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Protecting MIT's interests during expansion of the Grand Junction rail line through campus

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The Grand Junction rail line passes directly through the urban campus of the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts. The rail line is currently a seldom-used single track allowing for occasional freight and deadhead equipment movements, however State plans call for it to be expanded to allow for perhaps 12 to 24 commuter train passbys occurring day and night to facilitate passenger revenue service between Boston's North Station with towns to the west. These plans represented potentially significant noise and vibration impacts for MIT's students, classrooms, and research experiments. Parsons Brinckerhoff (PB) was retained by MIT to quantitatively evaluate these potential impacts on a proactive basis to protect MIT's best interests when negotiating with the State. Ambient noise and vibration measurements were conducted, and potential future commuter train noise and vibration conditions were predicted. The results were evaluated against the Federal Transit Administration's (FTA) noise and vibration criteria for annoyance and potential disruption to extremely sensitive research devices. This paper will describe the approach and findings of the study as well as the unique challenges associated with performing the study within a city university campus that included dormitories, classrooms, laboratories, and even a nuclear reactor.

1 INTRODUCTION

This paper will summarize the efforts and work performed by Parsons Brinckerhoff (PB) on behalf of the Massachusetts Institute of Technology (MIT) in anticipation of potential expanded commercial passenger rail service proposed by the State of Massachusetts Department of Transportation (MassDOT) involving the Grand Junction rail line. The Grand Junction is

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currently a seldom-used single track allowing for occasional freight and deadhead equipment movements that cuts directly through MIT's campus. However, MassDOT would like to see it expanded to allow for perhaps 12 to 24 commuter train passbys occurring day and night to facilitate passenger revenue service between Boston's North Station with towns to the west. These plans represented potentially significant noise and vibration impacts for MIT's students, classrooms, and research experiments.

PB's scope for this study was to (1) document baseline ambient noise and vibration levels currently affecting buildings along the Grand Junction rail line on the campus of the Massachusetts Institute of Technology, and (2) to estimate future noise and vibration levels affecting MIT's buildings in the event the Grand Junction line is used by MassDOT for commuter train service to/from North Station. By doing so PB was able to prepare MIT to protect its best interests during negotiations with MassDOT should the proposed project be pursued.

This paper summarizes PB's technical approach, terminology, relevant noise and vibration criteria, ambient noise and vibration monitoring instrumentation and measured data, prediction models, and anticipated noise and vibration consequences if the MassDOT project ever comes to fruition.

2 GENERAL APPROACH

The study was done in a manner consistent with the requirements MassDOT would have to follow - namely those found in the Federal Transit Administration's (FTA) *Transit Noise and Vibration Impact Assessment Manual* (2006) - should an Environmental Assessment (EA) be required prior to initiation of commuter service. In that manner MIT can express their concerns on a quantitative basis and compare these results with those MassDOT will have to produce should the Grand Junction rail line be expanded. MIT's noise and vibration concerns were three fold; (1) potential impacts to student dormitories and other on campus residences, (2) potential impacts and disruption of classroom activities, and (3) potential interference with MIT's research laboratory experiments and sensitive instrumentation.

To this end exterior ambient noise and vibration measurements were performed at several receptor locations along the Grand Junction rail corridor, and potential future noise and vibration consequences were predicted and evaluated for potential severity with the criteria contained in the FTA Manual. Future exterior noise levels were predicted using the Cadna-A® noise model augmented with the FRA/FTA module. Future ground-borne vibration levels were predicted using the FTA Manual's "general method" procedure for both exterior and interior levels.

2.1 Receptor Selection

Two noise receptors (see **Figure 1**) and two vibration receptors (see **Figure 2**) were selected as sites to both measure existing and predict future noise and vibration levels. The receptors were selected in order to evaluate dormitory, classroom and research areas as well as to spatially cover the extent of the Grand Junction corridor on MIT's campus. The four receptor sites, which all have direct exposure to the Grand Junction rail line, were located as follows:

- Noise Receptor Site N-1: Brain & Cognitive Sciences Complex (see **Photo 1**)
- Noise Receptor Site N-2: Simmons Hall and Warehouse Dormitories (see **Photo 2**)
- Vibration Receptor Site V-1: Brain & Cognitive Sciences Complex (see **Photo 1**)
- Vibration Receptor Site V-2: Nuclear Reactor Lab (see **Photo 3**)

3 AMBIENT MEASUREMENTS

In this case both ambient noise and vibration levels were measured at exterior receptor locations along the Grand Junction rail corridor. Ambient sources included local traffic along Vassar, Albany and Main Streets, building HVAC systems, pedestrian activities, aircraft and helicopter overflights, and occasional freight train or deadhead commuter train passbys (once per day).

3.1 Ambient Noise Measurements

Long-term exterior ambient noise monitoring was completed using Larson Davis (LD) Model 720 Environmental Noise Monitors. The LD 720s were programmed to record data in hourly intervals using an RMS "slow" time response. Measured noise metrics included the Leq, L10 and L90 noise levels in A-weighted decibels (dBA). The LD 720s were deployed in trees at each receptor location to avoid tampering and housed in weatherproof cases. The microphones were covered by 3-inch foam windscreens. LD 720 noise monitors meet or exceed accuracy requirements for a Type 2 instrument in accordance with ANSI Standard S1.4.

A CEL Instruments Model 593 Noise Analyzer was used to make short-term exterior noise measurements. The CEL 593 was programmed to record the Leq, L10, and L90 noise metrics in both broadband (dBA) and third-octave band formats using an RMS "slow" time response. The monitor was placed approximately 5-feet above ground with the microphone covered by a 3-inch foam windscreen. The CEL 593 analyzer meets or exceeds accuracy requirements for a Type 1 instrument in accordance with ANSI Standard S1.4. Both noise monitors were checked for calibration accuracy before and after use with a Bruel & Kjaer Model 4231 Calibrator. The results of the ambient noise monitoring task can be seen in **Table 1**.

3.2 Ambient Vibration Measurements

To measure ground-borne vibration, a PCB Model 393B05 Accelerometer was mounted to a seismic mass in the vertical direction. The mass was placed at the external facade of the chosen vibration-sensitive buildings facing the Grand Junction tracks. The accelerometer signal was amplified by a PCB Model 480E09 Signal Amplifier. Next, the signal was passed through a Bruel & Kjaer Model ZR-0020 Integrator set to acceleration (unity) and into a CEL Instruments Model 593 Analyzer which was configured to measure broadband Linear and third-octave band frequency spectra. At the end of the measurement chain, the acceleration signal was recorded as a WAV file using a Marantz PMD670 Solid State Data Recorder, as shown in **Photo 4**.

Third-octave spectral levels were later calculated using the SpectraPLUS spectrum analysis software and integrated to convert the acceleration levels into proportional velocity levels (VdB). The entire vibration measurement system was calibrated beforehand using a PCB Model 394C06 Calibrator. The results of the ambient vibration monitoring task can be seen in **Table 2**.

4 FTA NOISE AND VIBRATION CRITERIA

The Federal Transit Administration (FTA) guidance manual entitled *Transit Noise and Vibration Impact Assessment* provides direction for preparing the noise and vibration sections of environmental documents for proposed mass transit projects. The FTA Manual sets forth the basic concepts, methods, and procedures for analyzing the severity of noise impacts from transit projects, and provided criteria limits which should not be exceeded without proper mitigation.

4.1 FTA Noise Criteria

The FTA's noise criteria are shown in **Figure 4**. The FTA's *moderate* impact criterion is determined by the threshold at which the percentage of people highly annoyed by the project noise starts to become measurable. The corresponding criterion for *severe* impact is determined by a higher, more significant percentage of people highly annoyed by the project.

The FTA's noise impact criteria are based on a comparison of the existing noise levels, as determined through measurements, and the future outdoor noise levels attributable to the proposed project as determined through modeling. They incorporate both absolute criteria, which consider activity interference caused by the transit project alone, and relative criteria, which consider annoyance due to the change in the noise environment caused by the project. FTA's noise criteria are evaluated on the exterior side of the receptors' buildings facing the tracks.

The FTA's noise criteria and descriptors are dependent on land-use. Category 1 includes tracts of land where quiet is an essential element in their intended purpose, such as outdoor concert pavilions, recording studios, concert halls, and historical sites with significant outdoor land-use. Category 2 includes residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where nighttime sensitivity to noise is assumed to be of utmost importance. Category 3 includes institutional land-uses with primarily daytime and evening use, such as medical offices, churches, schools, libraries, and theaters. Most general purpose commercial buildings are not included in any category.

The relevant noise metric when evaluating Category 2 receptors is the Ldn, due to the receptor's sensitivity to nighttime noise intrusion. Category 1 and 3 receptors are analyzed using the Leq for the loudest hour of transit-related activity, or Leq(h), during hours of noise sensitivity. All noise levels measured or predicted using the FTA procedure are expressed in A-weighted decibels (dBA).

4.2 FTA Vibration Criteria

As shown in **Figure 5**, the FTA's vibration criteria are intended to avoid building occupant annoyance and are based on interior root-mean-squared (RMS) vertical vibration velocity levels expressed in decibel units of VdB relative to one micro-inch per second (VdB relative to 1 micro-inch/sec) for various categorized land-uses and occurrence rate of vibration events (i.e. train pass-bys). The frequency range over which vibration levels are evaluated typically ranges from about the 1 Hz to 100 Hz third-octave bands.

Buildings in which vibration could interfere with sensitive interior operations are classified as Category 1. Residential receptors are considered as Category 2 receptors, while institutional land-uses are placed in Category 3. Most general purpose commercial buildings are not included in any category. *Frequent* events are defined as more than 70 vibration events per day, *occasional* events range from 30 to 70 per day, and *infrequent* events are defined as fewer than 30 per day. Most commuter and inter-city rail systems fall into this latter category. The FTA's vibration criteria limits are absolute levels, not relative increases above existing conditions, and thus do not require ambient vibration levels to be established.

In addition to the criteria limits for human annoyance, the FTA Manual also provides criteria thresholds to avoid the disruption of instrumentation and equipment that may be particularly sensitive to vibration. These guidelines are called Vibration Criteria (VC) and are shown in **Figure 6** along with a description of the types of sensitive equipment intended for protection.

5 FUTURE NOISE AND VIBRATION

Future project-related train noise and vibration conditions were predicted using methods consistent with the FTA's Transit Noise and Vibration Impact Assessment Manual (2006). In this manner MIT could have credible warning in anticipation of potential impacts and disruptions to their students, classrooms, laboratories and facilities in the event MassDOT's plans to expand rail service on the Grand Junction come to fruition.

5.1 Cadna-A/FTA Noise Predictions

A noise assessment in accordance with the FTA's "detailed method" was completed in order to predict future noise levels associated with potential increased rail service along the Grand Junction. As discussed previously, the FTA noise assessment method predicts either the day-night sound level (Ldn) or the loudest-hour noise level (Leq(h)) depending on the activity category of the receptor, with both metrics being expressed in A-weighted decibels (dBA).

The Cadna-A® acoustic model, augmented with the FTA/FRA rail module, was used for all noise predictions. Cadna-A is a sophisticated, three-dimensional noise model that implements ISO Standard 9613 for environmental noise sources and outdoor sound propagation. It allows for noise sources to be assembled from point, line and/or area components; each emitting sound power levels (PWL) in octave bands or broadband A-weighted format. Distance losses, elevation differences, ground attenuation, wind effects, building shielding, and barrier/berm effects are computed in the Cadna-A model, and the resulting sound pressure levels (SPL) are predicted at any number of receptor locations of interest.

The FTA/FRA rail module integrates the FTA detailed method noise assessment into Cadna-A by allowing the user to specify parameters such as the type of locomotive, throttle setting, number of rail cars, vehicle speed, and number of day and night pass-bys, all of which are used to determine the noise emissions of a passing train per FTA guidelines.

The Cadna-A model for this project was first configured by importing a GoogleEarth® base map of the area. In this manner, the location of the rail line, buildings, and receptor locations could be modeled with a high degree of accuracy. Building structures flanking the Grand Junction corridor were then added to account for any acoustic shielding effects. Lastly, receptors (i.e. calculation points) were placed at the exterior facade of the noise-sensitive buildings along the corridor. A perspective view of the model is shown in **Figure 3**.

Because this project is in the early phases of planning, a number of different operational proposals for increased commuter rail service along the Grand Junction have been preliminarily discussed by MassDOT. The range of options included 6 or 12 round-trip trains per day, traveling at either 15 or 30 mph, with or without a station stop. However, based on a preliminary operations analysis, it was determined that the lower service, low speed scenario with a station stop is most likely, and thus most appropriate for the prediction of future noise levels. This scenario would include 12 train pass-bys per day (6 round-trip trains) with trains traveling at 15 mph. For the purposes of the Ldn noise level predictions, it was assumed that 10 pass-bys would occur during the daytime and two would occur at night. Two train pass-bys in one hour were assumed for the loudest-hour Leq(h) predictions. A station location between Massachusetts Avenue and Main Street was also assumed to simulate worst-case noise conditions. Higher speed and/or more frequent train service options would necessarily cause higher noise levels.

A typical MBTA commuter trainset was assumed to consist of one diesel locomotive and six rail cars. Additional noise sources associated with each train pass-by event include train horns and crossing signals at each grade crossing, and an idling train at the station. Noise emission levels for these additional sources were taken from the FTA manual and from measurements made for prior projects. Train horn noise was modeled as a line source along the approach to each grade crossing. The standard four-toot horn was assumed unless the train was exiting the station, in which case a horn with two-toots was assumed due to the reduced train speed while approaching the crossing. Crossing signals were modeled as a point source at each grade crossing and an idling train was modeled as a vertical area source at the potential station location. The duration of a typical event (i.e. a grade-crossing or station stop) was assumed to be 2-minutes for both the crossing signals and the idling trains.

The future project-generated exterior noise level predictions are summarized in **Table 3** along with the FTA noise criteria levels. **Figures 7 and 8** present the results of the Cadna-A model graphically and illustrate noise propagation throughout the project corridor with A-weighted (dBA) contours in 5-decibel increments for the Ldn and loudest hour Leq(h) levels, respectively.

5.2 FTA Vibration Predictions

In this case the FTA's "general method" ground-borne vibration model was used to predict future MBTA train pass-by vibration levels potentially affecting the two receptor locations. The FTA's model predicts maximum vibration velocity levels (Lmax) in units of VdB based on a train's type (in this case heavy rail), speed, distance to the receptor, number of events per day, coupling efficiency of the receptor's foundation to the ground, and any special track or ground conditions that may accentuate or diminish vibration.

Vibration predictions were performed both inside the buildings as well as immediately outside their exterior facades. The FTA's vibration model assumes a 10 decibel loss as vibration transfers from outside to inside a building's foundation. It was assumed that future tracks will be continuous welded rail (CWR), that there would be approximately 12 pass-by events per day, and that the trains would be moving through the Grand Junction corridor at 15 mph. Faster moving trains would necessarily cause higher levels of vibration.

The results of the future train-induced, ground-borne vibration annoyance predictions can be seen in **Table 4** for the two receptor locations. In addition, the vibration criteria limits and so-called "critical distance", or the distance from the tracks within which vibration velocity levels could reasonably be expected to exceed applicable FTA vibration criteria limits, are also shown.

Table 4 also provides the critical distances from the tracks for the various VC vibration criteria limits to protect highly sensitive equipment used inside buildings. MIT performed an internal survey in 2008, the results of which indicated that there were several buildings along the Grand Junction rail line within which potentially vibration-sensitive equipment are being used. Thus, if any of the types of sensitive equipment listed in **Figure 6** are in use inside these buildings, then there is a possibility that train-induced vibration could interfere with or disrupt the equipment's proper function. These buildings included the following:

- The Fuel Cell Laboratory (Building No. 41)
- Brain & Cognitive Sciences Complex (Building No. 46)
- Parsons Laboratory (Building No. 48)

6 UNUSUAL CHALLENGES

There were several unique challenges associated with performing this assignment in an urban scholastic setting. First of all was the security challenge of deploying long-term noise monitors without them being stolen by pedestrians or homeless people who tended to congregate near the tracks. This was overcome by hiding the LD 720 noise monitors in trees out of sight and out of reach. Another challenge was gaining access to the rail corridor, and especially the nuclear plant, on MIT's campus. This was resolved with close communication between PB's field staff and the MIT police department. Yet despite best efforts there was at least one measurement interruption from a police officer unaware of the project.

But the most time-consuming challenge came from trying to anticipate unscheduled freight train movements along the existing Grand Junction tracks so that vibration measurements could be performed. This was accomplished by coordination with the MBTA, long periods of simply waiting in the field for a train to pass, and to some degree, attempting to discern the movement patterns of trains from the long-term noise data. And finally, a one-week break in the measurement schedule occurred because the Ringling Brothers, Barnum and Bailey Circus was in town and their mile-long train was allowed to park on the Grand Junction line.

7 CONCLUSIONS

A noise and vibration study was performed in accordance with Federal Transit Administration (FTA) guidelines along the Grand Junction rail corridor on the campus of the Massachusetts Institute of Technology (MIT). The study's goals were to document baseline noise and vibration conditions affecting buildings adjacent to the corridor, and to anticipate future noise and vibration impact conditions in the event the corridor is expanded and used by the MBTA for revenue rail service. To this end two noise receptors and two vibration receptors were evaluated with ambient measurements and predictive modeling. The receptors included:

- Noise Receptor Site N-1: Brain & Cognitive Sciences Complex
- Noise Receptor Site N-2: Simmons Hall and Warehouse Dormitories
- Vibration Receptor Site V-1: Brain & Cognitive Sciences Complex
- Vibration Receptor Site V-2: Nuclear Reactor Lab

Existing exterior noise levels range from 58 to 66 dBA Leq(h) with an Ldn of 67 dBA at Site N-1, and 54 to 59 dBA Leq(h) with an Ldn of 62 dBA at Site N-2. Existing exterior ambient vibration levels are approximately 49 VdB and increase to 71 VdB during a train pass-by event at Site V-1, and are approximately 55 VdB and increase to 63 VdB during a train pass-by event at Site V-2.

Future MBTA train-induced noise levels are predicted to be 68 dBA Leq(h) exterior to Site N-1 and range from 60 to 61 dBA Ldn at the buildings represented by Site N-2. Future MBTA train-induced vibration levels are expected to range from 77 VdB (exterior) to 67 VdB (interior) at Site V-1 and from 71 VdB (exterior) to 61 VdB (interior) at Site V-2.

Based on the ambient noise levels, the FTA's noise criteria limits for exterior project-generated noise at Site N-1 are 63 dBA Leq(h) for moderate impact and 69 dBA Leq(h) for severe impact, and are 59 dBA Ldn for moderate impact and 65 dBA Ldn for severe impact at Site N-2. Based on the receptors' building type categories, the FTA's interior vibration criteria limits are 65 VdB at Site V-1 and 83 VdB at Site V-2.

Mitigation options are available to reduce the severity of train noise and vibration impacts which might include: noise barriers, acoustical window treatments, direct fixation track work, anti-vibration ballast mats, station enclosures, and horn-free "quiet zones" at street crossings.

Therefore, given the FTA's criteria limits for train-induced noise and vibration, there is potential that future MBTA trains could create impact conditions for noise and vibration sensitive receptors along MIT's Grand Junction rail corridor. However, given the ambient noise and vibration conditions of this urban setting, and the fact that several existing trains already make use of the corridor on a daily basis, it is unlikely that these potential impacts would significantly detract from the students' quality of life or ability to perform proficiently within classrooms and laboratories.

Consequently, should MassDOT's plans to expand MBTA commuter rail revenue service along the Grand Junction proceed, then any noise and vibration analyses prepared by the State should be carefully scrutinized by MIT to insure protection of their best interests as a potentially impacted abutter.

8 ACKNOWLEDGEMENTS

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Figure 1. Noise Receptors

Figure 2. Vibration Receptors

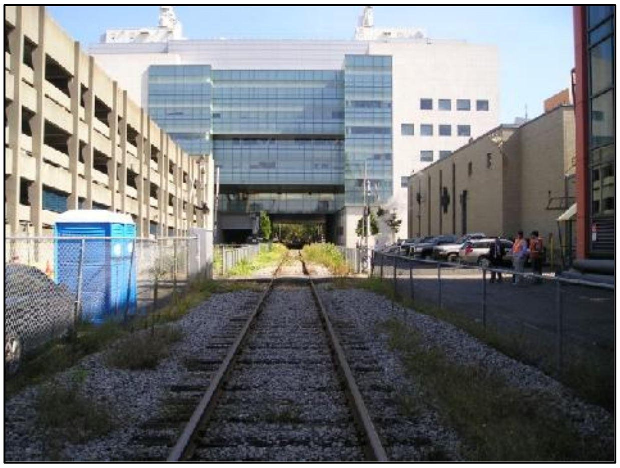

Photo 1. Brain and Cognitive Center

Photo 2. Simmons Hall Dormitory

Photo 3. Nuclear Research Reactor

Photo 4. Vibration Monitoring Equipment

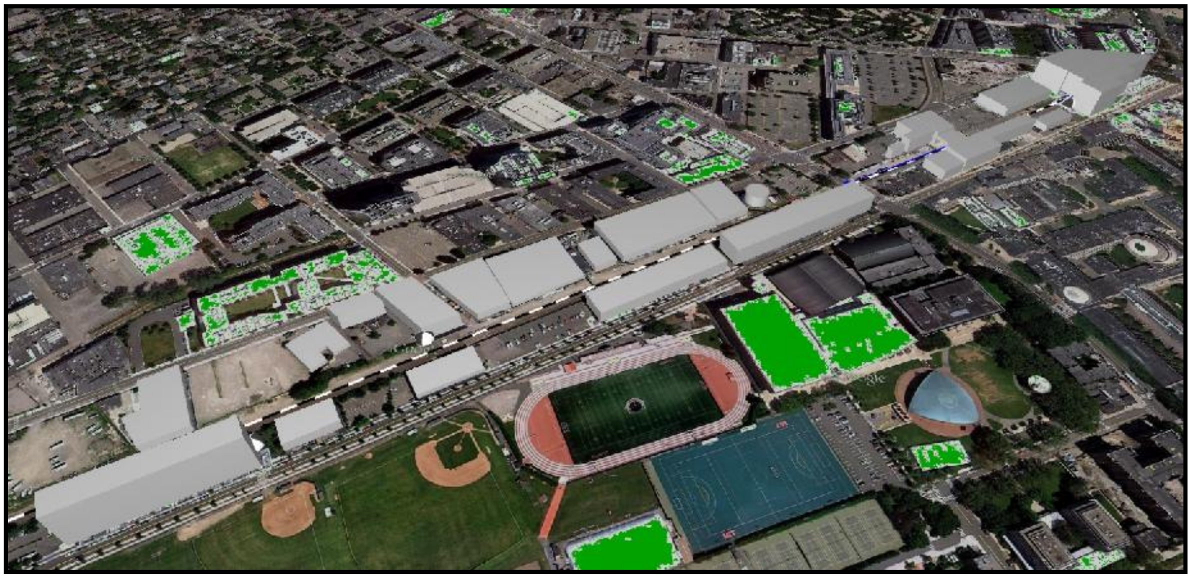

Figure 3. Cadna-A Noise Model Configuration

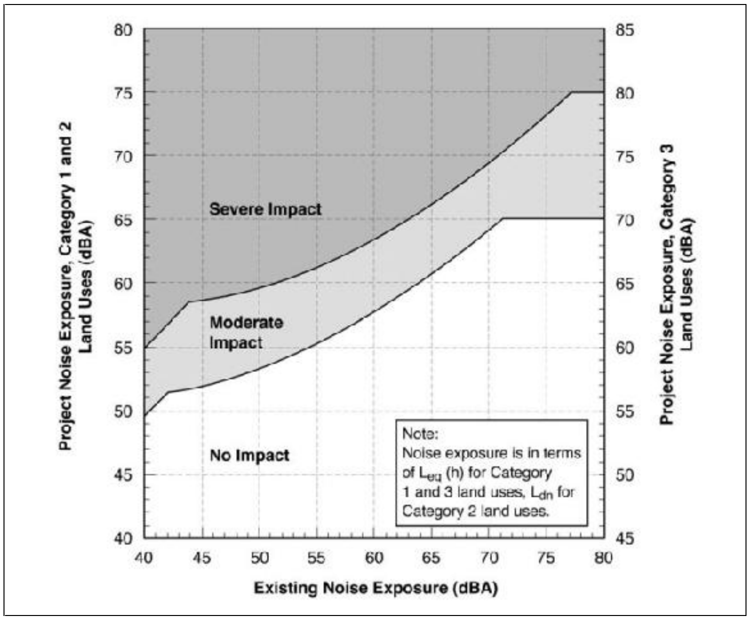

Figure 4. FTA Noise Impact Criteria

Land Use Category	GBV Impact Levels (VdB re 1 micro-inch /sec)			GBN Impact Levels (dB re 20 micro Pascals)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	N/A[4]	N/A[4]	N/A[4]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Notes:

1. "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5. Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

Figure 5. FTA Vibration Criteria (Annoyance)

VC Curve Name	Vibration Limit*		Intended Use
	micro-inch/sec	VdB re 1 micro-inch/sec	
VC-A	2,000	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment.
VC-B	1,000	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths.
VC-C	500	54	Appropriate for most lithography and inspection equipment to 1 micron detail size.
VC-D	250	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.
VC-E	125	42	The most demanding criterion for extremely sensitive equipment.

(*) Evaluated over the frequency range of 1 Hz to 80 Hz third-octave bands

Figure 6. FTA Vibration Criteria (Sensitive Devices)

Table 1. Noise Monitoring Site Details

Site No.	Site Location and Address	Land-Use (FTA Category)	Description	Ambient Noise Metric of Interest	FTA Noise Criteria Limits
N-1	Brain & Cognitive Sciences Complex at 43 Vassar Street	Institutional (Category 3)	Located at the Brain & Cognitive Sciences Complex, which extends over the Grand Junction tracks near the Main Street crossing.	61 dBA Leq(h) Loudest Hour*	Moderate Impact 63 dBA Leq(h) Severe Impact 69 dBA Leq(h)
N-2	Between the Warehouse Dorm at 224 Albany Street and Simmons Hall at 229 Vassar Street	Residential (Category 2)	Located SW of the crossing at Massachusetts Avenue between two student dormitories.	62 dBA Ldn	Moderate Impact 59 dBA Ldn Severe Impact 65 dBA Ldn

(*) Assumed loudest hour for future MBTA expansion project 7:00 to 8:00 AM

Table 2. Vibration Monitoring Site Details

Site No.	Site Location and Address	Land-Use (FTA Category)	Description	Ambient Vibration Levels	FTA Vibration Criteria Limit
V-1	Brain & Cognitive Sciences Complex 43 Vassar Street	Research (Category 1)	Research facility that extends over the Grand Junction tracks near the Main Street crossing.	49 VdB Ambient 71 VdB Train pass-by	65 VdB
V-2	MIT Nuclear Reactor Lab 138 Albany Street	Research (Category 3)	Lab with an operating nuclear reactor located near the crossing at Massachusetts Avenue.	55 VdB Ambient 63 VdB Train pass-by	83 VdB

Table 3. Future Project-Generated Noise Prediction Results

Site No.	Site Location	Land-Use (FTA Category)	Ambient Noise Metric of Interest	Predicted Project-Generated Noise Level	FTA Noise Criteria Limits
N-1	Brain & Cognitive Sciences Complex	Institutional (Category 3)	61 dBA Leq(h) Loudest Hour*	68 dBA Leq(h)	Moderate Impact 63 dBA Leq(h) Severe Impact 69 dBA Leq(h)
N-2	Warehouse and Simmons Hall Dormitories	Residential (Category 2)	62 dBA Ldn	60 – 61 dBA Ldn	Moderate Impact 59 dBA Ldn Severe Impact 65 dBA Ldn

(*) Assumed loudest hour for future MBTA Expansion Project 7:00 to 8:00 AM

Table 4. Future Project-Generated Vibration Prediction Results

Site No.	Site Location	Land-Use (FTA Category)	Predicted Train Vibration Level (exterior/interior)	FTA Vibration Criteria Limit	Critical Distance (interior)
V-1	Brain & Cognitive Sciences Complex	Research (Category 1)	77 VdB / 67 VdB	65 VdB	39 feet
V-2	MIT Nuclear Research Reactor Lab	Research (Category 3)	71 VdB / 61 VdB	83 VdB	4 feet
VC-A	Any	VC-A	n/a	66 VdB	35 feet
VC-B	Any	VC-B	n/a	60 VdB	72 feet
VC-C	Any	VC-C	n/a	54 VdB	148 feet
VC-D	Any	VC-D	n/a	48 VdB	307 feet
VC-E	Any	VC-E	n/a	42 VdB	634 feet

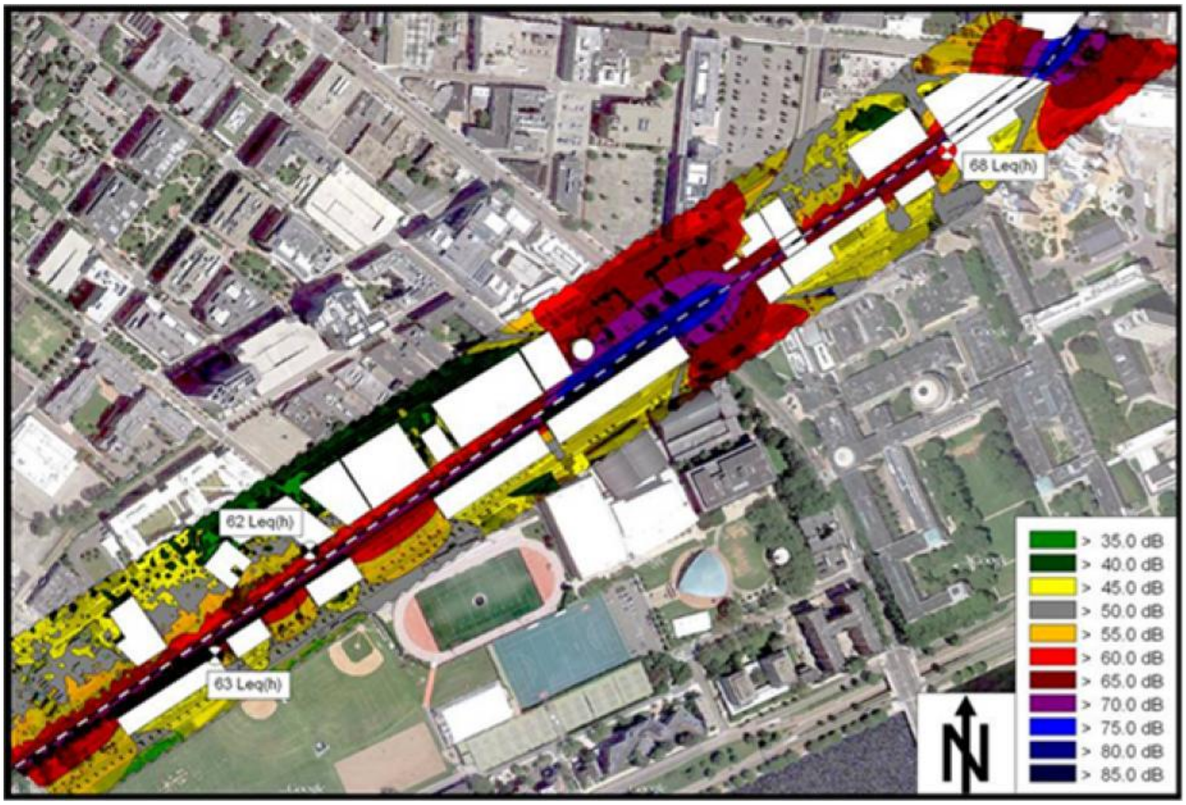

Figure 7. Future Ldn Noise Level Predictions

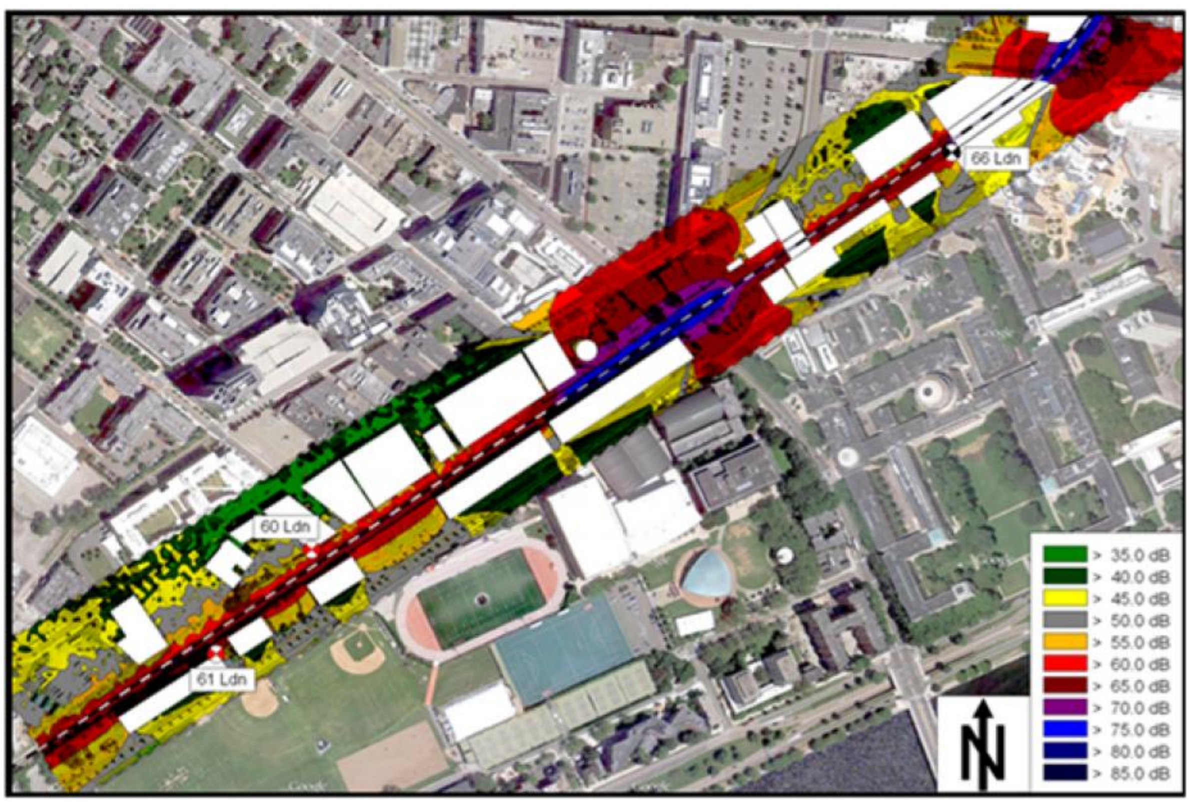

Figure 8. Future Loudest-Hour Leq(h) Noise Level Predictions