New Hampshire Department of Transportation Statewide Noise Barrier Study

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ABSTRACT

This paper presents the results of a statewide noise barrier study for the New Hampshire Department of Transportation (NHDOT). The feasibility and reasonableness of noise barriers throughout the state has been evaluated according to NHDOT acoustical and cost-effectiveness criteria. The study has provided the DOT an estimate of the potential noise barrier material costs associated with a newly implemented Type II noise barrier program. The study also has identified municipalities that the DOT can coordinate with for enacting noise-compatible planning regulations. The paper describes the methodology used to develop the screening-level noise barrier evaluation. Highway noise levels throughout the state and the distances from the highway where noise levels exceed the noise abatement criteria (NAC) were determined. A method to predict the noise reduction of barriers (insertion loss) based on a simple geometrical relationship of receptors and potential noise barriers was established and has been shown to correlate well to detailed traffic noise models using actual roadway and terrain geometry. The simplified prediction method was used to evaluate over 300 miles of highway, 300 candidate noise barrier study areas and over 30,000 receptors. This screening-level modeling approach is critical to the practicality of using TNM across the entire state given the significant number of receptors and noise barrier study areas. The results of the study including information about all 30,000 receptors and 300 noise barrier study areas were collected in Google Earth[™] data files for easy access when the DOT responds to noise complaints from the public.

INTRODUCTION

NHDOT has recently initiated a Type II noise barrier program to address growing concerns from the public with highway noise and the growing trend of new noise-sensitive uses being developed near the state's highways. Type II noise barriers are those constructed on existing highways when it is not part of a highway construction project that substantially alters the existing roadway geometry and/or increases capacity. The Type II Noise Barrier Program applies to residences and is documented in NHDOT's "Policy and Procedural Guidelines for the Assessment and Abatement of Highway Traffic Noise for Type I & II Highway Projects" (November 2016) which is the DOT's noise policy for implementing Federal Highway Administration's (FHWA) regulation "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (23 CFR 772).

In considering the Type II noise barrier program, the DOT administrators were interested in getting a preliminary cost estimate of noise barriers that may be considered feasible and reasonable according to the NHDOT noise policy and the length, height and location of the barriers. Understanding the approximate barrier costs will help in identifying local, state and federal funding for Type II noise barriers. Additionally, understanding where Type II noise barriers may be feasible and reasonable will help the DOT coordinate with specific municipalities that need to enact planning and development regulations which require avoidance, minimization or mitigation of exterior noise impact for new noise-sensitive developments.

This statewide noise barrier study included the development of a screening procedure to estimate highway noise emissions from all Tier 1 highways across the state and evaluate distances to exceeding the NHDOT NAC. This study also included an investigation of fundamental noise barrier design principles using the FHWA's Traffic Noise Model (TNM). Noise barrier

principles that were analyzed included determining how far back from a barrier can benefits be found, how the horizontal shielding angle of a noise barrier relates to insertion loss, and how building rows, barriers and terrain affect insertion loss. The study also provided easy access to the wealth of information on all 30,000 receptors and 300 noise barrier study areas that the DOT can use when responding to noise complaints from the public.

This paper includes a summary of the NHDOT criteria for Type II noise barriers to be considered feasible and reasonable, the method to identify and locate the large database of noise receptors adjacent to highways throughout the state, results of the analysis to determine the distances to highway noise levels approaching the NAC and the sensitivity of these distances to the range of traffic volumes, speeds, truck percentages and highway geometry, and the relationships of barrier shielding angle to insertion loss. The overall results of the statewide noise barrier feasibility and reasonableness evaluation are provided in regard to the total number of barriers, lengths and costs that were found to likely be feasible and reasonable. A detailed TNM analysis would be conducted for any potential Type II barrier being considered.

TYPE II BARRIER ELIGIBILITY CRITERIA

The NHDOT noise policy includes criteria to determine whether a noise barrier is eligible for the Type II program. The barrier shall be along an existing Tier I highway. This study evaluated approximately 300 miles of highways including the FE Everett Turnpike, Spaulding Turnpike, Blue Star Turnpike (I-95), Interstate 93, Route 101, Interstate 89, and Interstate 393. Type II noise barriers shall not be along a section of highway for which a Type I eligible project is programmed in the 10-year Transportation Improvement Plan. This study included Type I barriers in the evaluation for planning purposes. Prior Type I studies were reviewed to identify noise barriers that were previously determined not to be feasible and reasonable as these areas are not eligible for Type II barriers under the DOT policy.

The cost-effectiveness criteria is modified based on how recent residences were developed in relation to the existence of the highway. If a greater percentage of residences pre-date the highway, it is more reasonable to provide noise abatement. The criteria require that at least one benefiting receptor must have been permitted for development prior to the original opening date of the highway or prior to November 28, 1995 as required by FHWA regulation. The NHDOT uses a dimensional effectiveness index (DEI) criterion to evaluate the cost effectiveness of potential noise barriers. If the actual DEI of the potential barrier is below the DEI criterion (base criterion of 1500 square feet per receptor), then the barrier is considered to be cost effective. The base DEI criterion is adjusted negatively based on the percentage of receptors that have been developed in a study area after November 28, 1995 and adjusted positively based on the percentage of receptors that existed in a study area prior to the opening date of the highway according to Table 1.

Percentage	Adjustment for % of Receptors That Were Permitted or Constructed Prior to Opening Date of Highway	Adjustment for % of Receptors That Were Permitted After November 28, 1995
1 to 25%	+100	-100
25 to 50%	+200	-200
50 to 75%	+300	-300
75 to 100%	+400	-400

 TABLE 1 Dimensional Effectiveness Index Adjustments Based on Land Use

Source: NHDOT, 2016.

METHODOLOGY

The following section describes the methodology used to identify residential receptors within 1500 feet of the highway median, compute highway noise levels at all receptors, compute the insertion loss of 10, 15, 20, or 25-foot noise barriers and evaluate the DEI to determine eligibility of barriers in accordance with the NHDOT Type II Noise Barrier Program.

Identifying Receptors

Statewide parcel land use data have been used to identify receptors according to residential state land use codes. For land use codes indicating 2 to 4 dwelling units, the higher number of dwelling units was assumed to provide a slightly conservative estimate of the DEI. Land use information was reviewed along with aerial photography to further identify residential land uses. In some areas with multi-family buildings and condominiums, it was necessary to estimate the number of dwelling units based on reviewing Google Streetview[™] images of buildings and/or parking lots (assuming that each dwelling unit would have 2 to 3 parking spaces). Receptors were located in the geometric center of the parcels. These locations were generally representative of outdoor areas with frequent human use.

U.S. Census data for housing units within "census tracts" were analyzed between 1950 and 2015. The percentage of housing units built after 1995 was calculated for each census tract. Similarly, the percentage of housing units built prior to the highway opening date (typically late-1950's to mid-1960's) were calculated. The results were applied to each barrier study area. On average, 25% of the housing units were built after 1995 and 35% were built prior to the highway opening. Therefore, the average DEI criteria among all barrier areas evaluated was 1575. Figure 1 shows a typical aerial location (left) and the identification of residential land use and receptors (right). Each colored block indicates a tax parcel and its respective land use code, while each dot is the receptor location used for sound level analysis.



FIGURE 1 Parcel data, land use and receptors

Highway Noise Calculations

Highway noise levels were calculated using TNM version 2.5 using a straight and flat highway geometry accounting for the number of travel lanes and traffic data for each segment of highway. The most recent 3 to 5 years of traffic data available from the NHDOT Bureau of Traffic were used in the analysis. These data included average annual daily traffic volumes (AADT), peakhour factors (K-factor), posted and measured speeds and percentages of medium and heavy trucks. For highway segments where one or more of these traffic variables were not available, the nearest segment with the required data was assigned. Highway noise levels at distances every 10 feet up to 1500 feet of the median were computed for all 137 exit-to-exit highway segments. Additionally, a sensitivity analysis of how the different traffic conditions relate to different highway noise levels was conducted. The following summarizes the range of traffic data and highway noise levels throughout the state:

- Highways ranged from one to five lanes per direction and were typically composed of 12foot travel lanes with approximately a 45-foot median and 5 to 10-foot shoulders.
- AADT ranged from 3,100 to 120,828 vehicles per day across all Tier 1 highway segments. This large variation in AADT corresponds to a 16 dBA difference between the minimum and maximum highway noise levels.
- K-Factors across all the roadways varied from 8.5 percent to 15.9 percent. Multiplying the AADT by the K-Factor results in the Peak Hour Volume (PHV). The minimum PHV of 491 vehicles per hour (vph) occurs on
 I-93 between Exits 37 and 38 and the maximum of 12,445 vph is on the Everett Turnpike between Exit 5 and 6.

- Medium Truck percentages ranged from 2 to 6 percent of total volumes and Heavy Truck percentages ranged from 2 to 10 percent. The range of Medium Truck percentages correspond to only a 0.3-dBA variation in noise levels. The range of Heavy Truck percentages correspond to a 2-dBA variation in noise levels.
- Average speeds ranged from 59 to 73 mph which correspond to a 4-dBA variation in noise level.

Highway noise levels were calculated at every receptor (approximately 30,000) within 1500 feet of the highway median. The distance to impact from the highway median (where noise levels approach or exceed the NHDOT NAC for FHWA Activity Category B (residential) land use) was determined for each exit-to-exit highway segment. Figure 2 presents the distance to impact for all highway segments for both flat ground and for when the highway is in a 10-foot cut. This figure shows that the distance to impact is typically 300 to 400 feet from the median for flat ground and 150 to 250 feet when the highway is in a 10-foot cut.



FIGURE 2 Distance to noise impact for all exit-to-exit highway segments

It should be noted that building rows were not included in the highway noise calculations. While this overestimates highway noise levels for receptors with intervening building rows, it does not substantially affect the DEI calculations or the determination of Type II eligibility. This is because the criteria for eligibility only requires one or more receptors to exceed the NAC (which

typically occurs at first row receptors with no intervening buildings) and the barrier must benefit a sufficient number of receptors. As discussed in the next section, the presence of building rows has been found to not substantially affect barrier insertion loss.

Detailed TNM models were developed in two locations; the Pannaway Manor Neighborhood south of the Spaulding Turnpike adjacent to I-95 in Portsmouth, NH and the Keating Avenue neighborhood in Dover along the Spaulding Turnpike. The detailed TNM models include terrain lines, building rows and the actual highway geometry along with site-specific traffic conditions. Additionally, results from previous detailed TNM studies conducted for I-93 Salem to Manchester and Spaulding Turnpike Newington to Dover have been included. Figure 3 compares the highway noise predictions of the detailed TNM models and the method described herein for receptors in relatively flat sections of study areas. This figure shows that noise level predictions for most receptors are within 3 dB for both computation methods.



FIGURE 3 Detailed TNM vs. simplified TNM noise levels

Insertion Loss Calculations

Type II noise barrier study areas were defined by reviewing all highway segments and grouping locations of relatively dense receptors. A total of approximately 300 noise barrier study areas were evaluated. The acoustical effectiveness or insertion loss of noise barriers was evaluated based on a grid analysis which included a matrix of receptors behind a noise barrier along a straight segment of highway. The grid analysis computed the insertion loss of receptors behind 5, 10, 15, 20 and 25-foot barriers at distances out to 1500 feet. This analysis showed that the

insertion loss provided by a certain height barrier can be predicted with high accuracy based solely on the angle of shielding that the barrier would provide. This relationship allows us to estimate the insertion loss of various height barriers based only on the geometry of the receptors and the barriers which can be calculated in the Geographic Information System (GIS) program. This screening-level modeling approach is critical to the practicality of using TNM across the entire state given the significant number of receptors and noise barrier study areas.

As shown in Figure 4, the insertion loss of a 1,200-foot long and 20-foot tall barrier depends on the proximity of the receptor to the barrier and where along the barrier the receptor is. This figure shows that 5 dB of insertion loss, which is the minimum needed to be considered a benefited receptor, extends out up to approximately 500 feet from the highway median in the center of the barrier.



FIGURE 4 Noise barrier insertion loss grid analysis

Figure 5 shows the same results as in Figure 4, although the insertion loss of the barrier is plotted against the angle of shielding which the barrier provides. This curve shows that there is a high correlation between the barrier shielding angle and insertion loss and, in fact, that this relationship is not dependent on the distance of the receptor to the barrier. This relationship was found to be the same for shorter and longer barriers from 300 to 3,600 feet. This figure also demonstrates how much farther past the last receptor a noise barrier should extend. A common rule-of-thumb is to maintain a 4 to 1 ratio where if a receptor is 100 feet from a barrier the barrier should extend 400 feet past it. This rule-of-thumb is equal to a shielding angle of 165 degrees

which does maintain a high level of insertion loss. This figure also shows that if a noise barrier is extended less than the rule-of-thumb, such as only a 1 to 1 ratio (135 degrees of shielding), the insertion loss may be reduced 5 dB or more, but the barrier can still benefit receptors.



FIGURE 5 Noise barrier insertion loss vs. shielding angle

Barrier Height Effects on Insertion Loss

The grid analysis was conducted for 1,200-foot long barriers with heights of 5 to 25 feet. Figure 6 shows the relationships of insertion loss to barrier angle for 5, 10, 15, 20 and 25-foot barriers assuming flat ground. This figure shows that there is relatively little difference in insertion loss as a function of barrier height among barriers of 15, 20 and 25 feet height and that in some cases extending the length of the barrier can provide greater increases in insertion loss than increasing the barrier height.

Building Row and Building Barrier Effects on Insertion Loss

The relationship of insertion loss versus shielding angle is not substantially affected by intervening building rows of 25 or 50 percent building. Figure 7 shows the change in insertion loss with a 20-foot building row or 20-foot barrier located within 100 feet of the highway. This figure shows the building rows reduce insertion loss only up to 1 dBA at certain shielding angles. The 20-foot barrier, on the other hand, has a more substantial effect on insertion loss.



FIGURE 6 Noise barrier insertion loss vs. shielding angle (barrier heights 5 to 25 feet)



FIGURE 7 Insertion loss vs. shielding angle, building rows and buildings as barriers

Terrain Effects on Insertion Loss

Another important factor that has been shown to substantially affect insertion loss is whether there is intervening terrain (i.e. if the highway is in a cut). When the highway is in a cut, as shown in Figure 8, the existing terrain can break the line-of-sight to certain noise sources which both reduce highway noise and reduce the effectiveness of the incremental increase in acoustic shielding provided by a noise barrier.



FIGURE 8 Existing terrain breaking the line-of-sight and reducing barrier effectiveness

Figure 9 shows the significant degradation of insertion loss when the highway is in a 5 to 20-foot cut. To provide a conservative estimate of potentially eligible barriers, this evaluation assumes that the terrain of each study area is relatively flat ground and the highway is not in a significant cut or on embankment. The distance to noise impact, as shown in Figure 2, and insertion loss, as shown in Figure 9, are reduced when the terrain already breaks the line of sight between the receptors and the pavement, so the acoustical effectiveness and noise barrier DEI is substantially reduced. Therefore, detailed TNM noise modeling to further evaluate the eligibility of Type II barriers should include these terrain effects. Without any terrain effects, the results of this study conservatively assume there is a greater potential for feasible and reasonable barriers.



FIGURE 9 Noise barrier insertion loss vs. shielding angle (highway in cut 5 to 25 feet)

Comparison of Screening-Level and Detailed Noise Barrier Evaluations

Figure 10 and Figure 11 compare the insertion loss calculated in the detailed TNM studies at Pannaway Manor, Keating Avenue and I-93 with the grid analysis calculations. This figure shows that the insertion loss results are typically within 3 dB for receptors in a flat terrain.

It should be noted that the extent of the study areas - how far away from the highway receptors are included – has a significant effect on the number of benefits a barrier can provide and consequentially on the DEI of the barrier. If receptors only out to 750 feet from the highway median are included, the total number of eligible barriers is reduced substantially. Limiting the distance that receptors are included in the analysis may provide a more realistic determination of barrier insertion loss and potential benefit because background ambient noise becomes a more important factor at farther distances from the highway. Some DOT's such as North Carolina DOT actually limit the distance of receptors to 800 feet for Tier 1 highways and do not allow additional receptors to be included for the purposes of determining benefit. All receptors that would be impacted must be included in traffic noise studies regardless of distance from the highway.



FIGURE 10 Insertion loss for detailed TNM study vs. grid analysis (15-foot barrier)



FIGURE 11 Insertion loss for detailed TNM study vs. grid analysis (25-foot barrier)

Feasibility and Reasonableness Evaluation

For all study areas, noise barriers have been evaluated for feasibility and reasonableness according to the following criteria:

- Highway noise levels during existing loudest-hour conditions meet or exceed the NAC (66 dBA Leq).
- The barrier must provide a minimum of 7 dB insertion loss for at least one benefited receptor
- The DEI of the barrier (square footage of barrier per benefitted receptor) shall be less than the criteria which is nominally 1500 plus adjustments based on the date of developments.
- Constructability and safety shall be considered.
- It is also a goal (not a requirement) that the barrier should provide 10 dBA or greater insertion loss at first row receptors.

Based on highway noise level predictions and the grid analysis insertion loss calculations, the DEI for 10, 15, 20 and 25-foot barriers were computed. Study areas were evaluated according to NHDOT Type II eligibility, feasibility and reasonableness criteria. For all eligible barriers, the tallest barrier that meets all criteria was assumed. For ineligible barriers, the barrier height resulting in the lowest DEI that can be achieved has been reported.

SUMMARY OF RESULTS

The simplified prediction method was used to evaluate over 300 miles of highway, 300 candidate noise barrier study areas and over 30,000 receptors. The statewide noise barrier study showed that a total of 49 barriers over 37 miles at an estimated cost of approximately \$125,000,000 are likely to be eligible for the Type II program.

This screening-level modeling approach is critical to the practicality of using TNM across the entire state given the significant number of receptors and noise barrier study areas. The results of the study including information about all 30,000 receptors and 300 noise barrier study areas were collected in Google EarthTM data files for easy access when the DOT responds to noise complaints from the public. The files allow the user to view all study areas and their associated results (i.e. town/city, highway, distance to noise impact, number of impacts, number of benefits, DEI and eligibility) and receptors and their associated results (i.e. number of dwelling units, noise level and insertion loss for barriers 10 to 25 feet tall). Figure 12 shows a typical noise barrier study area and receptor information that is available in the Google EarthTM files.



FIGURE 12 Google Earth[™] noise barrier and receptor information