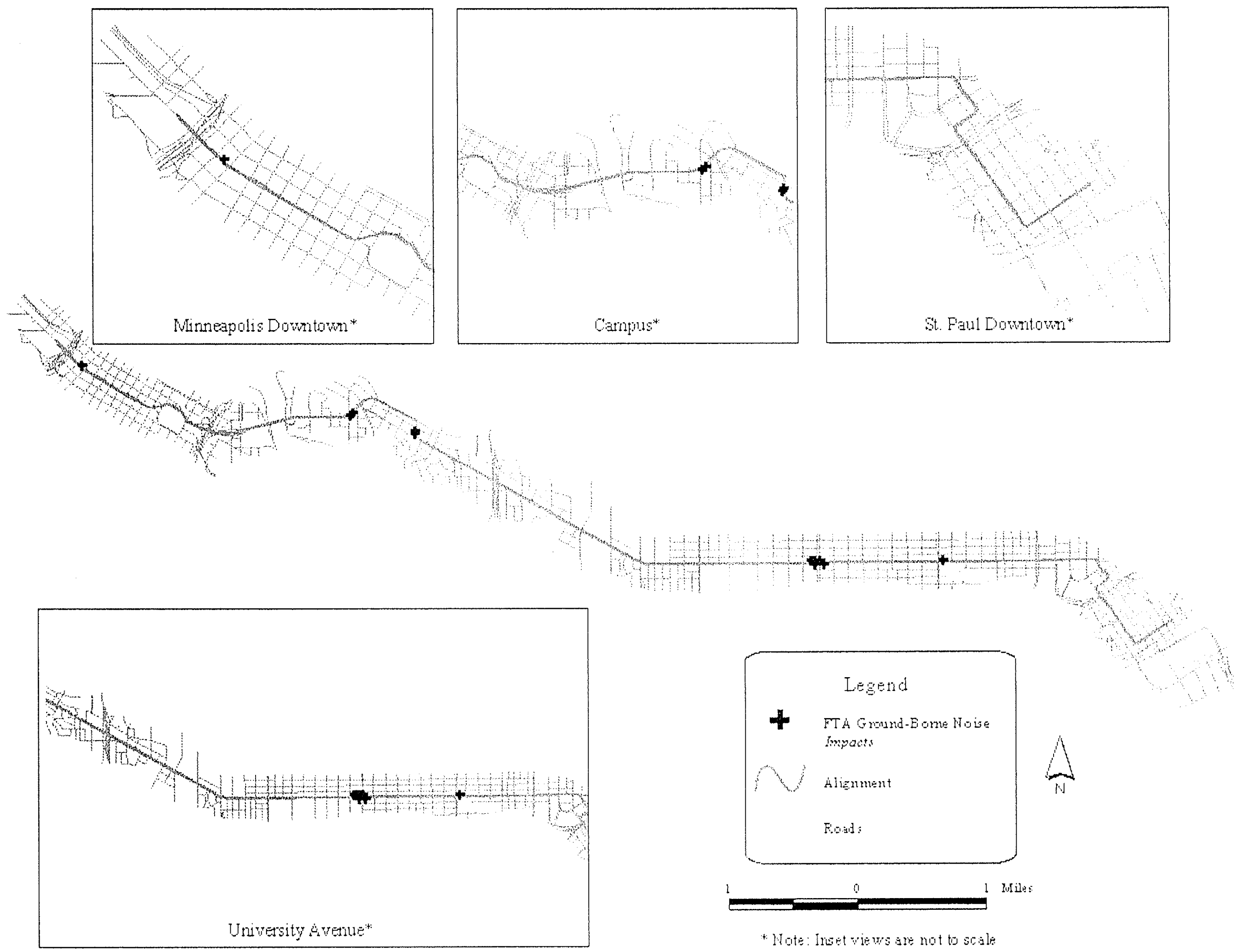


Figure A-6: Receptors Predicted to Exceed the FTA Ground-Borne Noise Impact Criteria Under the LRT Alternative

NOISE AND VIBRATION TECHNICAL REPORT

Figures Identifying Receptor Locations Predicted to Exceed the Noise Impact Criteria

A list of the Appendix figures identifying the receptor locations predicted to exceed the project noise criteria is shown in Table A-6. A description of each Figure and its contents is included under each sub-section.

Table A-6: Figures of the Noise and Vibration Technical Report Appendix

Appendix Figures		
No.	**Section**	**Description**
A-1	A.4	Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the BRT Alternative
A-2	A.4	Receptors Predicted to Exceed the APTA Impact Criteria Under the BRT Alternative
A-3	A.4	Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the LRT Alternative
A-4	A.4	Receptors Predicted to Exceed the APTA Impact Criteria Under the LRT Alternative
A-5	A.4	Receptors Predicted to Exceed the FTA RMS Vibration Impact Criteria Under the LRT Alternative
A-6	A.4	Receptors Predicted to Exceed the FTA Ground-Borne Noise Impact Criteria Under the LRT Alternative

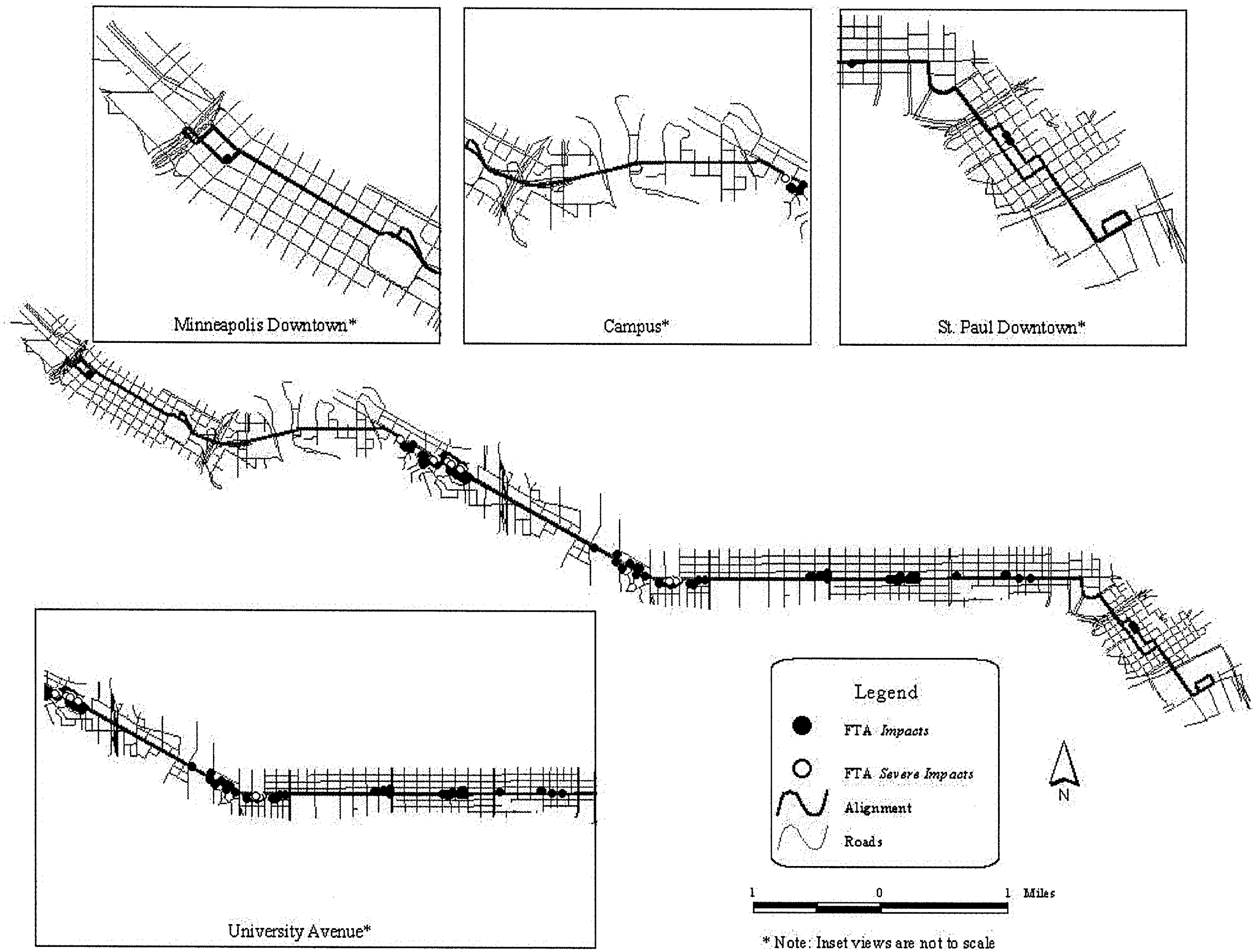


Figure A-1: Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the BRT Alternative

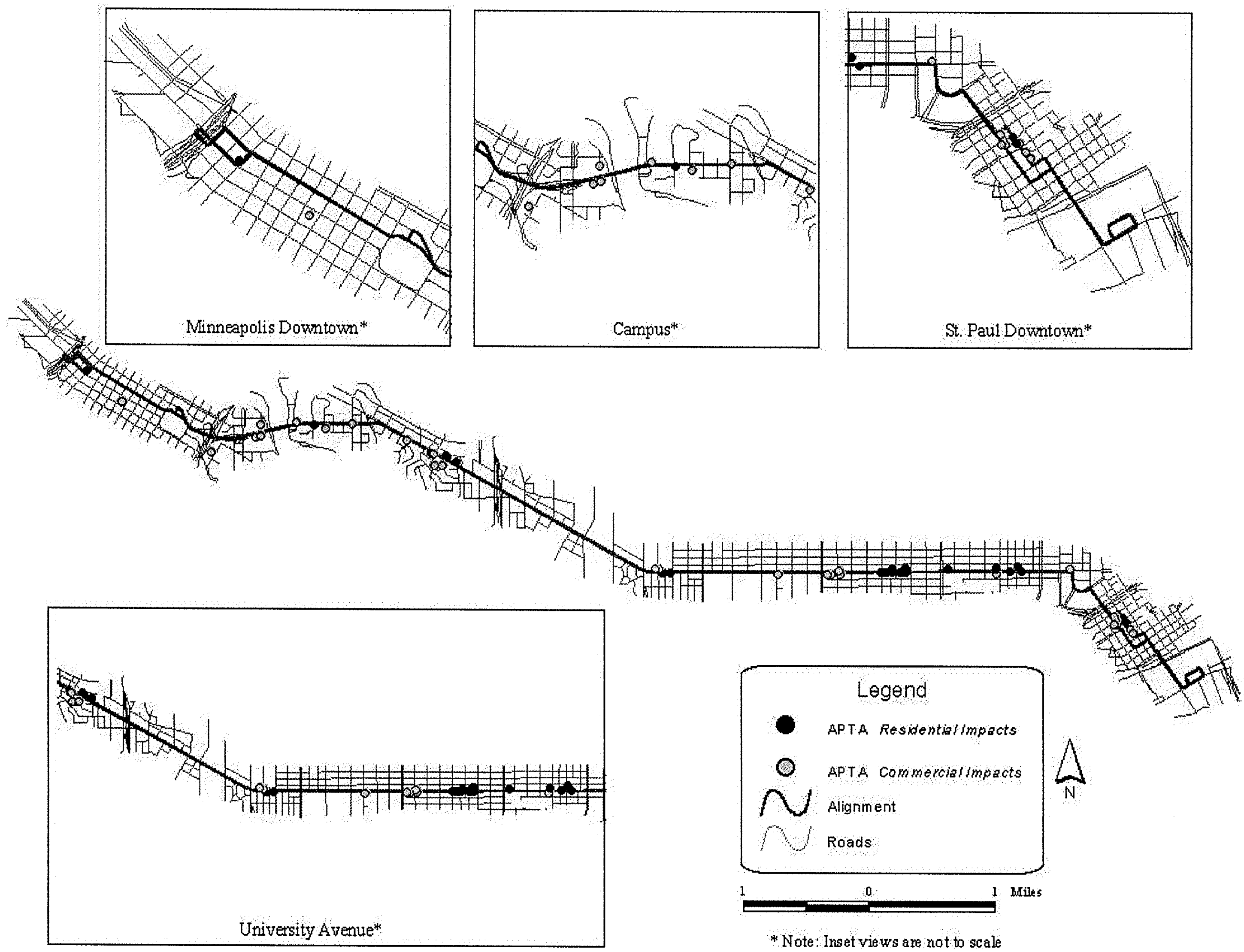


Figure A-2: Receptors Predicted to Exceed the APTA Operations Impact Criteria Under the BRT Alternative

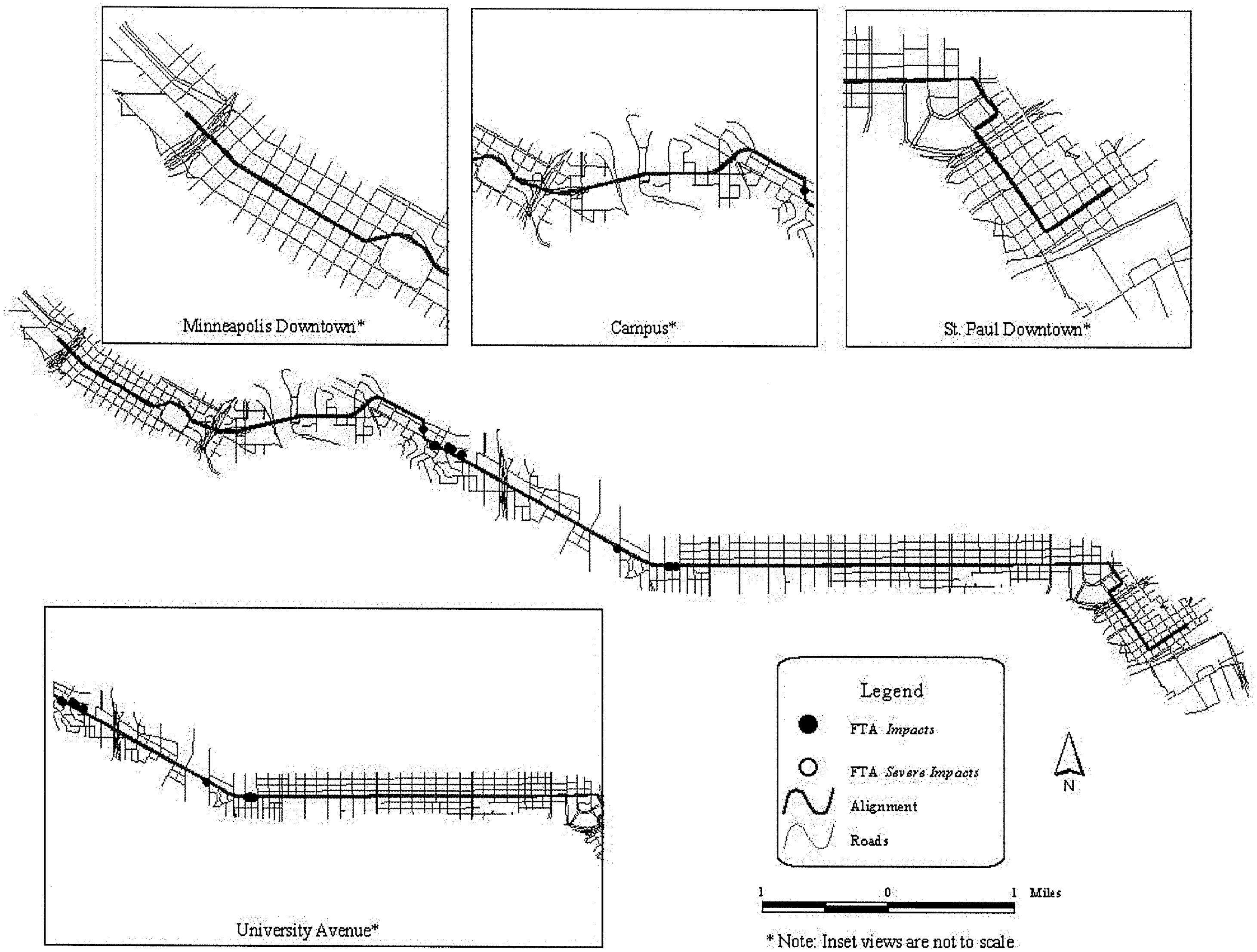


Figure A-3: Receptors Predicted to Exceed the FTA *Impact* and *Severe Impact* Criteria Under the LRT Alternative

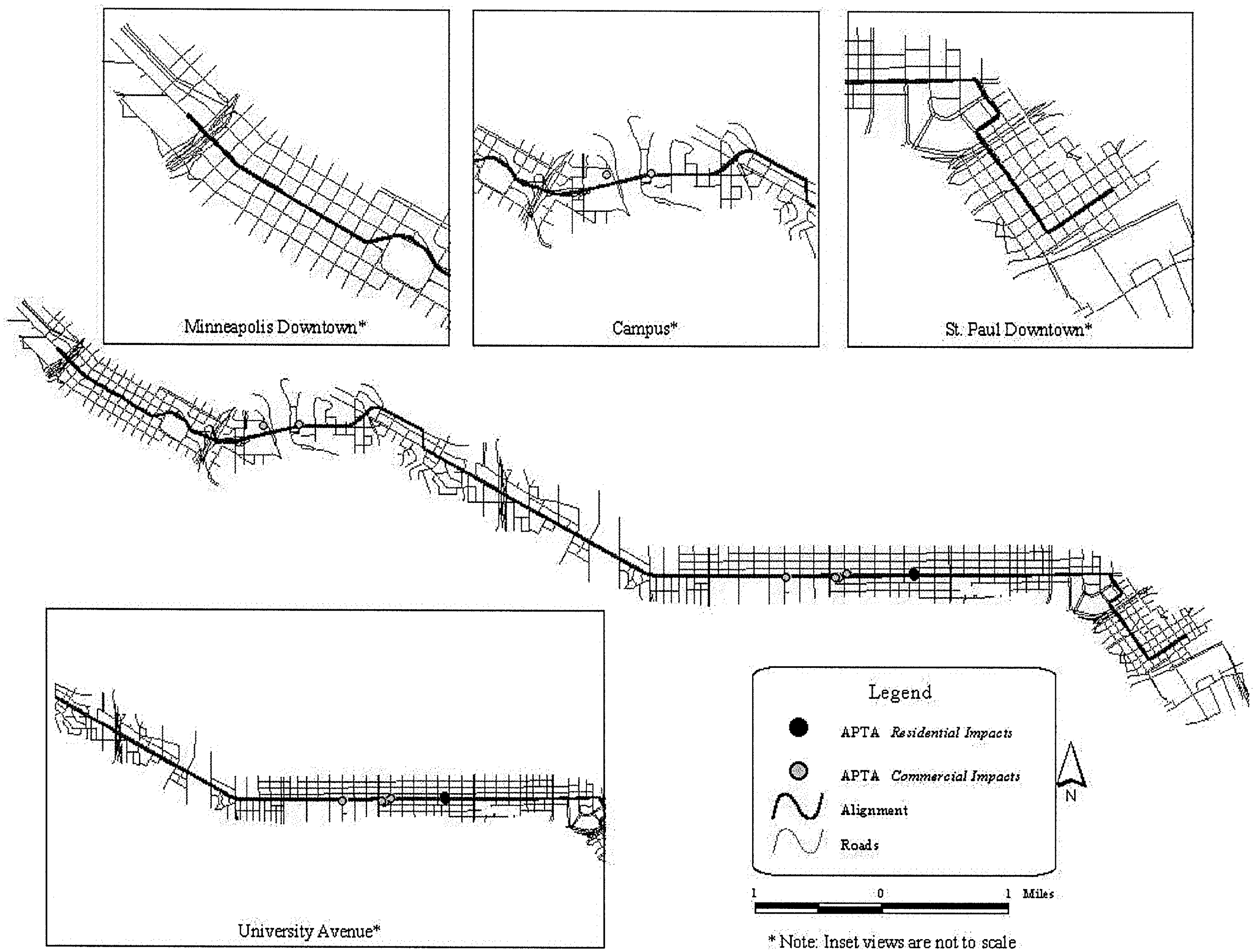


Figure A-4: Receptors Predicted to Exceed the APTA Operations Impact Criteria Under the LRT Alternative

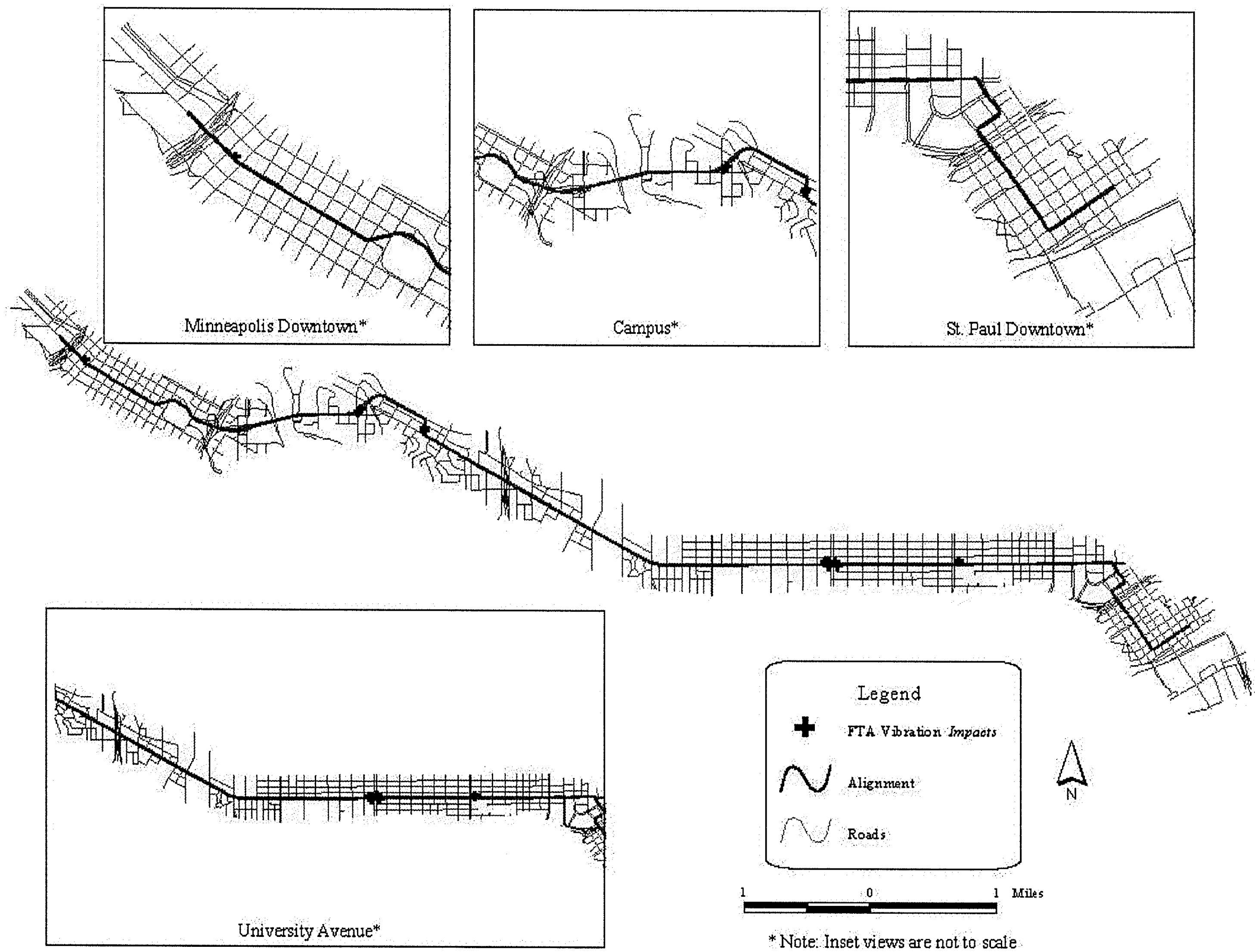


Figure A-5: Receptors Predicted to Exceed the FTA RMS Vibration Impact Criteria Under the LRT Alternative

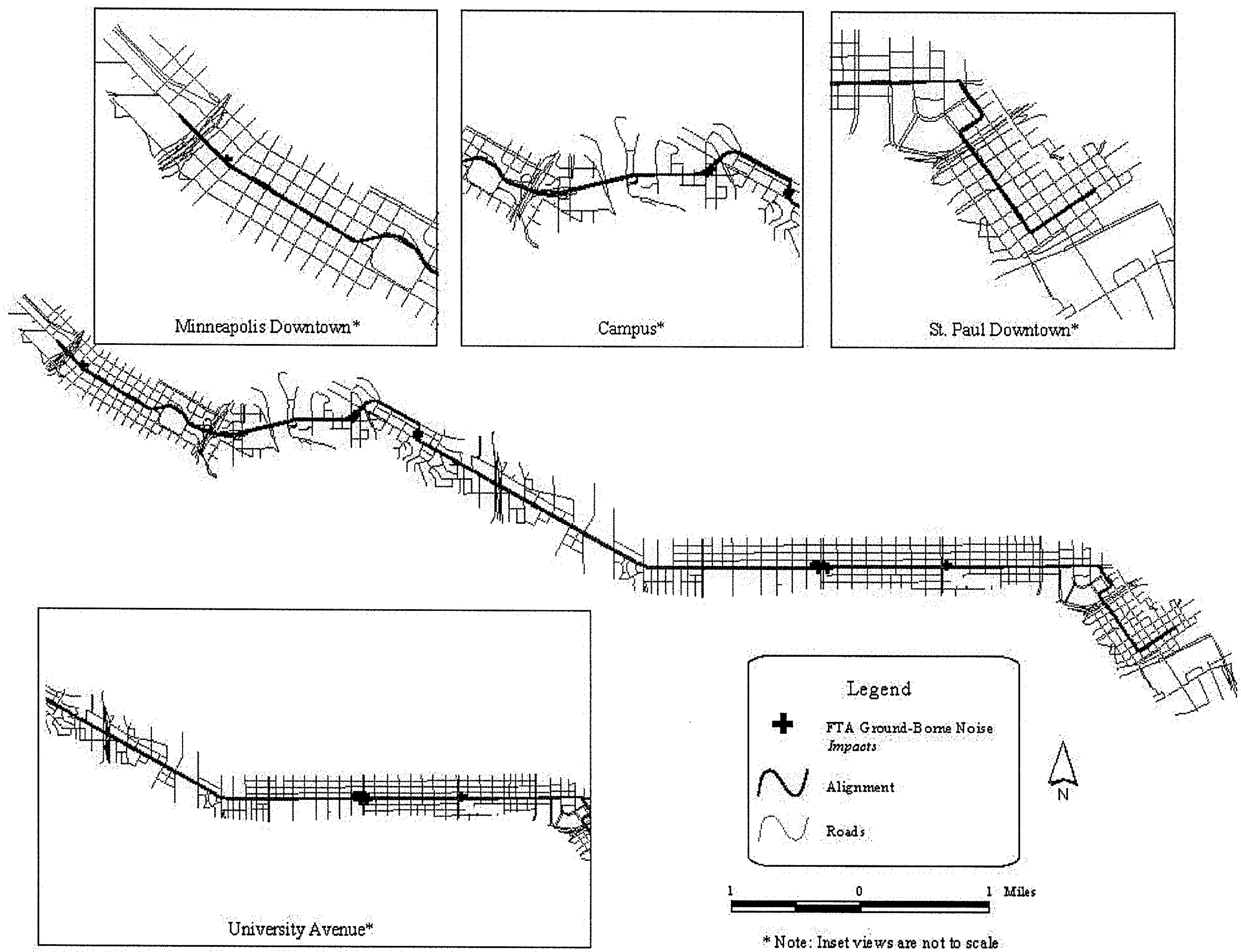


Figure A-6: Receptors Predicted to Exceed the FTA Ground-Borne Noise Impact Criteria Under the LRT Alternative