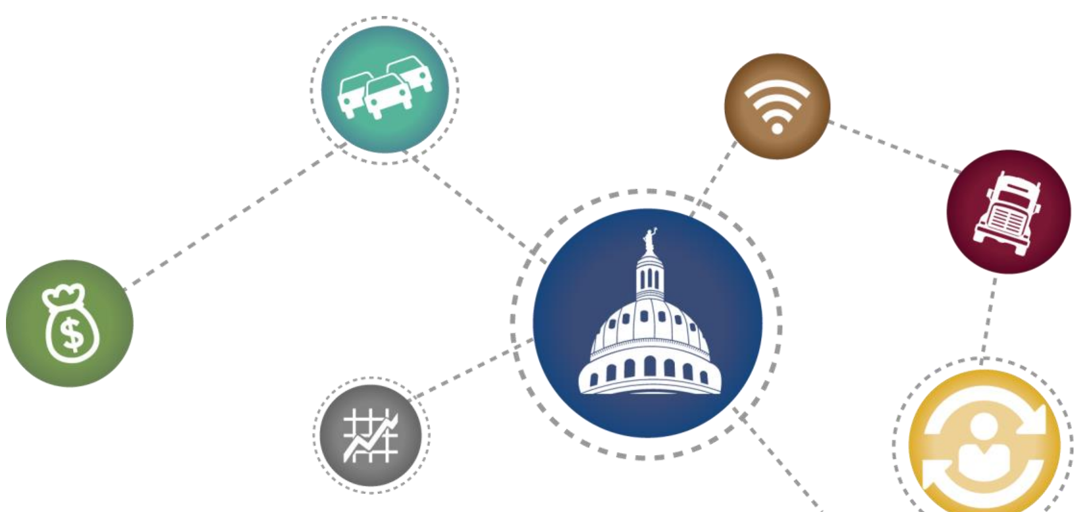
Texas A&M Transportation Institute

Implementation and Effectiveness of Sound Mitigation Measures on Texas Highways (HB 790)

Final Report

PRC 16-64 F



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Implementation and Effectiveness of Sound Mitigation Measures on Texas Highways (HB 790)

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October 2016

Authors

Jason A. Crawford, P.E.
Sushant Sharma, Ph.D.
Stephen Ranft
Beverly Storey, P.L.A.
Minh Le, P.E.
Yatin Rathod, P.E.
Alfredo Sanchez, P.E.
John Overman, AICP

Noise Mitigation One-Pager

TTI recently completed a study of roadway noise mitigation, as directed in 2015 by the 84th Texas Legislature. Researchers compared noise guidelines in Texas with those in five other states and interviewed officials representing several toll road authorities in Texas. They also measured sound levels behind noise barriers along three toll road sections in Harris County, Dallas County, and Williamson County to compare those measures with predicted levels after noise wall construction.

In Texas, noise walls are considered only for new or expanded roadways because the state has no provisions to retrofit existing walls. Two criteria must be satisfied before a noise wall can be built:

- Feasibility: A noise wall is considered feasible if it can reduce predicted noise by at least 5 decibels for at least half of the noise-sensitive properties adjacent to the proposed wall (or first-row property owners or tenants).
- Reasonableness: A noise wall is considered reasonable if three requirements can be met:
    - Economic: The estimated cost per benefitted property owner cannot exceed $25,000. If the estimated cost exceeds this threshold, then the agency is not required to install a noise wall. TxDOT is re-evaluating this threshold, which was established in 1992. It is based on an $18-per-square-foot cost and does not include costs for right-of-way or utility relocation. The actual cost of building a noise wall in Texas is higher than the estimated costs. The nationwide average material cost for all materials and wall types was $33.81 per square foot from 2011 to 2013. Federal requirements published in 2010 call for departments of transportation to routinely re-analyze noise abatement costs at least every five years. Most peer states tie cost-effectiveness criteria to the construction cost index.
    - Environmental: The predicted noise level must be reduced by at least 7 decibels for at least one first-row property owner.
    - Social: Federal regulations require that the decision to construct proposed noise abatement be made from the viewpoints of benefitted receptors—property owners and tenants. In Texas, anyone may participate in public meetings related to proposed noise walls, but only the votes of first-row property owners are counted toward formal approval with a simple majority. Some other states extend voting rights beyond first-row owners to tenants or second-row receivers.

To predict roadway noise levels, TxDOT and toll authorities use the Traffic Noise Model developed and required by the Federal Highway Administration. These predictions are included in each project's environmental assessment. Noise measurements are typically made in the environmental process prior to noise wall construction. Post-construction noise measurements typically are not taken.

Researchers measured noise levels at 16 locations behind noise walls along the three selected corridors. Measurements were taken at 15-minute intervals during morning, mid-afternoon, and evening periods. The results were as follows:

- Noise levels behind 8 of the 16 walls exceeded the predicted levels with a noise barrier in place for one or more of the three time periods.
- Of those eight locations, measured levels exceeded predicted levels at five walls at all three time periods.

A variety of factors could help to explain why many of the noise levels were higher than what was predicted:

- The noise wall did not block the line of sight between the roadway and the receptor.
- Traffic volumes are higher than those used for modeling.
- The share of trucks in overall traffic volume is higher than what was used for modeling.
- The pavement type (concrete) is noisier than the average pavement type used for modeling. (*Average* considers a combination of concrete and asphalt, which has a lower noise level than concrete alone).
- Land use developments or changes (building heights, etc.) contribute to higher ambient noise levels.

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Acknowledgements

The authors wish to extend thanks to the participating agencies contacted for this study for their cooperation and assistance with information requests and access to facilities. Many thanks are also given to the external and internal reviewers: Adam Alexander, Dr. Manuel Trevino, Cathy Reiley, Dr. Bill Stockton, and Brian Bochner. Thanks also to the many staff and students that collected field data and helped prepare information for this report: David Galicia, Diana Wallace, Richard Pham, Jeff Owings, Tiffany Hernandez, Christian Gonzalez, Alexandra Herrera, Leticia Uzodinma, Phillip Smith, Robert Huch, and Carol Court. Finally, thanks are given to Ginger Goodin and Steven Polunsky of the Policy Research Center, who guided questions to refine the report.

Executive Summary

The 84th Texas Legislature passed House Bill (HB) 790 directing the Texas A&M Transportation Institute (TTI) to perform a study on the implementation and effectiveness of sound mitigation measures on the state highway system and certain toll roads and turnpikes. The bill specified the following:

(1) an analysis of the process and methodology used by the Texas Department of Transportation or toll project entity for selecting and implementing sound mitigation measures, including factors that affect the process and how outcomes are determined;

(2) an analysis of whether any kind of live testing is conducted at any point to determine the actual traffic noise level for neighboring properties;

(3) an evaluation of the effectiveness of the process and methodology described by Subdivision (1) of this subsection in reducing the traffic noise level for neighboring properties; and

(4) an evaluation of the effectiveness of implemented sound mitigation measures in reducing the traffic noise level for neighboring properties.

TTI researchers pursued answers to these requirements through three major approaches. First, researchers conducted a thorough literature review on federal and Texas noise guidelines, comparing them against five peer state departments of transportation in California, Illinois, Florida, New York, and Washington. The literature review also included a state-of-the-practice review of noise mitigation techniques and a review of selected environmental assessment documents from 2010 to present that evaluated the estimated costs of noise walls. Second, researchers conducted interviews with Texas toll authorities that were included in the scope of HB 790. The interviews addressed a wide range of topics, from planning to design of noise mitigation measures. Finally, the researchers performed field sound level measurements within three projects to compare measured sound levels against predicted sound levels.

Acoustics is a technical field. At its foundation is understanding how sound is generated by frequency and pressure, transmitted through mediums such as air, and perceived by the human ear. Noise is simply unwanted sound. Sound is measured in decibels (dB). Adjustments are made to sound measurements to account for high and low frequencies to approximate how an average person hears sounds. This adjustment is called A-weighting, expressed as dB(A).

The following sections summarize the results of the HB 790 requirements. Detailed discussion is provided in the body and appendices of this report.

Sound Mitigation Process, Methodology, and Implementation

(1) *An analysis of the process and methodology used by the Texas Department of Transportation or toll project entity for selecting and implementing sound mitigation measures, including factors that affect the process and how outcomes are determined.*

The federal noise guidelines are straightforward in terms of criteria and process. States produce their own guidelines that echo the process and requirements of the federal guidelines. Toll authorities typically follow the same process as their state department of transportation's (DOT's) noise guidelines. The Texas Department of Transportation (TxDOT) follows federal guidelines and relies on the prescribed Federal Highway Administration (FHWA) Traffic Noise Model® (TNM) to predict noise levels in future years. Interviews conducted with toll authority agencies indicate they generally follow TxDOT's established guidelines for the analysis and implementation of noise mitigation measures on Texas highways.

Noise along highways is predicted using the acoustics modeling software developed by FHWA known as TNM Version 2.5. The TNM is a three-dimensional model that predicts sound levels from roadway traffic to surrounding properties. Noise mitigation measures are evaluated within the noise model to determine if any reduction in noise may be obtained.

Federal and Texas guidelines require the use of the TNM when a noise analysis is performed. When noise analyses are performed, the results are included in the project's environmental assessment documentation. If project changes occur (e.g., horizontal and vertical alignments) after the environmental documentation has been approved, a reevaluation of the environmental assessment is required using the most recent TNM version.

Noise analysis is performed for new-location or expanded-capacity roadway projects (Type I) or for retrofits (Type II). Because Texas does not participate in the statewide Type II program to retrofit noise walls, only new or expanded-capacity roadway projects are eligible for noise mitigation.

In Texas, federal aid for noise mitigation is only available for new-location or added-capacity projects. In addition, noise mitigation actions such as noise walls must meet two criteria—feasibility and reasonableness. In Texas, the feasibility criterion is achieved if there is a predicted noise reduction of at least 5 dB(A) at greater than 50 percent of the first-row impacted receptors (abutting specific or representative noise-sensitive properties defined in FHWA's noise abatement criteria [NAC]).

The reasonableness criteria must meet a combination of social, economic, and environmental factors. All three reasonableness factors must be met. The three reasonableness factors are as follows:

- First, the estimated noise mitigation cost per benefited receptor must be at or under a defined cost threshold. These thresholds are set by states and vary. In Texas, the cost-effectiveness threshold is $25,000 per benefited receptor, as established in the 1990s. The noise wall costs are estimated at $18.00 per square foot, also established in the 1990s. As confirmed by several agencies, the actual cost to construct noise walls exceeds the estimated costs used in the environmental process. Costs are determined for the noise wall placement only and typically do not include right-of-way, utility relocation, etc. TxDOT is currently evaluating the state's noise barrier costs used in the environmental analysis process.

- The second reasonableness factor is based on predicted future noise levels with and without noise abatement. States may set these noise abatement design goals, and in Texas, the noise design goal is that at least one first-row receptor must achieve a reduction of at least 7 dB(A).
- The third and final reasonableness factor is that the preferences of those individuals affected by the placement of the noise abatement measure (the benefited receptors) are included. States address individual benefited receptor preferences through noise workshops and balloting. In Texas, ballots cast by property owners are the only ones that count toward determining if an abatement measure is built. Texas acknowledges the viewpoints of non-owning residents, but their ballots do not count toward an approval vote. Texas requires a majority vote (50 percent + 1) to favor the noise abatement measure for it to be advanced.

Federal regulations require consideration of viewpoints of both tenants and property owners. Other states include viewpoints of tenants in the balloting process. For instance, Florida, Illinois, and Washington consider both owner and resident opinions in balloting. Also in those states, second-row receivers are considered and given different balloting weights. Like TxDOT, toll agencies welcome the public to participate in noise workshops. Also, like TxDOT, toll agencies only count ballots from affected first-row property owners in the process to determine noise wall implementation.

Direct Field Sound Measurement Studies on Highways

(2) An analysis of whether any kind of live testing is conducted at any point to determine the actual traffic noise level for neighboring properties.

Direct field measurements are conducted **before** a noise assessment for new-location roadways and as inputs into the TNM. These measurements are referred to as ambient noise measurements. Generally, there are no routine direct field measurements made **after** the highway, or noise abatement, has been constructed.

Sound Mitigation Process and Method Efficacy

(3) An evaluation of the effectiveness of the process and methodology described by Subdivision (1) of this subsection in reducing the traffic noise level for neighboring properties.

Noise modeling and noise mitigation methods and processes are inherently complicated. The process and methods used by TxDOT follow similar feasibility criteria as Florida, Illinois, California, Washington, and New York (1 dB[A] lower than the value set by the federal NAC) for each activity. Washington and Illinois have tier-based, cost-effectiveness criteria to address higher noise levels, or larger sound level increases, whereas California, Florida, New York, and Texas have a fixed value.

Based on the results of the literature search, interviews, and field measurement tasks, several observations have emerged. The results of the literature search point to the following observations:

- The federal regulations published in July 2010 state that "the highway agency shall reanalyze the allowable cost for abatement (cost-effectiveness criteria) on a regular interval, not to exceed 5 years." This statement was not in earlier federal regulations, and it only mandates a recurring analysis but does not require the criteria to be changed. TxDOT has used the same $25,000 cost-effectiveness criterion since 1992. The cost effectiveness was last analyzed in 1999. Researchers were unable to determine when this initial value was set.
- The definition of the first-row receiver varies throughout the peer states. In Texas, first-row receivers are owners and residents who are adjacent to proposed noise barriers, whereas in California and Washington, the definition depends on topography and highway geometrics.
- In Texas, only the opinions of the benefited property owners adjacent to a proposed abatement measure are considered for the reasonableness criteria, whereas Florida, Illinois, and Washington consider both owner and resident opinions. Also in those states, second-row receivers are considered and given different weights.
- Most of the peer states have a cost-effectiveness criterion tied to the construction cost index. Texas does not tie the cost-effectiveness criterion to any index.
- The land use activity area definitions used by all peer state highway agencies are consistent with each other; they are also consistent with those listed in the current federal regulations.
- Federal guidelines state the development and implementation of Type II projects are not mandatory requirements. Currently, TxDOT, the Florida Department of Transportation (FDOT), and the Illinois Department of Transportation (IDOT) do not participate in a Type II (retrofit) program.

The results of the interviews point to the following observations:

- The toll authority agencies generally follow TxDOT established guidelines for the analysis and implementation of noise mitigation measures on Texas highways.

- FHWA's TNM Version 2.5, the most current version available, is used for traffic noise modeling and analysis by the agencies.
- Most of the agencies use an average pavement type for noise analysis as specified by FHWA. FHWA averages the sound levels associated with both Portland cement concrete and dense-graded asphaltic concrete. Noise levels do vary between changes in pavement types and tire size interaction.
- Costs for noise wall mitigation are determined using the TxDOT guidelines of $25,000 per benefited receiver and $18 per square foot of noise wall. Costs are determined for the noise wall placement only and typically do not include right-of-way, utility relocation, etc. The actual cost to build a noise wall generally exceeds the $18 per square foot estimated cost.
- The public is welcome to participate in noise workshops; however, consistent with TxDOT guidelines, only the affected first-row property owners cast votes in the process to determine noise wall implementation.
- Only one of the queried agencies has conducted noise measurement analysis after construction of a noise wall measure.
- Social media, such as email, Twitter™, Facebook™, and websites, is becoming an additional useful tool for the dissemination of upcoming workshop and public meeting announcements.

Effectiveness of Sound Mitigation Measures

(4) An evaluation of the effectiveness of implemented sound mitigation measures in reducing the traffic noise level for neighboring properties.

In the absence of direct post-construction field measurement data to evaluate sound mitigation effectiveness, the research team selected three study corridors in Texas to measure current sound levels after the highway and noise abatement structures had been constructed. The three study corridors selected were:

- SH 99 (Grand Parkway) Segment G, between I-45 and I-69, Harris County.
- US 183A, between SH 45 and the San Gabriel River, Williamson County.
- President George Bush Turnpike Eastern Extension (PGBT-EE), between SH 78 and I-30, Dallas County.

Sound level measurements were taken at eight locations along each study corridor at the approximate locations described in each project's environmental assessment document and the TNM results. Fifteen-minute measurements were recorded at each of the eight locations per corridor in the morning, mid-afternoon, and evening. The sound level measurements were taken behind existing noise walls where they were present.

Overall, the sound measurement results at 16 receiver locations behind noise walls across the three study corridors show that the sound levels behind eight of these walls exceeded the TNM predicted sound level with a noise barrier in place for one or more of the time periods observed. Of these eight locations, measured sound levels exceeded the TNM modeled sound levels with a noise barrier at five walls during all three time periods observed. In contrast, sound levels were measured below the design year predicted sound level at eight of these locations.

The differences between TNM modeled sound levels and direct field measurements at completed highway facilities may be a result of many different TNM model variable assumptions and changes to the built environment associated with the highway corridor. Although it is impossible to determine at this time which variable or which changes in the built environment affected these observed outcomes, there are some familiar factors that can influence sound level measurements, including but not limited to:

- The noise wall did not break the line of sight.
- Total current volume of traffic is higher than traffic TNM volume inputs.
- Percent truck traffic is higher than truck traffic TNM inputs.
- Actual pavements used in the corridor have resulted in higher noise levels (e.g., Portland cement concrete) than the average pavement type used in the TNM.
- Land use changes or developments in the surrounding area have contributed to increased ambient background noise levels.
- Differences exist between the measured locations and modeled locations since exact coordinates were not available or right of entry was not granted.
- Unknowable and unpredictable changes exist in the built environment beyond and adjacent to noise walls placed along right-of-way lines.

TTI researchers found that material used in barrier construction that has a transmission loss of at least 25 dB(A) or greater is desired and would always be adequate for a noise barrier. The research team developed the following conclusions based on the evidence found through the literature review process:

- The criteria for selection of noise barrier material in order of decreasing importance are the following: durability, acoustical properties, material and installation costs, maintenance, aesthetics, public opinion, and graffiti resistance.
- Precast concrete, earthen berm, and block barriers are commonly used noise wall materials that have proven cost effectiveness. Mostly concrete and metal (steel and

aluminum) barriers can provide transmission loss of 25 dB(A) or greater, as desired, from adequate noise barriers.

- Wooden barriers most frequently have problems related to warping, rotting, weathering, and ultraviolet (UV) degradation, whereas concrete barriers can have UV degradation, cracking, and spalling.
- The average unit cost across the nation combining all materials and barrier types from 2011–2013 was $33.81 per square foot, whereas between 2004 and 2013, it was $35.46 per square foot.[1]
- Additional research is needed to investigate the performance and life-cycle costs of asphalt pavement to mitigate highway noise.

[1] According to an FHWA source, there may be non-uniformity in the data due to differences in individual state DOT definitions of barrier components and the respective component costs that the DOTs include in the report as the overall noise barrier cost.

Section 1. Introduction

The 84th Texas Legislature passed HB 790 directing TTI to study the implementation and effectiveness of sound mitigation measures on the state highway system and certain toll roads and turnpikes (see Appendix B). TTI researchers conducted an analysis of how sound mitigation measures are selected and implemented. As part of this effort, TTI investigated whether agencies conducted live testing to determine noise levels for neighboring properties. Finally, TTI researchers evaluated the effectiveness of sound mitigation measures at reducing traffic noise levels.

This section introduces concepts of sound and noise. It then introduces noise barriers, their types, and their functionality.

What Is Sound and Noise? How Is it Measured?

Sound is the result of vibrations at a source that vibrate the medium (e.g., air) around it, producing longitudinal waves that are received and perceived by the human ear. Merriam-Webster defines noise as a loud or unpleasant sound.

Sound generated from roadway traffic comes from a vehicle's tires on the pavement, the vehicle's engine, and the vehicle's exhaust. According to the FHWA *Noise Barrier Design Handbook* (*1*), the most pervasive sources of noise in our environment today are associated with traffic. Each of these sources of roadway noise produces sound energy that, in turn, translates into tiny fluctuations in atmospheric pressure as the sources move and vibrate. These fluctuations are commonly expressed as sound pressure and measured in units of micronewtons per square meter ($\mu N/m^2$) or microPascals (μPa). Sound pressure is more commonly expressed on the decibel scale, a logarithmic scale relating the magnitude of physical quantity relative to a specific reference level. On this scale, a value of 0 dB is equal to a sound pressure level (SPL) of 20 μPa and corresponds to the threshold of hearing for most humans. A value of 140 dB is equal to an SPL of 200 million μPa, which is the threshold of pain for most humans. Figure 1 shows a scale relating various sounds encountered in daily life and their decibel values.

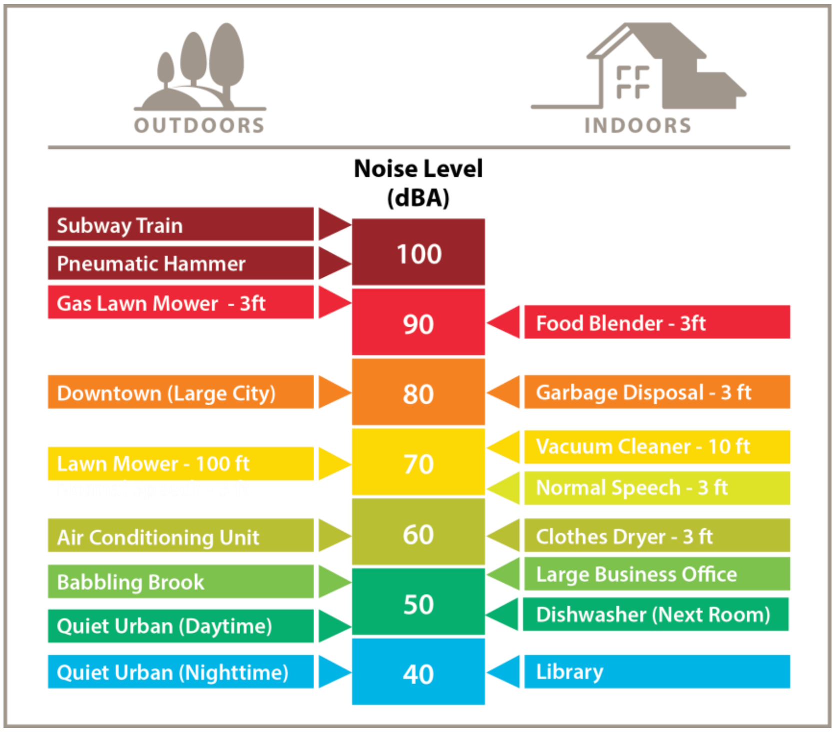

Figure 1. Comparison of Sound Level with Typical Surroundings.

The human ear can typically hear in a range from 20 Hz to 20,000 Hz. At the same time, the human ear is not equally sensitive to all frequencies. Adjustments are made to sound measurements to account for frequencies between 1,000 Hz and 6,300 Hz to approximate how an average person hears sounds. This adjustment is called A-weighting. It is expressed as dB(A).

Roadway traffic varies in the volume of traffic, mix of vehicles, and speed of vehicles. Because of these constant changes, sound levels from a roadway are never constant. A single value is used to represent the average or equivalent sound level. This value is expressed as Leq.

How Do Noise Barriers Work?

As shown in Figure 2, noise walls reduce the sound that enters a community from a busy highway by absorbing it, transmitting it, reflecting it back across the highway, or forcing it to take a longer path. This longer path is referred to as the diffracted path.

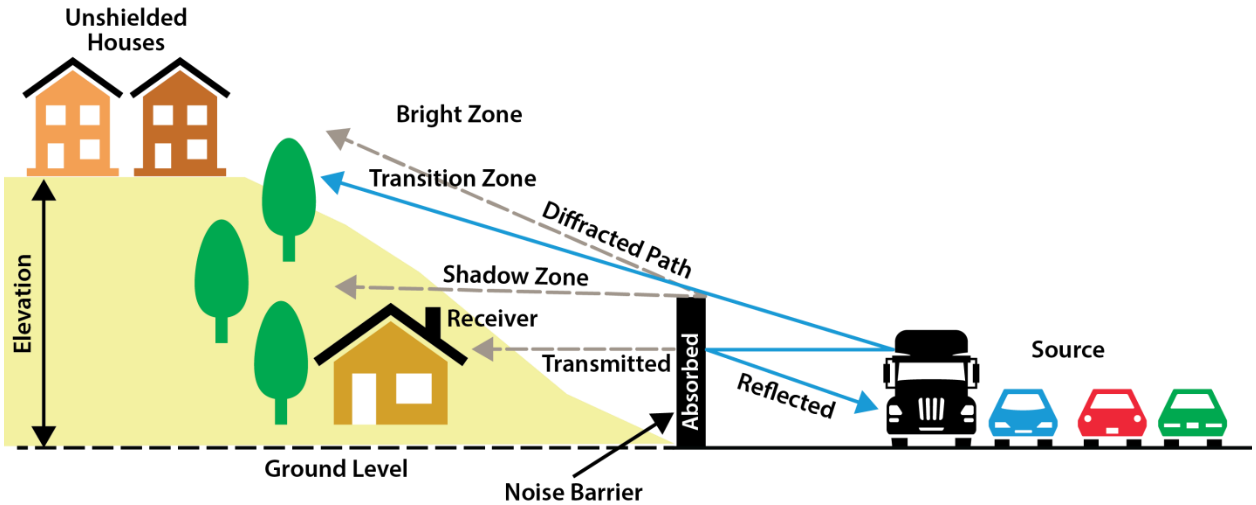

Figure 2. Noise Barrier Absorption, Transmission, Reflection, and Diffraction.

Absorption is the sound energy absorbed by the noise barrier or sound wall, whereas transmission is sound energy that passes through the noise barrier. Any transmitted sound through a noise barrier can be dismissed because it will be at such a low level relative to the diffracted sound. According to an FHWA report (*2*), typically, any material weighing 4 lb/sq ft or more has a transmission loss of at least 20 dB(A); this weight (4 lb/sq ft) can be attained by a lighter and thicker material or a heavier and thinner material. The sound energy that bounces off the surface of the wall is referred to as reflection. Diffraction is the process by which sound waves are spread out as a result of passing through a narrow orifice or across an edge, typically accompanied by interference between the wave forms produced (*2*). An illustration of sound wave diffraction that leads to the creation of a shadow zone and bright zone is in Figure 2.

What Is a Shadow Zone?

Noise barriers create a shadow zone. The vertical nature of a noise barrier causes an area of decreased sound energy on the non-highway side due to diffraction, reflection, and transmission loss. Receivers that are located within the shadow zone (see Figure 2) will benefit the most from the noise barrier. Although the noise barrier protects the shielded house, it also leaves the unshielded house unprotected (*2*).

What Are the Types of Noise Barriers and Their Characteristics?

Noise barriers are the most commonly used form of noise abatement on federal or federal-aid projects to meet requirements of 23 Code of Federal Regulations (CFR) Part 772. Typically, noise barriers come in the form of:

- Earthen mounds along the road, called earth berms.
- High, vertical barriers, called noise walls or sound walls.
- A combination of earth berms and noise walls or sound walls.

A more thorough review of noise barriers and other applications is provided in Appendix C.

Earth Berms

Traditionally, this type of noise barrier is made of earth mounds, or berms, parallel to the road (see Figure 3). Earth berms have a very natural appearance, but due to their large footprint, very tall berms require large amounts of land. Additional landscaping may be placed on these berms to improve their aesthetic appearance.

Source: (*3*).

Figure 3. Typical Usage of Berm for Traffic Noise Abatement.

Noise or Sound Walls

Noise walls are typically vertical masonry or concrete walls (see Figure 4) that require less space but may have height restrictions because of cost considerations, structural requirements, and aesthetic considerations. Noise walls can be comprised of wood, stucco, concrete, masonry, metal, and other materials. Some states also include aesthetic requirements for color and texture applications on noise barriers to improve their appearance.

For a noise wall to work, it must be high enough and long enough to block the view of the adjacent road. Noise walls do very little good for homes on a hillside overlooking a road and the wall or for multistory buildings that rise above the barrier. A noise barrier can achieve a 5 dB(A) noise level reduction when it is tall enough to break the line of sight from the highway to the receiver. A noise wall can achieve an approximate 1 dB(A) additional noise level reduction for each 2 ft of height after it breaks the line of sight (with a maximum theoretical total reduction of 20 dB[A]) (*4*).

To avoid undesirable end effects, a good general rule is that the barrier should extend four times as far in each direction as the distance from the receiver to the barrier. Openings in noise barriers for driveway connections or intersecting streets reduce the effectiveness of barriers. In some areas, homes are scattered too far apart to permit construction of noise barriers at a reasonable cost. Noise barriers are most effective in reducing highway traffic noise for receivers within approximately 200 ft of a highway but may also provide some benefit beyond this distance (*4*).

Source: (*5*).

Figure 4. Typical Sound Wall for Traffic Noise Abatement.

Generally, How Effective Are Noise Barriers, and What Factors Influence Their Effectiveness?

Noise barriers are solid obstructions built between a highway and, typically, residential areas along the highway to reduce overall noise levels from the roadway. Effective noise barriers usually reduce noise levels by 5 to 10 dB(A), cutting the loudness of traffic noise by as much as one-half on the logarithmic scale. A barrier that achieves a 10-dB(A) reduction can lessen the sound level of a typical tractor-trailer pass-by to that of a car pass-by without a barrier. Further, whereas reduction in sound level up to 10 dB(A) (90 percent reduction in acoustic energy) is attainable through noise barriers, any more reduction is very difficult (15-dB[A] reduction) to nearly impossible (20-dB[A] reduction) (*2*). Further, the noise-reducing effect of a noise barrier depends on the following factors (*3*):

- The effective height of the barrier.
- The distance between the noise source and barrier.
- The distance between the barrier and receiver.
- The length of the barrier.
- The thickness of the barrier.
- The materials used for the barrier.
- Gaps present at the bottom of the barrier, between panels, and between panels and posts.

What Are Quiet Pavements? How Effective Are They?

Quiet pavements are a descriptive term associated with those pavements that reduce noise generated by vehicle tires rolling over the pavement. Though 23 CFR 772 does not allow quiet pavements to be officially claimed as a noise abatement measure, quiet pavements are often implemented to reduce noise. Research on quiet pavements has shown mixed results, from small noise decreases (e.g., 2 dB[A]) to large noise decreases (e.g., >10 dB[A]) (*6*). The benefits gained from quiet pavement are often degraded over time as the pavement wears.

Section 2. Literature Review

This section of the report documents the literature review findings of highway sound mitigation laws, regulations, guidelines, analysis processes and methods, and measures. The literature review included federal rules, guidelines, and models. Current laws, regulations, and guidelines from peer states (California, Florida, Washington, Illinois, and New York) were reviewed. The peer states were selected based on qualitative factors: geographic size (as compared to Texas), location within the United States, state-of-the-art practice in noise abatement measures, and sensitivity to environmental issues. The research team contacted and requested sound mitigation and sound wall state regulations and policies from these peer states' agencies and toll authorities. The literature review compares peer state definitions of feasible and reasonable for noise abatement analysis and documents TxDOT's definitions and analysis process.

Federal Authority, Regulations, and Guidelines

The FHWA noise standard in 23 CFR Part 772 provides procedures for noise studies and noise abatement measures. These procedures protect the public's health, welfare, and livability by supplying noise abatement criteria and establishing requirements for information to be given to local officials for use in the planning and design of highways approved pursuant to the Title 23 United States Codes (USC) (*7*). The highway traffic noise prediction requirements, noise analyses, noise abatement criteria, and requirements for informing local officials in this regulation constitute the noise standards mandated by 23 USC 109(i). Highway projects developed in conformance with these regulations are deemed to be in accordance with FHWA noise standards (*7*).

According to FHWA noise standards, the **feasibility** of a noise abatement measure is defined as:

(i) achievement of at least a 5 dB(A) highway traffic noise reduction at impacted receptors and

(ii) determination that it is possible to design and construct the noise abatement measure (*7*).

Further, the following factors define **reasonable**:

(i) consideration of the viewpoints of the property owners and residents of the benefited receptors,

(ii) cost-effectiveness of the noise abatement measures, and

(iii) noise reduction design goals for noise abatement measures. These three factors must collectively be achieved in order for a noise abatement measure to be deemed reasonable.

According to federal guidelines, for cost effectiveness, each highway agency shall determine and receive FHWA approval for the allowable cost of abatement by determining a baseline cost reasonableness value. This determination may include the actual construction cost of noise abatement, cost per square foot of abatement, maximum square footage of abatement/benefited receptor, and either cost/benefited receptor or cost/benefited receptor/dB(A) reduction.

The recent federal guidelines explicitly state that the highway agency shall reanalyze the allowable cost for abatement on a regular interval, not to exceed five years (*8*). A highway agency has the option of justifying, with FHWA approval, different cost allowances for a particular geographic area within the state; however, the highway agency must use the same cost reasonableness/construction cost ratio statewide.

Further, for noise reduction design goals, the highway agency should define and receive FHWA approval for the design goal of at least 7 dB(A) but not more than 10 dB(A), and shall define the number of benefited receptors that must achieve this design goal and explain the basis for this determination.

Project Types and Federal Participation

This section lists project types and their definition in FHWA noise standards (*7*) and describes federal participation.

Type I Project

A Type I project is defined as (*7*):

- *a) The construction of a highway on new location.*
- *b) The physical alteration of an existing highway where there is either: (i) Substantial Horizontal Alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition; or (ii) Substantial Vertical Alteration. A project that removes shielding, exposing the line-of-sight between the receptor and the traffic noise source. This is done by either altering the vertical alignment of the highway or by altering the topography between the highway traffic noise source and the receptor.*
- *c) The addition of a through traffic lane(s). This includes the addition of a through traffic lane that functions as a high occupancy vehicle lane, high occupancy toll lane, bus lane, or truck climbing lane.*
- *d) The addition of an auxiliary lane, except for when the auxiliary lane is a turn lane.*
- *e) The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange.*
- *f) Restriping existing pavement for the purpose of adding a through traffic lane or an auxiliary lane.*
- *g) The addition of a new or substantial alteration of a weigh station, rest stop, rideshare lot, or toll plaza.*
- *h) If a project is determined to be a Type I project under this definition then the entire project area as defined in the environmental document is a Type I project.*

Federal funds may be used for noise abatement measures Type I and Type II (described later) projects when:

- Traffic noise impacts have been identified.
- Abatement measures have been determined to be feasible and reasonable.

Type I projects are *generally* projects to construct roadways at a new location, or projects for existing roadways that will substantially change their location or add a through lane.

Type II Project

A Type II project is defined as (*7*):

> *a federal or federal-aid highway project for noise abatement on an existing highway. For a Type II project to be eligible for federal-aid funding, the highway agency must develop a priority system, based on a variety of factors, to rank the projects in the program. This priority system shall be submitted to and approved by FHWA before the highway agency is allowed to use federal-aid funds for a project in the program. The highway agency shall re-analyze the priority system on a regular interval, not to exceed 5 years. However, the development and implementation of Type II projects are not mandatory requirements of section 109(i) of title 23, U.S.C.*

Type III Project

A Type III project is defined as (*7*):

> *a federal or federal-aid highway project that does not meet the classifications of a Type I or Type II project. Type III projects do not require a noise analysis.*

Federal Noise Abatement Criteria

Table 1 shows the current federal NAC according to 23 CFR Part 772. The activities and activity descriptions in this table were last updated in the 2010 federal guidelines.

Table 1. Federal Noise Abatement Criteria (after July 2010).

Activity Category	Activity Criteria (dB[A])[1,2] Leq(h)	L10(h)	Description of Land Use Activity Areas
A	57	60	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B[3]	67	70	Residential.
C[3]	67	70	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings.
D	52	55	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.
E[3]	72	75	Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A–D or F.
F	—		Agricultural, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.
G	—		Undeveloped lands that are not permitted.

[1] Either Leq(h) or L10(h) (but not both) may be used on a project.
[2] The Leq(h) and L10(h) activity criteria values are for impact determination only and are not design standards for noise abatement measures.
[3] Includes undeveloped lands permitted for this activity category.
Source: (*7*).

Each activity category of the NAC listed in Table 1 is defined as below.

- *Activity Category A.* This activity category includes the exterior impact criteria for lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential for the area to continue to serve its intended purpose. Highway agencies shall submit justifications to FHWA on a case-by-case basis for approval of an Activity Category A designation.

- *Activity Category B.* This activity category includes the exterior impact criteria for single-family and multifamily residences.

- *Activity Category C.* This activity category includes the exterior impact criteria for a variety of land use facilities. Each highway agency shall adopt a standard practice for analyzing these land use facilities that is consistent and uniformly applied statewide.

- *Activity Category D.* This activity category includes the interior impact criteria for certain land use facilities listed in Activity Category C that may have interior uses. A highway agency shall conduct an indoor analysis after a determination is made that exterior abatement measures will not be feasible and reasonable. An indoor analysis shall only be done after exhausting all outdoor analysis options. In situations where no exterior activities are to be affected by the traffic noise, or where the exterior activities are far from or physically shielded from the roadway in a manner that prevents an impact on exterior activities, the highway agency shall use Activity Category D as the basis of determining noise impacts. Each highway agency shall adopt a standard practice for analyzing these land use facilities that is consistent and uniformly applied statewide.
- *Activity Category E.* This activity category includes the exterior impact criteria for developed lands that are less sensitive to highway noise. Each highway agency shall adopt a standard practice for analyzing these land use facilities that is consistent and uniformly applied statewide.
- *Activity Category F.* This activity category includes developed lands that are not sensitive to highway traffic noise. There is no impact criterion for the land use facilities in this activity category, and no analysis of noise impacts is required.
- *Activity Category G.* This activity includes undeveloped lands. Typically, undeveloped land (Activity G) is not sensitive to highway traffic noise and does not have exterior areas of frequent human use.

State of Practice in Texas

The TxDOT manual *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*) has guidance on roadway traffic noise analysis and abatement for federal projects authorized under 23 USC. This guidance describes how TxDOT will implement the requirements of the FHWA noise standard in 23 CFR 772. TxDOT developed and reviewed the guidance in 2011, and the guidelines were concurred by FHWA. These guidelines apply to all federal, federal-aid, and state-funded Type I roadway projects authorized under Title 23 USC and apply to any roadway project or multimodal project that requires FHWA approval regardless of funding sources. TxDOT does not participate in a Type II program (i.e., a federal or federal-aid highway project for noise abatement on an existing highway [retrofit project]), and Type III projects do not require a noise analysis.

Definition of Feasible and Reasonable

Noise mitigation measures must be both feasible and reasonable to be proposed for construction and ultimately accepted by the adjacent community. This section presents details of how these criteria are defined.

Feasible

According to the TxDOT manual *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*), the term feasible is the determination of whether it is possible to build an abatement measure given site constraints and whether the abatement measure provides the minimum reduction in noise levels. Feasibility is limited by:

- Topography.
- Access requirements for driveways, ramps, etc.
- Presence of local cross streets.
- Other noise sources in the area (e.g., aircraft, rail, commercial, and industrial noise sources).
- Addressing the project purpose.
- Drainage.
- Utilities.
- Maintenance.
- Noise reduction.

A noise abatement measure is feasible when the measure achieves a noise reduction of at least 5 dB(A) at greater than 50 percent of first-row impacted receptors. Blocking the line of sight between the source and receptor usually provides a 5-dB(A) noise reduction (*9*). This is a feasibility criterion and not the noise reduction goal. TxDOT defines the noise reduction design goal as achieving a reduction in noise by at least 7 dB(A) for at least one first-row receptor.

Reasonable

The TxDOT manual *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*) considers the combination of social, economic, and environmental factors in the evaluation of a noise abatement measure. According to the manual, determination of reasonableness for abatement measures includes consideration of the following range of factors.

Cost Effectiveness

To determine cost effectiveness, the estimated cost of constructing a noise barrier is divided among the number of benefited receptors (those who would receive a reduction of at least 5 dB[A]). A cost of $25,000 or less per benefited receptor (using a construction cost of $18 per square foot) is considered cost effective under current TxDOT guidelines. The $25,000 figure includes only the cost of construction of a noise barrier and not the cost of any additional right-of-way or utility adjustments (*10*). According to the current TxDOT manual, this cost is based on a 1999 study sponsored by TxDOT (*11*). However, there is evidence that shows that this cost-effectiveness value was in use in the year 1992 (*12*, *13*), as shown in the excerpt in Figure 5.

```
"CFR Part 772 requires that five noise abatement measures be considered for
highway noise abatement. Each measure must be considered and discussed in
the environmental document. This discussion should include the feasibility
and cost-effectiveness of each measure. Feasibility is the ability to lower
the noise levels an average of 5 dB for first-row receivers. Reasonable
equates with cost-effectiveness and is defined as costing no more than
$25,000 for each first-row receiver benefitted. An abatement measure should
lower the noise level an average of 5 dB and cost $25,000 or less per
receiver along the right-of-way to be reasonable and feasible. In some
circumstances, this figure may be exceeded to provide mitigation for a
second-row or offset receiver to benefit from noise mitigation. In these
cases the additional receiver(s) may be counted in determining the cost per
receiver.

You may encounter situations where you need to lower noise levels by more
than 5 dB to reach the Noise Abatement Criterion. Since it is very difficult
to reduce noise levels more than 8 dB for $25,000 per receiver, you may
elect to calculate effectiveness by dividing the cost per receiver by the
insertion loss achieved. Mitigation is considered cost-effective if the cost
is less than or equal to $5,000 per dB reduction. (A wall costing $35,000
per receiver will reduce noise levels 8 dB--- $35,000/8 = $4375 per
decibel.) The $25,000 per receiver or $5,000 per dB per receiver figures
should be used in considering all forms of noise mitigation discussed below.
The figures should not include the costs of additional right-of-way, utility
adjustments, or access rights."
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Source: (*13*).

Figure 5. Excerpt from TxDOT 1992 Noise Guidelines.

For Category C and D land use facilities, to determine the equivalent number of residences to assess cost effectiveness, the land area of the Category C or D land use facility shall be divided by the representative receptor single-family residential lot size development within the study area.

The number of multifamily residences (NAC Category B) is determined by a count of every impacted unit. For NAC Category E receivers, the number of receptors is determined by the capacity limit of areas of frequent outdoor human use (e.g., swimming pool at hotel/motels, restaurant patio).

Noise Reduction Design Goal

When noise abatement measures are being considered, the desired noise reduction determined from calculating the difference between the future build traffic noise levels at a noise receptor with noise abatement compared to that noise receptor without noise abatement is called the noise design goal. TxDOT defines the noise reduction design goal as achieving a reduction in noise that is at least 7 dB(A). At least one first-row receptor must achieve the noise reduction design goal.

Views of Benefited Receptors

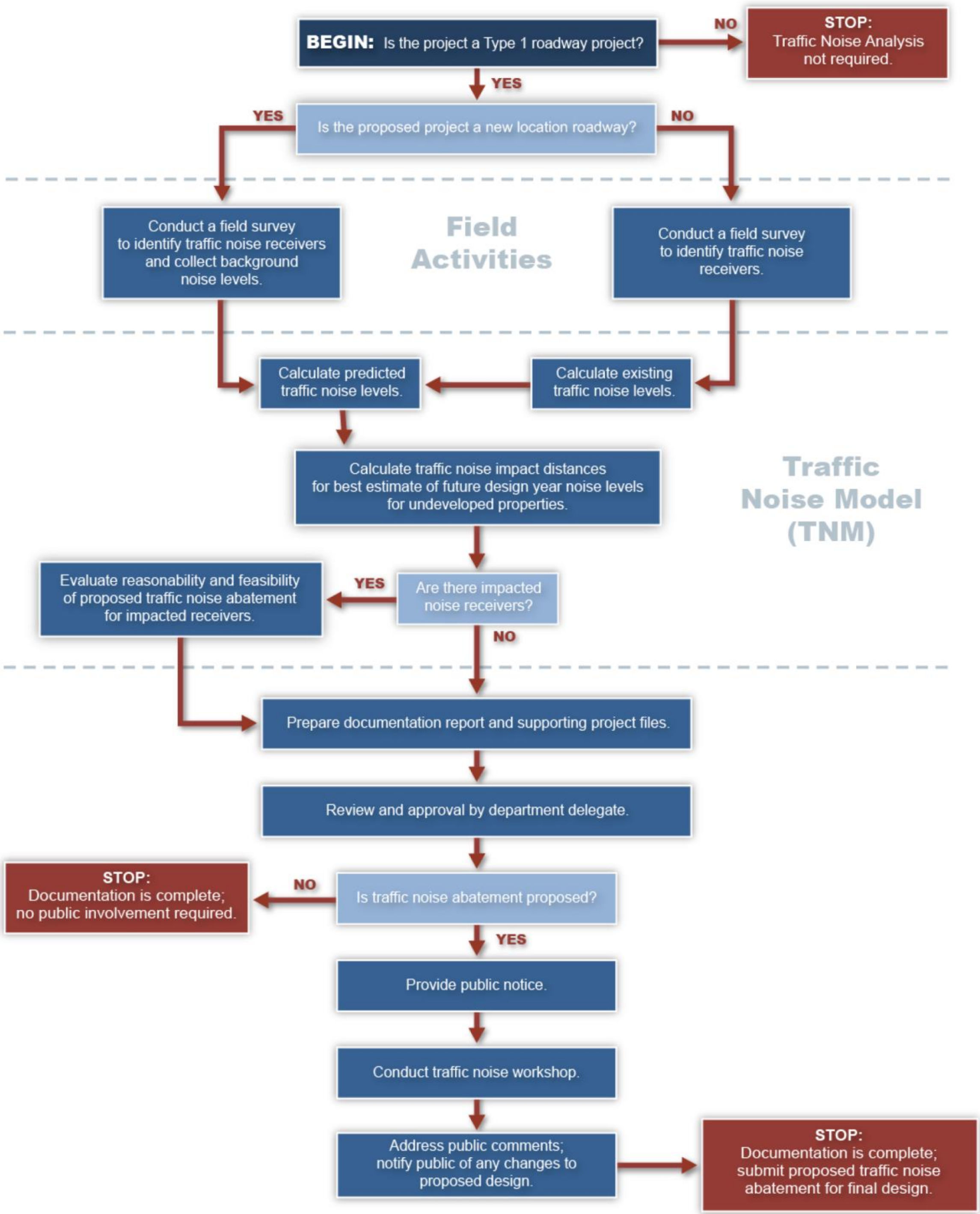
If noise abatement is determined to be feasible and cost effective, the benefited property owners and residents (first-row receptors) who are adjacent to proposed noise barriers will be contacted/surveyed early in project development and given an opportunity to provide input on their desire to have a barrier. This survey/ballot will preferably be sent by pre-stamped/pre-addressed return envelope and will include a package of material that describes the noise barrier under consideration and the noise effects with and without the barrier. It will also describe the decision-making process that TxDOT will follow to assess the survey/ballot results and decide whether to build the barrier.

A noise workshop is conducted after a public hearing to discuss the results of noise studies and solicit input from the public on barriers to be included in the final design. Ballots cast by residents are obtained for viewpoints, but only ballots cast by property owners count toward determining whether a noise barrier will be constructed. A majority (50 percent + 1) of the total benefited receptors must indicate on the survey/ballot that they want a barrier constructed for it to be considered reasonable. If the total respondents to the survey/ballot do not total a majority (50 percent + 1) of the benefited receptors, then a second attempt will be made to solicit the views of those who did not respond. No third attempt is required if a majority (50 percent + 1) do not respond. If a majority (50 percent + 1) of the total benefited receptors do not respond by the due date or do not respond after the second attempt, then TxDOT will base its decision on the survey responses it received even though a positive majority of benefited receptor responses were not received.

If a barrier is to be constructed, adjacent property owners will be given options regarding the aesthetic treatment of the barrier facing away from the roadway. TxDOT will select the color and texture of the barrier surface facing the roadway. Barriers proposed early in project development may change due to other revisions to the project scope or alignment. If a barrier's status (reasonableness and/or feasibleness) changes, additional notification will be made to affected property owners to discuss the changes.

TxDOT Traffic Noise Analysis Process

TxDOT's traffic noise analysis process is well documented. Figure 6 shows the process flowchart. TxDOT conducts noise analysis only for Type I projects and not for Type II projects (i.e., a federal or federal-aid highway project for noise abatement on an existing highway [retrofit project]). Therefore, the analysis process begins by determining if a proposed project is a Type I project. Type I projects are generally projects to construct roadways at a new location, or projects for existing roadways that will substantially change their location or add a through lane. If a project is identified as Type I, the first step is to identify the areas with potential for noise impacts, the associated land uses in each area, the receptors of noise in each area, and the applicable NAC for each receptor identified. All impacted receptors are identified for each reasonable alternative noted in the National Environmental Policy Act (NEPA) evaluation. Once identified, receptors are classified by land use and the appropriate activity category, as identified previously in Table 1.



Source: (*9*).

Figure 6. Traffic Noise Analysis Process Flowchart.

If the proposed project is a new location, the first step is to conduct a field survey to identify traffic noise receivers and collect background (ambient) noise levels; the second step is to calculate predicted noise levels using the FHWA required version of TNM, followed by the third step, which is to calculate traffic noise impact distances.

If the project is for an existing roadway or not at a new location, then the first step is to conduct a field survey to identify traffic noise receivers, then calculate existing traffic noise levels using the FHWA required version of TNM, and then calculate the predicted traffic noise levels with TNM.

Existing (ambient) noise levels are measured for new-location projects or calculated for existing roadways at each receptor or representative set of receptors (for very large numbers of receptors). Measurements for existing roadways must be taken at a time of day that reflects the loudest hourly highway traffic noise levels occurring on a regular basis under normal traffic conditions. Measurement should be in units of decibel Leq (dBA). Receptors in both cases should be located at a location where frequent human outdoor activity occurs. This may be a yard, patio, or other area of frequent use depending on the particular location. The FHWA required version of the TNM computer model must be used in the noise analysis and, if appropriate, should be validated with noise measurements taken at noise receptors.

Predicted noise levels should be derived according to the FHWA required version of TNM. Currently, FHWA requires the use of the FHWA TNM v2.5 for projects that require FHWA approval, regardless of funding source, or that are funded with federal-aid highway funds (23 CFR 772.7[a]). FHWA distributes the TNM v2.5 free of charge. FHWA is currently developing TNM v3.0 (*14*). Input data such as future traffic volumes, traffic speed, and percent of vehicle types should reflect the traffic characteristics that yield the loudest hourly traffic noise levels on a regular basis under normal conditions.

Traffic noise receptors are identified as impacted under either of two conditions:

- The predicted noise levels approach (TxDOT defines as 1 dB[A] under the NAC) or exceed the FHWA NAC (see Table 1).
- The predicted traffic noise levels substantially exceed the existing noise levels (TxDOT defines this as a 10 dB[A] increase).

The next step is to compare the predicted noise levels for each project alternative under detailed study with the NAC and existing noise levels.

If traffic noise impacts are projected to occur at a receptor, TxDOT must consider measures to mitigate/abate the traffic noise impacts. Once traffic noise impacted receptors have been identified, an assessment must be conducted to evaluate how to abate the noise impacts and determine whether the abatement is both reasonable and feasible, as discussed previously.

Traffic noise abatement measures can be in many forms and may include traffic control measures, alteration of vertical or horizontal alignment, acquisition of buffering land, noise insulation of NAC Category D, and/or construction of traffic noise barriers. TxDOT will choose the most feasible and reasonable form of abatement.

State of Practice in Peer States

The review of peer states was focused on how they define their feasible and reasonable criteria, noting differences in approaches. Five peer states were selected from different areas of the country. These are more populous states with large metropolitan areas and well-developed highway networks that have been experiencing system expansion. The five peer states selected were California, Florida, Illinois, New York, and Washington.

California

The California Department of Transportation (Caltrans) policy regarding noise abatement addresses the public sensitivity to noise generated by traffic along highways. The abatement of noise is a design consideration required by state and federal statutes and regulations and by Caltrans' policy (*15*). In California, project sponsors are required to assess if their projects "could result in substantially increased noise levels" and, when reasonable and feasible, consider noise abatement. Initially, the project engineer (PE) should work with Caltrans' environmental unit to determine preliminary design and project details on the abatement facilities. Later in the project, "it is the responsibility of the PE to determine the feasibility and reasonableness of constructing the noise abatement facility" (*15*).

Caltrans defines three types of projects that involve noise abatement:

- The construction of new highways or the reconstruction of existing highways.
- The construction of noise abatement features to retrofit existing freeways through residential areas.
- The construction of noise abatement features to retrofit existing freeways to reduce the level of freeway traffic noise that intrudes into public and privately owned primary and secondary schools.

If results of environmental studies demonstrate that noise abatement facilities are preferable to protect specific properties, abatement facilities (barriers) should be constructed if they are determined to be reasonable and feasible. This determination is the PE's responsibility, as noted in Section 1 of the general policy in the *Project Development Procedures Manual—Chapter 30: Highway Traffic Noise Abatement* (*15*).

Feasible

Feasibility is defined "with regard to engineering considerations" (*15*). For a barrier to be considered feasible, a 5-dB(A) noise reduction must be reached. Four factors can limit the ability to achieve the 5-dB(A) noise reduction:

- Topography.

- Access requirements for driveways, ramps, etc.
- Presence of local cross streets.
- Other noise sources in the area.

Reasonable

Caltrans defines reasonable as a more subjective criterion than feasible, implying that "commonsense and good judgment have been applied in arriving at a decision" (*15*). Some of the factors that should be taken into consideration when making a reasonable analysis include cost effectiveness, change in noise levels, development along the freeway, environmental impacts of abatement construction, land use controls by local agencies, large noise impacts, residents' views, and outside construction.

Caltrans states that the following six criteria should be used to make a basic determination of the reasonableness of constructing noise barriers and that these criteria should not always be rigidly applied (*15*).

1. **Cost Effectiveness.** Projects are considered cost effective if they cost no more than the criterion established for each residential unit protected by the barrier (i.e., the barrier cost per residence). The cost-effectiveness criterion was established as $35,000 for the 1996 and 1997 calendar years. This criterion is adjusted every two years by using the California Construction Cost Index as a guide and is issued in each even-numbered year by the Headquarters Noise Abatement Program Manager. The current cost-effectiveness criterion is $71,000 (year 2015).
2. **Impacted Housing.** The percentage of the impacted housing development that predated the initial highway construction.
3. **10-Year Impacted Housing.** The percentage of the impacted housing development that has been in place for at least 10 years.
4. **Future Noise Levels.** The future build noise levels (i.e., with the proposed project).
5. **Increased Noise Levels.** The increase in the proposed project's build noise levels over the existing noise levels.
6. **Future Build versus No-Build Noise Levels.** The increase in the proposed project's future build noise levels compared to the future no-build noise levels.

Some additional considerations also include environmental impacts, enforcement or lack of enforcement of land use controls by local agencies, large noise impacts, residents' views, and other reconstruction.

Florida

FDOT reported an outline of the steps that are followed to assess traffic noise as a part of the project development and environment (PD&E) process. Chapter 17 of the *Project Development & Environment Manual* (*16*) establishes the official FDOT noise policy and procedures for the purpose of meeting the requirements of 23 CFR Part 772 and applicable state laws. Some of the definitions based on FDOT noise guidelines are discussed below.

Feasible

Florida defines feasibility as "the combination of acoustical and engineering factors considered in the evaluation of a noise abatement measure" (*16*). Feasibility factors include noise reduction, design and construction, safety, access, right-of-way, maintenance, drainage, and utilities.

Reasonable

Reasonableness is defined as "the combination of social, economic, and environmental factors considered in the evaluation of a noise abatement measure" (*16*). The following reasonableness factors must be achieved for the noise abatement measure to be deemed reasonable:

- Consideration of the viewpoints of the benefited property owners and residents.
- Cost effectiveness of the highway traffic noise abatement measure.
- Achievement of the FDOT noise reduction design goal.

The noise reduction design goal is met when there is a 7-dB(A) noise level reduction for one or more benefited receptors.

Regarding the cost-effectiveness criteria, FDOT has provided approximately 1,400 sq ft of noise barrier per benefited receptor at a reasonable cost (*16*). The noise analysis guide describes the current (May 2011) unit cost of $30 per square foot, a reasonable cost of $42,000 per benefited receptor, as the upper limit. The cost factor elements are reviewed annually by FDOT and adjusted every five years. The relationship between unit costs and the upper limit for cost reasonableness is based on maintaining a constant upper limit of 1,400 sq ft of noise barrier per benefited receptor. FDOT considers these elements as part of the cost of a noise barrier:

- The cost of materials and labor.
- The cost of additional right-of-way.
- The cost of relocation of utilities when they are outside of the FDOT right-of-way.
- The cost of new or upgraded drainage structures required by the construction of a noise barrier.

Cost elements do not include the cost of designing the noise barrier, relocation of utilities (above or below ground) that are permitted within the FDOT right-of-way, clearing and grubbing, mobilization, maintenance of traffic, construction engineering and inspection, and related activities that are considered part of the total construction project. To be considered as a noise abatement cost, the costs must be incurred because of the installation of the noise barrier, for example, when a culvert needs to be extended to construct the noise barrier but not for roadway construction. FDOT does not consider third-party funding in the development of noise abatement measures or to subsidize the cost of a noise barrier for the purpose of making the noise barrier feasible or reasonable.

Illinois

IDOT's *Highway Traffic Noise Assessment Manual* describes the methods and procedures taken into consideration for analyzing and reporting the impacts of traffic noise (*17*). IDOT has established general criteria that must be met before a noise barrier is implemented.

Feasible

The noise barrier feasibility addresses engineering aspects such as safety, drainage, and utilities for the consideration of a noise barrier implementation. For a noise abatement measure to be considered feasible, it must achieve the traffic noise reduction feasibility criterion of at least 5 dB(A) for at least one impacted receptor.

Reasonable

According to IDOT's *Highway Traffic Noise Assessment Manual* (*17*), the reasonableness criteria for the evaluation of noise abatement consists of three parts, as explained below:

a) Economic reasonability—The economic reasonability is defined as the cost-effective evaluation of the noise barrier. It determines the total cost of the noise barrier, the number of benefited receptors, and the cost per benefited receptor. The estimated build cost for noise barriers is determined by the current standard unit cost approved by IDOT. The current unit cost (set in 2011) for noise barriers used by IDOT is $25 per square foot.

b) Noise reduction design goal—The noise reduction design goal must not be less than an 8 dB(A) traffic noise reduction for at least one benefited receptor location.

c) Viewpoints of the benefited receptors—The viewpoints of benefited receptors are solicited for noise barriers that are determined (as mentioned previously) to be feasible, cost-effective, and achieve the noise reduction goal. They also must be solicited to determine the desire for the implementation of noise abatement measures.

IDOT's *Highway Traffic Noise Assessment Manual* (*17*) includes Categories A through G for the NAC, based on 23 CFR 772.7. The NAC and noise procedure regulations apply to Type I and Type II projects only. IDOT does not maintain a Type II program.

New York

New York State Department of Transportation (NYSDOT) policy and procedures for analyzing traffic noise impacts and considering abatement measures that are consistent with FHWA's noise regulation were last reviewed in 2011(*18*). NYSDOT's noise analysis policy and procedures describe the types of projects similarly to other peer states reviewed in this section.

According to the NYSDOT guidelines (*18*), if a project is determined to be a Type I project, then the entire project area as defined in the environmental document is a Type I noise project. NYSDOT has not developed a Type II program in accordance with Section 772.7(e); therefore, no NYSDOT Type II projects are eligible for federal-aid funding. Furthermore, the development and implementation of Type II projects is not to be considered without separate additional funding by the legislature for this specific purpose.

NYSDOT's guidance on noise analysis (*18*) follows the federal regulations for the description of activities for the NAC. Activities include Categories A through G.

According to NYSDOT guidelines (*18*), an abatement measure is recommended only if it is both feasible and reasonable. In determining feasibility and reasonableness, the number of impacted receptors must first be established using the methodologies described in the state noise guidelines and procedures. The methodology used for determining impacted receptors is used for determining benefited receptors when establishing reasonableness. Appendix F provides an example feasibility and reasonableness worksheet used by NYSDOT.

Feasible

Feasibility involves the practical capability of the noise abatement measure being built and the capacity to achieve a minimum reduction in noise levels. Overall, feasibility deals primarily with engineering considerations (e.g., can a barrier be built given the topography of the location; can noise reduction be achieved given certain access control, drainage, safety, or maintenance requirements; are noise sources other than from the project present in the area).

According to NYSDOT noise guidelines (*18*), when noise abatement measures are being considered, every reasonable effort shall be made to obtain noise reductions of 10 or more dB(A). For a measure to be deemed feasible, it must provide a minimum 5-dB(A) reduction to the majority of impacted receptors.

Reasonable

Reasonableness deals with the social, economic, and environmental factors to be considered when evaluating abatement measures. Reasonableness is based on the items listed below (*18*).

- Cost—NYSDOT has established the following reasonableness cost indices for abatement measures:

- For a noise berm or noise insulation, a cost index of $80,000 per benefited receptor shall be used, based on the total cost of the material installed. The base index was not clearly identified.
- For barrier walls, a maximum of 2,000 sq ft of wall per benefited receptor shall be used.

All owner-occupied and rental dwelling units, detached, duplex, and mobile homes, and multifamily apartment units shall be counted if they are benefited, regardless of whether they were identified as impacted. The threshold of noise reduction that establishes a benefited property is at least 5 dB(A) determined at a point where frequent human use occurs and a lowered noise level would be of benefit.

- Noise reduction—NYSDOT noise policy establishes a noise reduction design goal of 7 dB(A). For an abatement measure to be determined reasonable, a majority of the benefited receptors must achieve the design goal. For example, if 10 receptors were benefited (i.e., would receive at least a 5-dB[A] noise reduction if the abatement measure were implemented), then at least six receptors must receive a 7-dB(A) noise reduction for the abatement measure to be considered reasonable under this criterion.
- Viewpoints—The viewpoints of the property owners and residents of the benefited receptors shall be a major consideration in reaching a decision on the reasonableness of abatement measures. The property owners and residents shall be contacted using one or more of these methods: informational meetings in or near the neighborhood, direct mailings with return envelopes, telephone or Internet surveys, or door-to-door inquiries. A response shall be obtained from at least half of the benefited property owners and residents, and a majority of the responses must favor the abatement measure.

  Although the viewpoints shall be determined and addressed during the preliminary design phase of project development, the property owner and resident viewpoints on the desirability and acceptability of abatement need to be reexamined periodically during the final design phase prior to plan, specification, and estimate (PS&E) approval.

Washington

The Washington State Department of Transportation (WSDOT) traffic noise policy (*19*) complies with 23 CFR 772 and describes how traffic noise and noise abatement must be addressed on federal-aid highway projects. The traffic noise policy and procedures provide the criteria for conducting traffic noise analysis, evaluating traffic noise impacts, and determining the need for abatement based on the federal highway traffic noise standards in 23 CFR 772.

The department evaluates traffic noise from highways under two sets of circumstances defined in its traffic noise policy and procedures (*19*):

- Type I (new construction) including roadways, bus lanes, restriping for new lanes, weigh stations, toll plazas, rideshare lots, ramps and interchange lanes, and auxiliary lanes, except when the auxiliary lane is a turn lane.
- Type II as retrofit projects. WSDOT provides noise abatement for neighborhoods that were established before many of the state or federal highways were built or expanded. Traffic noise abatement was not part of any project prior to May 14, 1976. WSDOT has a statewide ranking on traffic noise levels; the resulting list is the state noise retrofit list.

Traffic noise impacts are considered for the hour with the highest average noise levels; the same hour should be used for all modeled conditions. If peak-hour traffic volumes are not available, 10 percent of total daily volumes can be used to represent this hour. If vehicle mix data are not available, estimates shall be generated in consultation with the appropriate WSDOT region Traffic Office (*19*).

The noise study area must include all receptors within the project limits that may experience traffic noise impacts, including non-residential land uses, as described in Table 1. The noise study will also evaluate local zoning to determine if existing noise-sensitive land uses would benefit from the proposed noise abatement under the current zoning code or ordinance. Noise abatement measures must be feasible and reasonable.

Feasible

WSDOT defines feasibility as a combination of acoustic and engineering considerations. The following criteria should be met for abatement measure to be considered feasible (*19*):

- Abatement must be physically constructible.
- Majority first-row impacted receivers must obtain a minimum 5 dB(A) of noise reduction as a result of abatement (insertion loss), assuring that every reasonable effort will be made to assess outdoor use areas as appropriate.

The minimum design goal for abatement is at least 7 dB(A) of reduction for one receiver, and noise walls cannot be recommended if they do not achieve the design goal. In addition to the design goal requirement, WSDOT will make a reasonable effort to get 10 dB(A) or greater insertion loss (noise reduction) at the first row of receivers for all projects where abatement is recommended.

Reasonable

Reasonableness is determined after abatement is found to be feasible and based on several factors. Required factors are (*19*):

- Cost effectiveness—The cost of noise abatement sufficient to provide at least the minimum feasible noise reductions must be equal to or less than the allowable cost of abatement for each noise wall location analyzed. Based on noise wall costs from 2007–2010, the current average costs for Washington State are as follows: Type I noise walls = $51.61 per square foot, and Type II noise walls = $75.10 per square foot. A noise barrier is considered highly cost effective when noise levels behind the barrier are reduced by 10 dB(A) for the majority of front-row receivers at less than 75 percent of the maximum reasonable cost allowed for abatement.

  Either the barrier size or cost outlined in the state guidance can be used to describe the reasonableness evaluation. However, a cost description must be included if there are non-standard additional costs or costs that would not occur but for the barrier (e.g., additional foundation costs for steep slopes, unique drainage requirements). Additional cost estimates for abatement are added to the planning-level costs as part of the reasonableness evaluation.

  Allowable costs are shown in Appendix E and are a function of the current planning-level barrier cost ($51.61 in 2010) multiplied by the allowable wall size for receiver benefiting from the noise wall. Appendix E shows the allowable costs for each receiver based on the predicted build condition noise levels or sound level increases. Higher noise levels, or larger sound level increases, are allowed more money for abatement. The cost evaluation used to determine WSDOT planning-level cost estimates for a standard noise wall includes the following examples:

  - Noise barrier construction labor and materials, including clearing and grubbing and the acquisition of property needed for the noise barrier.
  - Traffic management measures, as necessary only for the barrier construction.
  - Percent of the total project's workforce mobilization costs.
  - Sales tax.

- Benefited receptor viewpoints—The viewpoints of the property owners and residents of benefited receptors are considered for locations at or above the NAC or locations where traffic sound levels are expected to increase by at least 10 dB(A) in the build versus existing condition. Benefited receivers are properties that receive at least 5 dB(A) of sound level reduction from abatement, regardless of whether they are impacted. The same cost reasonableness value that is applied to receivers with build condition noise levels of 66 dB(A) is applied to benefited receivers below the NAC in the build condition.

- Noise abatement performance—The minimum design goal for abatement is at least 7 dB(A) of reduction for one receiver. Noise walls cannot be recommended if they do not achieve the design goal. In addition to the design goal requirement, WSDOT will make a reasonable effort to get 10 dB(A) or greater insertion loss (noise reduction) at the first row of receivers for all projects where abatement is recommended.

  A larger noise barrier than the minimum feasible and reasonable size shall be constructed when a barrier is highly cost effective. A barrier is considered highly cost effective when it reduces noise levels behind the barrier by 10 dB(A) or more for the majority of front-row receivers at less than 75 percent of the maximum reasonable cost allowed for abatement.

  If abatement is determined to be desired by the benefiting receptors, cost effective, and able to achieve the design goal for abatement, then the assumption shall be that the abatement is reasonable.

  Initial recommendations about whether noise abatement will be feasible and reasonable can be made early in the design/environmental documentation phase. However, WSDOT makes final decisions on the construction of noise barriers after the final horizontal and vertical alignments are determined and a detailed engineering analysis of the feasibility and reasonableness of noise abatement can be made. Barriers that meet WSDOT's criteria, as accepted by FHWA, will be constructed. On projects where noise barriers are considered for multiple locations, noise barriers, or barrier systems, a feasibility and reasonableness evaluation will be done for each area independently.

  The WSDOT design office works closely with the impacted community to ensure that reasonable requests regarding the design of the wall are included in the project plans. Public involvement must occur when traffic noise abatement is recommended for Type I and Type II projects, even when public involvement is not required as part of the NEPA or State Environmental Policy Act processes. Public opinion is considered when determining reasonableness for traffic noise abatement. Noise abatement is not planned if the majority of eligible property owners oppose the proposed noise abatement.

State Funds Option

At WSDOT, project offices have the option of limiting the traffic noise analysis areas on projects that do not use FHWA funding or require FHWA approvals by implementing the State Funds Option policy (*20*). Instead of analyzing all areas adjacent to the roadway between the full project limits, this policy allows limiting analysis to the specific location(s) adjacent to where Type I noise activities occur on a project. The State Funds Option also reduces the burden of analysis on projects where there are no sensitive receivers present or where noise barriers are not likely to be feasible and reasonable. This policy is intended to promote the responsible use of transportation funds by focusing analysis and mitigation on areas where traffic noise impacts are caused by a project and are directly tied to project activity. The State Funds Option uses the same methodology required by FHWA for federally funded projects, except for three major differences:

- Only the limits of the Type I activity may be considered, rather than the full project boundaries.
- A straight-line noise screening model using the TNM may be considered sufficient for projects where noise barriers are not likely to be reasonable or feasible.
- If no sensitive receivers are located adjacent to the Type I project activity, a noise impact analysis is not required.

The State Funds Option is intended for projects where there is clear division of activities (Type I versus non-Type I) and the effect of those activities will not directly influence traffic noise levels for all sensitive receivers within the full project boundaries.

Comparison with Peer States

Researchers compared the noise abatement criteria used by peer states with those of TxDOT and federal guidelines by activity category. The federal guidelines set the upper maximum value, and the state highway agencies can choose the lower (approach) limit. This lower approach value is the noise level that triggers noise mitigation analysis. All peer states have a threshold 1 dB(A) lower than the federal guidelines set forth in 23 CFR 772 (*7*), as shown in Table 2. The activity definition of these state highway agencies is consistent with the federal guidelines.

Table 2. Comparison of Federal and TxDOT Noise Abatement Criteria with Peer States.

Activity Category	Leq(h) (dB[A])						
	Federal	**Texas**	**California**	**Florida**	**Washington**	**Illinois**	**New York**
A	57	56	56	56	56	56	56
B	67	66	66	66	66	66	66
C	67	66	66	66	66	66	66
D*	52	51	51	51	51	51	51
E	72	71	71	71	71	71	71
F	—	—	—	—	—	—	—
G	—	—	—	—	—	—	—

* Interior.

Table 3 compares the current cost-effectiveness criteria and old cost-effectiveness criteria (Year 1999) in Texas and selected peer states. The cost-effectiveness criterion in Texas is the same as in year 1999, whereas the other states have updated their criteria. This criterion is tied to the construction cost index within these states. Washington and Illinois have tier-based systems for cost-effectiveness criteria, whereas California, Florida, New York, and Texas have a fixed value. In New York, the cost-effectiveness criterion is $80,000 per benefited receptor if a berm is proposed; otherwise, the criterion is $2,000 sq ft of wall per benefited receptor if a barrier wall is proposed.

Table 4 compares the construction cost per square foot used to calculate the cost effectiveness of noise abatement measures and what the cost includes. California reported not using cost per square foot as a parameter; however, the cost-effectiveness value is adjusted every two years with the California Construction Index.

Based on a combination of the results in Table 3 showing cost-effectiveness thresholds and Table 4 showing the estimated cost per square foot, Table 5 shows a comparison of noise barrier coverage per benefited receptor. These results show that Texas is nearly equivalent to Florida in square footage of noise barrier per benefited receptor. The costs and thresholds used in Illinois and Washington yield 30 to 50 percent less noise barrier for qualifying walls.

Table 3. Comparison of Current Cost-Effectiveness Criteria and Cost-Effectiveness Criteria from the Year 1999 in Texas and Selected Peer States.

State	Current Cost-Effectiveness Criterion ($)	Cost-Effectiveness Criterion in 1999 (*11*)	Criterion Set Year (Criteria Updated)
Texas	$25,000	$25,000	before 1992 (1999)
California	$71,000	$35,000	1996–1997 (2015)
Florida	$42,000	$25,000	2012 (not available)
Washington	$36,127–$71,222*	$20,000	2011 (2011)
Illinois	$24,000–$37,000**	$30,000	2011 (2011)
New York	$80,000***	$50,000	2011 (2011)

* Higher noise levels, or larger sound level increases, are allowed more money for abatement. For example, an increase of 10 dB(A) as a result of a project for design year traffic sound of 71 dB(A) with allowed wall surface area per qualified residence of 1,040 sq ft results in a reasonableness allowance of $53,674.

** Base value of $24,000 per benefited receptor is adjusted considering other factors, resulting in a potential maximum allowable noise abatement cost of $37,000 per benefited receptor.

*** Per benefited receptor if a berm is proposed; 2,000 sq ft of wall per benefited receptor if a barrier wall is proposed.

Table 4. Comparison of Construction Cost (per Square Foot) Used in Calculating Cost Effectiveness in Peer States.

State	Cost per Square Foot	Year (Adjustment Criteria)	Cost Includes
Texas	$18	Prior to 1992 (last evaluated in 1999, criterion not changed)	The $25,000 figure includes only the cost of construction of a noise barrier and not the cost of any additional right-of-way or utility adjustments (*10*).
California	NA	(adjusted every two years with California Construction Cost Index)	Includes cost of any necessary widening, retaining walls, drainage, right-of-way, etc. needed to accommodate the noise barrier if those features will not be funded by another programmed project.
Florida	$30	2012 (reviewed annually and adjusted every 5 years)	Cost factors will include the cost of construction (material and labor), additional right-of-way (including construction and easements, etc.), relocation of utilities when they are outside of the right-of-way, and new or upgraded drainage structures required by the construction of a noise barrier. Cost elements **do not** include the cost of designing the noise barrier, relocation of utilities permitted within the FDOT right-of-way, clearing and grubbing, mobilization, maintenance of traffic, construction engineering and inspection, and related activities that are considered part of the total construction project.
Illinois	$25	2011 (evaluated every 5 years based on actual construction costs)	Based on actual construction costs (materials and installation) and engineering design. The cost of right-of-way acquisition for the purpose of noise barrier construction should also be included if acquisition is needed solely for noise barrier construction.
Washington	$51.61	2012	Noise barrier construction labor and materials, including clearing and grubbing and the acquisition of property needed for the noise barrier; traffic management measures, as necessary only for the barrier construction; a percent of the total project's workforce mobilization costs; sales tax.
New York	NA		

Note: NA = not available.

Table 5. Comparison of Barrier Equivalent Square Footage per Benefited Receptor from Application of Cost per Square Foot and Cost per Benefited Receptor.

State	Cost per Square Foot	Cost per Benefited Receptor	Square Foot per Benefited Receptor	Percent Difference from Texas
New York	NA	NA	2,000	+44
Florida	$30	$42,000	1,400	+11
Texas	$18	$25,000	1,389	0
Illinois	$25	$24,000–$37,000	960–1,480	−31 to +4
Washington	$51.61	$36,127–$71,222	700–1,380	−50 to −1

Note: NA = not applicable.

State of Practice with Selected Toll Authorities in Peer States

The research team contacted toll authorities in California, Illinois, Florida, and New York. Sound mitigation and sound wall policies from each of the toll authorities were reviewed. The research team discovered that the toll authorities follow the noise abatement guidelines set forth in their respective state, which are the same guidelines followed by their state DOT regardless of funding source. Table 6 lists the toll authorities contacted to obtain the information on noise guidelines and regulations in the peer states.

Table 6. State Toll Authority Representatives Contacted.

State	Toll Authority
Florida	Central Florida Expressway Authority
California	Orange County Transportation Authority; 405 Project
New York	New York State Thruway
Illinois	Illinois State Toll Highway Authority

Other Relevant Information

Benefited Receiver Input in Noise Mitigation

Texas

A benefited receiver is defined as a recipient of an abatement measure that receives a noise reduction at or above the minimum threshold of 5 dB(A), regardless of whether the receptor was impacted. The total number of benefited receptors is used to evaluate the cost effectiveness of an abatement measure. In Texas, benefited property owners and residents adjacent to proposed abatement measures may provide input on the traffic noise abatement to be included in the final design, including whether the abatement measures are desirable.

The ballots cast by residents are obtained for viewpoints, but only ballots cast by property owners count toward determining whether a noise barrier will be constructed. A majority (50 percent + 1) of the total benefited receptors must indicate on the survey/ballot that they want a barrier constructed for it to be considered reasonable. However, if sufficient receivers do not respond by the due date or do not respond after the second attempt, then TxDOT can base its decision on the survey responses it received even though a majority of responses were not received.

Generally, residential property owners prefer traffic noise barriers, while commercial property owners prefer to maintain visibility for their business from adjacent roadways. This can cause conflicts in mixed-use developments because noise barriers may block the line of sight to adjacent businesses. When a mutually satisfactory compromise cannot be reached between businesses and residences, noise barriers may be terminated at property lines dividing the two areas (*9*).

California

In California, the views and opinions of the residents living immediately adjacent to the freeway and *affected* by the traffic noise are considered in reaching a decision on noise abatement measures. Noise barriers are not provided if 50 percent or more of those affected residents do not want them. The opinions of these residents are obtained through public hearings, community meetings, or other means as appropriate.

The opinions of those affected residents are also considered regarding the height of proposed noise barriers. If the majority of those residents object to the proposed height of the noise barrier, the barrier may be constructed at a lower height under certain conditions. The affected residents should be informed of the proposed height of the noise barrier determined necessary by noise analyses. If they request a lower noise barrier, the shorter height may be constructed if it will still reduce the noise by a minimum of 5 dB(A) and if the line of sight to the truck exhaust stack height (11.5 ft) is broken.

During preliminary design, consideration must be given to the opinions from the adjacent residents on all relevant factors, such as whether they favor the construction of the proposed noise abatement facilities, heights of the proposed facilities, materials to be used, etc. When the final design proposes significant revisions to the preliminary design, attention must be given to verify that the proposal will still be commensurate with the desires of the impacted residents.

Florida

In Florida, a detailed process to obtain the viewpoint of the benefited receptors is invoked during the design phase of the project. All benefited receptors (owners and residents) are given the opportunity to provide input to FDOT regarding their desire to have the proposed noise abatement measure constructed. They may also be given the opportunity (at the discretion of the district) to provide input regarding their aesthetic preferences from a list of pre-selected options.

During the design phase of the project, FDOT uses either a noise abatement workshop and/or a public survey to determine the wishes of the benefited receptors. FDOT tries to obtain a response for or against the noise barrier from a majority of the benefited receptors (owners and residents) that respond to the survey. If a majority of the benefited residents and property owners responding to the survey do not favor construction of a noise barrier, FDOT does not provide the noise barrier. The viewpoints of the property owners will be considered as having the greatest weight in the decision on whether FDOT will provide noise abatement. While the viewpoints of the non-owner residents are considered, their viewpoints carry less weight, consistent with the formula shown in Table 7.

Table 7. Weight Given to Viewpoints of Residents and Owners in Florida.

Property Type	Owner Occupied Weighting Factor	Owner Non-Occupied Weighting Factor	Renter Occupied Weighting Factor
Single Family	100%	90%	10%
Multifamily (duplex, apartments)	100%	90%	10%
Condominium	100%	90%	10%
Mobile Home Park (single owner)	NA	80%	20%
Offices, Businesses	100%	80%	20%

For example, if a renter of a single-family home wished to have noise abatement but the owner did not, the opinion of the homeowner would prevail. If the homeowner did not respond for or against the noise abatement measure, then the renter's opinion would be used to be the equivalent of 10 percent of the vote of a homeowner. This means that 10 renters in favor of the noise abatement would equal the vote of one owner-occupied home.

Illinois

In Illinois, a benefited receptor is considered any sensitive receptor that receives at least a 5-dB(A) traffic noise reduction as a result of the noise barrier, regardless of whether the receptor was identified as impacted. As an example, a single-family residence is considered one benefited receptor if it receives at least a 5-dB(A) traffic noise reduction. In the case of multiunit dwellings (i.e., condominiums, townhouses, apartments, and duplexes), each unit is counted as one receptor. The viewpoints of benefited receptors are solicited to determine the desire for implementation of the noise abatement measure. Benefited receptors include property owners (including non-residential properties) and renters/leasers residing on the benefited property. While the desire is to obtain as many responses as possible, the goal is to obtain responses from at least one-third (33 percent) of the benefited receptors for each noise abatement measure (i.e., for each noise barrier being considered).

For a proposed noise abatement measure to be implemented, greater than 50 percent of the benefited receptors responding must be in favor of the proposed abatement measures. Viewpoints are tallied for each individual abatement measure (i.e., for each noise barrier being considered). A response from first-row benefited receptors (receptors sharing a property line with the highway right-of-way) is counted and weighted as two responses. Benefited receptors not in the first row count as one vote. The purpose of providing more weight to the front-row receptors is to give them additional consideration for the proposed noise barriers. In the case of rental properties, the tenant is counted as one response and the owner is counted as one response per benefited unit.

New York

In New York, the viewpoints of the property owners and residents of the benefited receptors are a major consideration in reaching a decision on the reasonableness of abatement measures. The property owners and residents are contacted using one or more of these methods: informational meetings in or near the neighborhood, direct mailings with return envelopes, telephone or Internet surveys, or door-to-door inquiries.

A response is obtained from at least half of the benefited property owners and residents, and a majority of the responses must favor the abatement measure. Although the viewpoints shall be determined and addressed during the preliminary design phase of project development, the property owner and resident viewpoints on the desirability and acceptability of abatement need to be reexamined periodically during the final design phase prior to PS&E approval.

Washington

WSDOT conducts a poll early in the design process to verify the opinions of people impacted by the project and benefiting from the proposed barrier. The opinions of impacted or benefited receivers within the noise study area are considered eligible for formal polling. The purpose of abatement is to noticeably reduce noise for those most affected by highway traffic noise. Noise barriers primarily benefit and/or affect those closest to the wall, so weighting of eligible receivers is based on their locations within the noise study area. Specific weighting of polling responses from benefiting receivers is as follows:

- First-row eligible receivers are granted 1.5 votes per residential unit.
- Eligible receivers beyond the first row are granted one vote per residential unit.
- If eligible receiver locations are not owner occupied, the opinions of both the renter and property owner shall be considered. When the two opinions differ, the renter’s opinion shall reduce the weight of the property owner’s response for that unit by one-half. When polling responses are not received from the renter, the property owner’s vote will represent the voting unit.

- Non-residential units identified as sensitive receivers (churches, schools, public parks, cemeteries, etc.) will be evaluated on a residential equivalent basis. Eligible receivers in the first row will receive 1.5 votes for each residential equivalent, and benefiting receivers beyond the first row will be granted one vote. Eligible receivers will always receive at least one vote.
- Noise-sensitive receivers within the study area that can demonstrate a negative effect to their property values from the proposed abatement, but who are neither impacted nor benefited, may be eligible for a maximum of one vote.

First-Row Receivers and Line of Sight

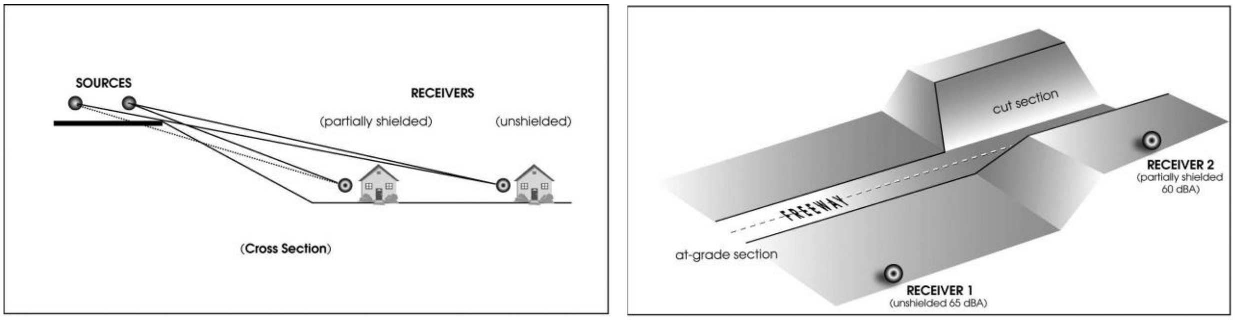
Line of sight is defined as a straight line between the observer's location and a specific noise source. Typically, the first-row receiver should be the one with clear line of sight. However, the existence and definition of first-row receivers varies throughout the states, as documented below.

Texas

In Texas, property owners and residents who are adjacent to proposed noise barriers are considered first-row receptors (*9*). Researchers did not find documentation on impacts of topography (or elevation) on line of sight and its impact on definition of first-row and second-row receivers.

California

California considers role of topography (site geometry) in determining locations of worst exposure to highway noise. Typically, receivers located farther from a highway may be exposed to higher noise levels, depending on the geometry of a site. For example, for a highway on a high embankment, the first-tier receivers may be partially shielded by the top of the fill, whereas unshielded second- or third-tier receivers may be exposed to higher noise levels even though they are farther from the source. Another situation cited in a technical supplement for traffic noise analysis (*21*) involves a receiver close to the source, shielded by the top of a highway embankment, and an unshielded receiver farther from the source. The attenuation provided by the embankment is often more than the distance effect, resulting in higher noise levels at the farther receiver, as shown in Figure 7. Other examples can be generated in which the nature of terrain and natural or artificial obstructions cause noise levels at receivers closer to the source to be lower than those farther away. This concept is an important consideration in impact analysis, where interest usually focuses on the noisiest locations.



Source: (*21*).

Figure 7. Impact of Highway Geometry and Topography on Receivers and Line of Sight.

Florida

Florida defines impacted receptors as the recipients of a traffic noise impact. The FDOT guidelines have no explicit mention of first-row and second-row receptors and impact of elevation on their definition. However, the traffic noise prediction using noise receptors considers topography and traffic conditions in location of the receptor (*16*).

Illinois

IDOT guidelines state that there are times when traffic noise from elevated roadways may be louder on second or third floors that are within the direct line of sight of the roadway. For these situations, the receptors within the direct line of sight of the roadway, (i.e., second-floor apartment units) shall be evaluated under the feasibility criteria. This approach shall be used for multifamily residences when ground-level, exterior areas do not exist, but shall not be used to address second floors of single-family residences. When identifying impacts, impacted receptors may include both the ground level and higher levels within a multifamily dwelling. Typically, IDOT defines first-row benefited receptors as receptors sharing a property line with the highway right-of-way. A benefited receptor does not need to be an impacted receptor.

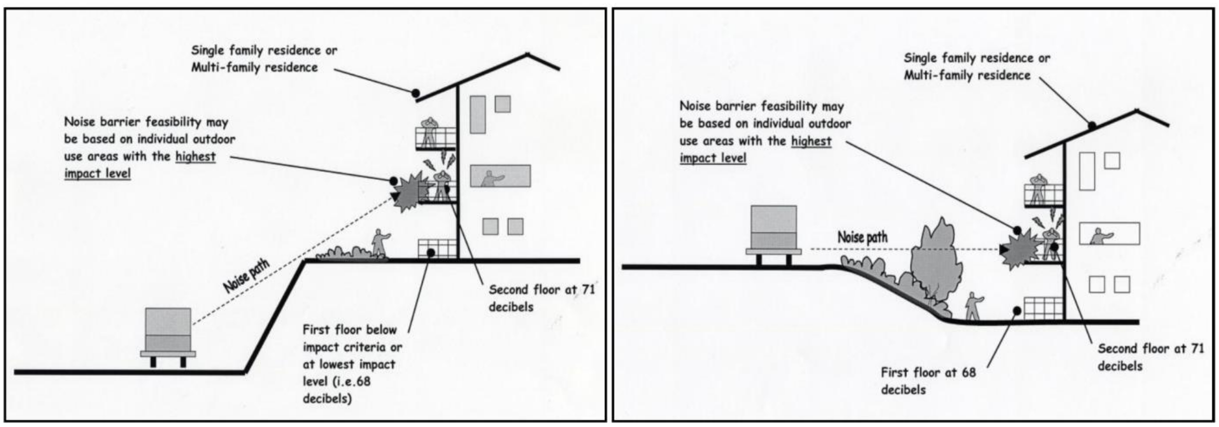
New York

NYSDOT defines impacted receptors as the recipients of a traffic noise impact. The NYSDOT guidelines do not mention impact of elevation on definition of first-row and second-row receptors. However, they explicitly mention that balconies above a certain elevation will not likely be benefited by constructing noise barriers. Though the elevation threshold is mentioned, it was not found in the guidelines and could not be confirmed (*18*).

Washington

According to WSDOT, in most situations, first-row receivers are the nearest receivers to the roadway along the entire length of the project. On some projects, first-row receivers in one location may be farther from the highway than second- or third-row receivers in other locations in the same neighborhood. In most situations, the first-row receiver should have a direct line of sight to traffic. At times, traffic noise from elevated roadways on fill or naturally elevated topography does not impact receivers within the descending noise shadow but instead impacts second- or third-row receivers with a more direct line of sight to vehicles traveling along the roadway. For these situations, the first row of receivers with a direct line of sight to the roadway is counted as the first row per the feasibility criteria (*19*). If receivers that are not closest to the roadway are being considered first-row receivers, justification shall be documented. Figure 8 shows an illustration where the first row may be positioned at locations higher than the ground floor.

If including receiver locations above the ground floor, the analyst shall only account for viable outdoor use areas. Outdoor use areas must include enough space to reasonably place a chair. For multistory residences, only one unit per vertical column of a building can be considered a first-row receiver. Priority should be given to ground-floor outdoor areas of frequent outdoor use, with a direct line of sight to traffic, when determining first-row receiver location. Identify the appropriate line of sight for impacted receivers and count only one receiver per story within the vertical column of the building.



Source: (*19*).

Figure 8. Identification of First-Row Receiver above the Ground Floor.

Type II Projects

According to 23 CFR 772, a Type II project is a federal or federal-aid highway project for noise abatement on an *existing* highway. For a Type II project to be eligible for federal-aid funding, the highway agency must develop a priority system and a Type II program in accordance with Section 772.7(e). However, the development and implementation of Type II projects are not mandatory requirements of Section 109(i) of Title 23 USC (*7*).

Currently, TxDOT does not participate in a Type II (retrofit) program. Similarly, Florida and Illinois do not maintain a Type II program. Table 8 shows involvement of peer state highway agencies in Type II programs.

Table 8. State Highway Agency Participation in Type II Projects.

State	Type II
Texas	No
California	Yes
Florida	No
Illinois	No
Washington	Yes
New York	No*

* Shall not be considered without separate additional funding by the legislature for this specific purpose.

In 1996, the Texas Transportation Commission funded a study to explore whether it would be practical to develop and carry out a statewide Type II noise abatement program for TxDOT. Following are the highlights as presented in the study (*22*):

- Noise barriers constructed under Type II projects would benefit only those people in the immediate vicinity of the barrier who receive some substantial noise level reduction.
- A formal administrative infrastructure would be required to ensure consistent, fair, and uniform application of a statewide program. Staffing requirements would remain indefinitely for proper update and maintenance of the program.
- Even if actively implemented, the program would produce only a limited amount of noise abatement for a limited number of impacted residents.
- In many cases, even if a noise barrier may be the only technically effective way to reduce traffic noise levels at residential locations, other alternate actions, such as landscaping, may be less expensive and more effective in improving relations between TxDOT and impacted residents.

According to this study, the main criteria for the implementation of a Type II program were that it should be fair, consistent, and uniformly applicable statewide. Figure 9 includes an excerpt from this study on steps for implementation of a Type II program. However, a revised study should be conducted because federal guidelines have been updated since publication of this study. The most recent update to the federal noise guidelines was in the year 2010 (*7*).

“The program consists of four steps. First, a statewide survey must be conducted to determine the location of candidate noise abatement projects. A comprehensive survey of all highways in Texas could require up to 1 year and 2 man-years of effort. If the work is contracted, costs should be on the order of $200,000. Once collected, the data should need only periodic review and updates. Second, a detailed analysis of each candidate project must be conducted to ensure it meets all FHWA and TxDOT criteria. Third, a quantitative means of prioritizing projects should be used to rank the projects. Fourth, projects are selected for implementation. The status of selected projects should be monitored throughout the construction process and follow-up contacts should be made with neighborhood residents. Currently, the Environmental Affairs Division (ENV) of TxDOT is responsible for the statewide noise abatement program for Type I projects. It is logical that ENV should also assume the overall responsibility of any Type II program.” – CTR study, 2000.

Source: (*22*).

Figure 9. Excerpt from Landsberger et al.’s Study of Type II Noise Abatement for TxDOT.

Noise Barrier Construction Cost in Texas

TTI obtained a statewide average bid cost for noise walls from TxDOT (*23*). As shown in Table 9, the statewide 12-month average bid code range for noise and sound walls is between $21–$32. Current TxDOT noise guidelines cite a construction cost of $18 per square foot for arriving at the $25,000 cost-effectiveness criterion (*9*). The Usage column in Table 9 shows the number of contracts that used that bid item in the past 12 months. Thus, the sample used to arrive at this cost range is small (n = 7), but at the same time, not many noise walls have been constructed in the 12-month period.

Table 9. Statewide Average Bid Cost for Noise Walls.

			12-Month Moving Average		
Item No	**Description**	**Units**	**Quantity**	**Avg Bid**	**Usage**
4017 6001	Noise wall	SF	20,161	$28.33	2
4041 6001	Noise wall	SF	19,720	$21.00	1
4686 2001	Noise wall	SF	53,406	$28.30	1
4036 2007	Sound wall (Horiz scheme) (8 ft)	SF (LF)	(3,892)	$32.29* ($259.11)	2
4036 2011	Sound wall (10 ft)	SF (LF)	(600)	$ 22.56* ($225.64)	1

* Converted from linear foot (LF) to square foot (SF).
Source: (*23*).

Review of Environmental Assessments to Review Costs and Cost-Effectiveness Results

TTI researchers also reviewed 25 environmental assessment reports documenting 206 noise walls proposed and/or built after the year 2010 in the following counties: Bexar, Brazoria, Dallas, El Paso, Ellis, Galveston, Grimes, Harris, Hays, Hill, Kenedy, Kleberg, Montgomery, Nueces, Rockwall, Tarrant, Travis, Willacy, and Williamson. The research team developed the following conclusions based on the evidence found through the review process:

- 78 percent of reviewed noise walls were feasible and 62 percent (100) of these feasible noise walls were reasonable based on TxDOT cost-effectiveness criterion of $25,000 per benefited receptor.
- 75 percent of the non-reasonable noise walls (exceed criterion of $25,000 per benefited receptor) that were feasible do not have a specifically reported cost per benefited receptor value in the environmental assessment report.
- All noise walls that met the reasonableness criteria reported cost per benefited receptor value.
- In some instances, when the individual cost per benefited receptor for a wall is higher than the $25,000 criterion, multiple walls are grouped together to bring the average cost down and qualify for the cost-effectiveness criterion. This is called cost averaging, or a neighborhood concept. TxDOT policy is to allow individual district discretion in use of cost averaging on a case-by-case basis.
- TxDOT's unit construction cost value of $18 per square foot that is used to calculate the cost-effectiveness criterion of $25,000 is well below the current national average cost for noise barriers (combining all materials and barrier types) of $33.81 per square foot. However, it is somewhat of an arbitrary value alone, only having value in the context of how it relates to the cost-effectiveness criterion and a resultant barrier area per benefited receiver.

Findings

The research team developed the following findings based on the evidence found through the literature review process:

- Texas follows similar feasibility criteria as Florida, Illinois, California, Washington, and New York (i.e., 1 dB[A] lower than the value set by the federal NAC for each activity; see Table 2).
- Washington and Illinois have tier-based, cost-effectiveness criteria to address higher noise levels, or larger sound level increases, whereas California, Florida, New York, and Texas have a fixed value.

- The federal regulations published in July 2010 state that "the highway agency shall reanalyze the allowable cost for abatement (cost-effectiveness criteria) on a regular interval, not to exceed 5 years" (*7*). This statement was not in earlier federal regulations. TxDOT has used the same $25,000 cost-effectiveness criterion since 1992. Researchers were unable to determine when this initial value was set. The cost-effectiveness criterion was last reviewed in 1999. The criterion was not changed after that review.

- The definition of the first-row receiver varies throughout the peer states. In Texas, first-row receivers are owners and residents who are adjacent to a proposed project, whereas in California and Washington, the definition depends on topography and highway geometrics.

- In Texas, only the opinions of the benefited property owners adjacent to a proposed abatement measure are considered for the reasonableness criteria, whereas Florida, Illinois, and Washington consider both owner and resident opinions. Also in those states, second-row receivers are considered and given different weights.

- Most of the peer states have cost-effectiveness criteria using costs tied to the construction cost index.

- The definitions of feasible and reasonable noise abatement measures vary in terms of descriptions and standards.

- The land use activity area definitions used by all peer state highway agencies are consistent with each other, and they are consistent with those listed in the current federal regulations.

- The toll authorities in the peer states follow noise abatement guidelines set forth by their state highway agencies regardless of funding source.

- Federal guidelines state that the development and implementation of Type II projects are not mandatory requirements. Currently, TxDOT, FDOT, and IDOT do not participate in a Type II (retrofit) program.

Section 3. Interviews with Texas Agencies

Introduction

The purpose of the interviews was to identify and document noise mitigation measure issues for planning, design, public involvement processes, and policies and procedures. TxDOT and each toll authority received the questionnaire prior to the interview to facilitate the interview process and to give each agency an opportunity to collect and provide the necessary detailed information. The interview questionnaire is provided in Appendix H. A summary of the interview responses collected from each agency interviewed is provided in Appendix I. Table 10 lists the agencies and corresponding interview date.

Table 10. Agencies Interviewed and Interview Date.

Authority	Agency	Interview Date
Texas Department of Transportation	Environmental Affairs Division	Feb 11, 2016
Chapter 370 Regional Mobility Authorities	Central Texas Regional Mobility Authority (CTRMA)	Mar 29, 2016
	Cameron County Regional Mobility Authority (CCRMA)	May 12, 2016
	Northeast Texas Regional Mobility Authority (NETRMA)	Mar 29, 2016
	Camino Real Regional Mobility Authority (CRRMA)	Mar 30, 2016
Chapter 366 Regional Toll Authorities	North Texas Tollway Authority (NTTA)	Feb 23, 2016
Chapter 284 County Toll Authorities	Harris County Toll Road Authority (HCTRA)	Feb 18, 2016
	Fort Bend County Toll Road Authority (FBCTRA)	Feb 18, 2016
	Montgomery County Toll Road Authority (MCTRA)	Feb 19, 2016

Agency Interview Highlights

This section highlights the agency responses to various questions in the interview process.

In general, the tolling agencies follow TxDOT established guidance when planning and implementing noise mitigation measures on Texas toll roads.

TxDOT relies on two guidance documents to comply with regulations for federal projects authorized under 23 USC:

- *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*) (2011).
- *Environmental Handbook: Traffic Noise* (*24*) (updated January 2016).

These documents outline how TxDOT will implement the requirements of the FHWA noise standard in 23 CFR 772. These guiding documents apply to all federal, federal-aid, and state-funded Type I roadway projects authorized under Title 23 USC and apply to any roadway project or multimodal project that requires FHWA approval regardless of funding sources.

Planning

TxDOT and the tolling agencies were interviewed about planning for noise mitigation measures as they relate to benefit/cost analysis, local government involvement, the project development process, noise prediction, insertion loss, and environmental justice. The following sections highlight some of the key responses related to planning noise abatement measures.

Benefit/Cost Analysis

TxDOT uses the TNM Version 2.5 (*14*) to analyze noise prediction levels to determine if noise mitigation measures are warranted when considering the reconstruction of a highway or for a planned new highway. The inputs considered for the analysis include the planned roadway geometry, traffic inputs for the current year and design year (typically 20 years in horizon), average weather, average pavement type, and design speed limit for the planned roadway.

The costs included in the noise mitigation analysis conducted by TxDOT are based on the cost of the noise wall only, which is currently $18 per square foot, with a cost-effectiveness threshold per benefited receptor of $25,000. These costs are established to meet environmental justification and are typically less than the actual cost to build a wall. These cost-effectiveness limits are noted in TxDOT's *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*).

The guidelines for noise abatement analysis are established on a five-year cycle review, with the latest update results expected in late 2016. The tolling agencies choose to follow these guidelines when conducting a noise mitigation analysis for toll roads that are within their respective jurisdiction.

Local Government Role

Local government's role in funding noise abatement is usually not considered in TxDOT projects, except when considering the use of local funding for functional enhancements such as absorptive treatments, access doors, or aesthetic purposes. Local funding may not be used to help a proposed barrier meeting reasonableness criterion. The decision to partner with local government is typically left up to the individual TxDOT district.

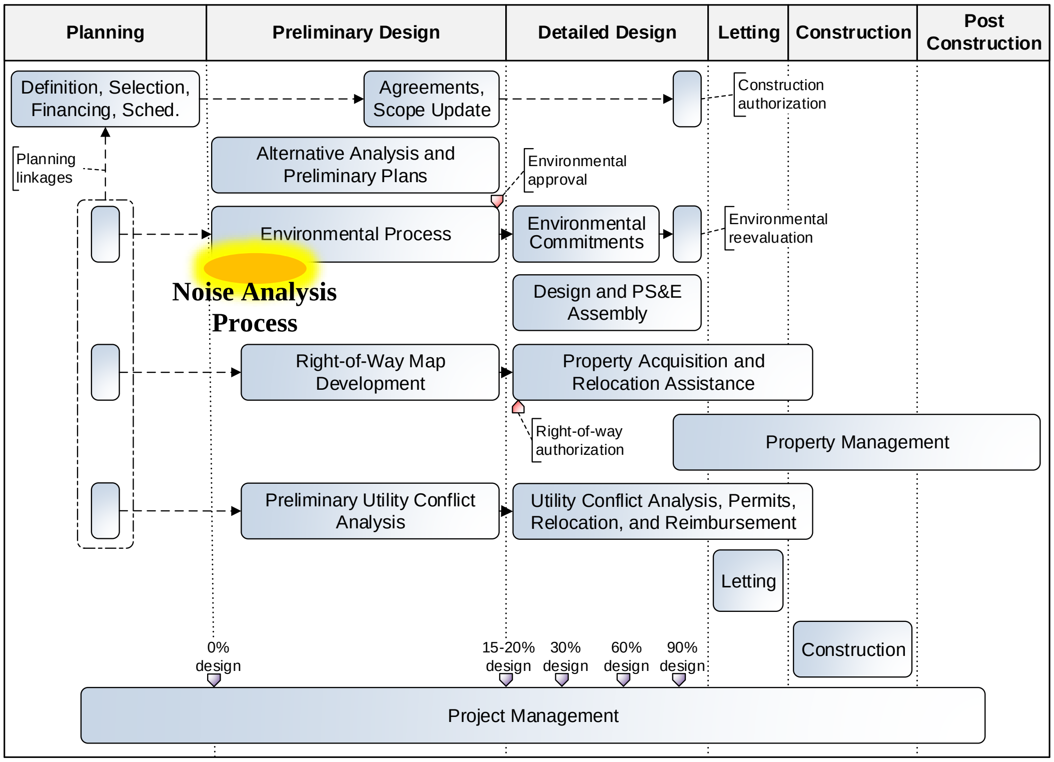
The tolling agencies collect toll revenues and use grants for funding, and may include funding from TxDOT in the form of right-of-way (ROW) property as needed. Most of the tolling agencies would be willing to partner with local entities on noise mitigation measures if a firm commitment and financial incentives from the local entities were made available.

Project Development Process

The decision for TxDOT to mitigate noise impacts is decided as early as possible in the project's environmental process. Figure 10 shows the TxDOT project development process.

TxDOT and most of the tolling agencies prefer to construct noise abatements early in a construction project, and noise abatement may be included as a provision in the construction contract. However, some of the interview respondents stated that if a provision is not included in the construction contract concerning when noise abatement is to be constructed, that decision can be left up to the contractor to decide based on constructability and any constraints, and it is generally project specific.

The interview respondents stated that noise abatement placement (noise wall location) is generally dictated by the land use adjacent to the project location and is decided based upon the existing building permit status of the adjacent properties (whether a building is planned or is a vacant lot) at the time of the noise analysis, which is after environmental scoping and review have occurred.



Source: (*25*).

Figure 10. TxDOT Project Development Process.

Traffic Noise Prediction Model

As previously stated, TxDOT and all the responding tolling agencies use the latest FHWA TNM, currently Version 2.5 released in April 2004, to perform noise mitigation analysis. The TNM uses input values that include pavement type, vehicle data including type and number of vehicles, noise source height, weather, and terrain characteristics.

The agencies stated that they use the default average pavement setting for a road surface type when conducting a noise analysis, except for CTRMA. CTRMA stated that it specifies “the pavement type per the project design” in its noise analyses. The TNM defaults to *average* for pavement type, and noise is determined by averaging the sound levels associated with both Portland cement concrete and dense-graded asphaltic concrete. Noise levels do vary when considering changes in pavement types and the corresponding interaction with various tire sizes. However, current information related to the extent that different types of pavements and tire size interaction contribute to traffic noise is limited, especially related to large truck volumes. The use of any other pavement type must be substantiated and approved by FHWA when federal funding is involved.

TxDOT, CCRMA, CRRMA, and CTRMA stated that they use TxDOT Transportation Planning and Programming Division (TPP) data as input for traffic vehicle volume and vehicle type. FBCTRA, HCTRA, MCTRA, and NTTA stated that they use agency data, private consultant data, or respective regional planning data to acquire traffic input data to be used in the model.

Other input information for the TNM relates to the characteristics of the noise source height, surrounding terrain features, and weather. Varied responses related to noise source heights used in noise analysis were provided by each of the different agencies and included input values as the roadway surface elevation (noise generated by tire interaction with pavement), the average car exhaust height, and the height of heavy-vehicle exhaust (noise generated from exhaust).

Responses by TxDOT related to land features located near a project location included characteristics of ground cover types, terrain, water sources, and existing barriers. Generally, average weather conditions are used as the input for the weather variable in the noise model. Most of the tolling agencies stated that they follow TxDOT guidance related to the input information for the TNM.

Insertion Loss

TxDOT and the tolling agencies typically do not field measure the actual benefit from noise barriers (insertion loss) to determine actual before/after noise measurement analysis. Rather, most of the agencies use the TNM to determine how noise abatement is expected to perform. If there is a need to perform this measurement in the field, respondents stated that the procedures follow FHWA guidance. One agency, NTTA, reported that in one instance, the NTTA Board of Directors requested an after sound study. NTTA reported following TxDOT procedures measuring noise at the first-row receptors but did not provide specific details. The after analysis warranted no further noise mitigation.

Environmental Justice

The agencies were asked if environmental justice (EJ) influences noise abatement treatments. EJ refers to the fair treatment and meaningful involvement of all people to avoid disproportionate impacts on certain populations. The general consensus of the agencies was that everyone is treated fairly and that EJ does not influence the design of noise abatement treatments. TxDOT noise policy favors denser communities since the number of benefited receivers behind proposed noise barriers increases, versus a low-density community where the cost-effectiveness criterion limits the amount of coverage available or large parcels.

Design

TxDOT and the tolling agencies were interviewed about the design of noise mitigation measures as they relate to community input, noise wall mitigation, and noise abatement. The following information highlights some of the key responses related to the designing of noise abatement measures.

Community Input

TxDOT and the tolling agencies receive input from the community on design details of noise wall mitigation measures. This input is commonly received from the community during a noise workshop when a noise wall has been proposed for a highway project. One tolling agency, FBCTRA, has developed a standard design for the highway side of noise wall barriers for roadways that the agency has jurisdiction over. However, FBCTRA will consider input on the receiver side of the proposed noise wall. NTTA has its own noise wall design that it uses along all the roadways the agency has jurisdiction over, and NTTA does not solicit input on noise wall design aspects.

Community input participants are generally identified through the local tax appraisal records as the property owners that are directly impacted by a planned noise wall, typically the first row of property owners adjacent to the planned noise wall. Various methods are used to contact the adjacent property owners to announce noise abatement workshops, including direct mailers, websites, email blasts, public outreach, and door hangers.

Noise Wall Mitigation

TxDOT and most of the tolling agencies use the TNM to determine the height and length of a planned noise wall. This procedure is generally performed by adjusting the height and length of the wall within the TNM until the optimal performance of the noise wall is determined. TxDOT stated that a noise wall typically has a design goal of one receiver to get a 7-dB(A) reduction (highest critical receptor) and a more feasible (reasonable) goal of greater than 50 percent of the receivers getting a 5-dB(A) reduction (most critical receptors). Tolling agency responses for this procedure varied from using the highest critical receptor benefited to the most critical receptors benefited.

The Oxford English Dictionary defines *line of sight* as a straight line along which an observer has unobstructed vision. When the various agency representatives were asked to define line of sight as it relates to noise analysis, various responses were provided and include the following:

- The unobstructed line between the noise source and the receiver.
- The height of the receiver to the source of noise.
- The receptor "seeing" the noise source—the average height of a standing person.
- From where the receptor location is defined to the noise source.
- The receiver seeing the sound source.

These responses tend to acknowledge that line of sight as it relates to noise is consistent in that the noise source can be seen unobstructed at the receiver location. With that in mind, noise walls are generally placed somewhere between the noise source and the receiver. When asked about the lateral placement of noise walls, the agency responses varied, as follows:

- TxDOT: Project specific (either closer to the receiver or closer to the source [not typically an intermediate location]).
- CCRMA: Close to the receiver/right-of-way.

- CRRMA: First try to put it on the right-of-way line; then will adjust one way or the other if needed.
- CTRMA: Closer to the receiver/right-of-way.
- FBCTRA: At the right-of-way line.
- HCTRA: Ideally on the right-of-way line and closer to the source.
- MCTRA: The right-of-way.
- NTTA: Site specific—closer to the receiver if possible.

In general, TxDOT and the tolling agencies will attempt to place a noise wall as close as possible to the affected receivers and ideally within the public right-of-way. According to TxDOT, if a noise wall were to be placed outside the public right-of-way, a formal agreement with the local jurisdictional entity or affected property owners precluding TxDOT from any future noise wall maintenance obligations would have to be finalized.

Other Noise Abatements

Neither TxDOT nor any of the responding tolling agencies have used any nontraditional noise abatement materials, such as insulated windows or absorbent panels, on existing building structures located off the right-of-way in lieu of using noise walls. The agency responses were generally that those noise abatement measures would have to be located off the right-of-way. Long-term maintenance by the agency would become an issue and would make the costs too high to be feasible.

Public Involvement

TxDOT and the tolling agencies were interviewed about the public involvement in noise abatement decision making, the extent of community involvement, and any litigation involving noise abatement. The following sections highlight some of the key responses related to public involvement in noise abatement measures.

Noise Abatement Decisions

Once the planning process has determined that a noise wall is both reasonable and feasible at a certain location, the decision to implement a noise wall is then presented to the public for discussion. In general, the agencies' responses were that only first-row adjacent property owners have a say (or vote) in the acceptance and implementation of a noise wall. This is consistent with TxDOT guidelines. TxDOT and all interviewed tolling agencies use the process of a simple majority vote for or against to decide the outcome of the noise wall implementation. The residents of rental property and multifamily residents located along an area that is considered for a noise wall may provide comments at a noise wall workshop, at a public hearing, or to the property owner, but only the property owner of the rental property has a vote. Additionally, offset or second-line receivers located near a proposed noise wall site can comment on a noise wall option but have no vote.

Community Involvement

Involvement of the community in the planning of a noise wall treatment typically occurs during the early stages of project development. For TxDOT and some of the tolling agencies, this is commonly during the project development process. TxDOT and the interviewed tolling agencies stated that, in general, formal and informal public meetings and noise workshops are used to present the planned noise wall to a community and record any feedback from the community.

Workshops include the use of electronic presentations, poster boards, and graphics/schematics to display noise wall design concepts. TxDOT and NTTA stated that computer visualization has been used to show or render a proposed noise wall and is used to customize presentations for different types of stakeholders, such as separate business locations and separate neighborhood homeowners' association presentations.

Techniques used to announce public meetings to the community continue to include traditional methods such as newspaper notices and direct mailers to the adjacent property owners. Newer concepts used by some of the agencies to announce information to the community about roadway projects and noise wall mitigation involve social media techniques such as project-specific websites, Twitter, Facebook, and email blasts. A unique technique among those interviewed is CTRMA's use of door hangers for announcements of public meetings and workshops.

Policy and Procedures

TxDOT and the tolling agencies were interviewed about standard policy and procedures in noise abatement decision making. The following sections highlight some of the key responses related to the public involvement in noise abatement measures.

Exceptions

The tolling agencies follow the standard guidance as outlined and provided by TxDOT. TxDOT did provide some instances where exceptions occurred from its standard guidance. One instance included a re-vote on a noise wall. Normally, the voting process includes only one opportunity for the affected adjacent property owners to get to vote, and the decision is made from the simple majority vote to build or not build a noise wall; at that point, the process is concluded. However, in one instance, an unknown utility impacted the constructability of a planned noise wall after a vote had occurred to accept the plan. A new noise wall design near the same location was initiated and a second vote was allowed due to the extenuating circumstance.

In another instance where an exception from the standard guidance occurred, a noise wall was proposed to be extended off the right-of-way (which is not a normal TxDOT practice). The off-right-of-way noise wall had to be accepted by 100 percent of the affected adjacent property owners, and the agreement included that TxDOT would not maintain the noise wall upon completion of the project. The off-right-of-way noise wall was accepted by all affected adjacent property owners. An unresolved question for TxDOT at the time of this situation was presented and continues to this day: How will the property owners perform and manage maintenance of the off-right-of-way noise wall in the future?

Planned Changes

TxDOT is currently reviewing the cost basis for implementing a noise wall and moving to a noise wall square-foot-per-receiver approach. The findings of this study are expected by December 31, 2016, with possible implementation sometime in 2017. TxDOT is also considering updating the *Guidelines for Analysis and Abatement of Roadway Traffic Noise* (*9*) to clarify procedures and possibly changing the standard guidance requirement for the feasibility to build a noise wall: it would have to benefit at least two receivers. No time frame for this possible update was provided.

In general, the tolling agencies will follow TxDOT guidance and consider changes only when TxDOT has incorporated those changes into its standard policy and procedures. All the tolling agencies stated that they have not made any changes to their current standard policy and procedures for noise abatement consideration.

Findings

Based on the discussions with representatives from TxDOT and the interviewed tolling agencies in Texas, the research team compiled the following findings about noise mitigation measures and practices along Texas highways:

- The toll authority agencies generally follow TxDOT established guidelines for the analysis and implementation of noise mitigation measures on Texas highways.
- The FHWA TNM Version 2.5, the most current version available, is used for traffic noise modeling and analysis by the agencies.
- Most of the agencies use the required TNM default average pavement type for noise analysis, which is represented by the sound levels associated with both Portland cement concrete and dense-graded asphaltic concrete. Noise levels do vary between changes in pavement types and tire size interaction. However, current information related to the extent that this contributes to traffic noise is limited, especially as it relates to large truck volumes. Presently, the use of any other pavement type must be substantiated and approved by FHWA when federal funding is involved.
- Costs for noise wall mitigation are determined using the TxDOT guidelines of $25,000 per benefited receiver and $18.00 per square foot of noise wall. The costs are determined for noise wall placement only and typically do not include right-of-way, utility relocation, etc. These costs are established to meet environmental justification and are typically less than the actual cost to build a wall.

- The public is welcome to participate in noise workshops; however, consistent with TxDOT guidelines, only the affected first-row property owners cast votes in the process to determine noise wall implementation.
- Only one of the queried agencies has conducted noise measurement analysis after construction of a noise wall measure (after studies).
- Social media, including email, Twitter, and websites, is becoming an additional useful tool for the dissemination of upcoming workshop and public meeting announcements.

Section 4. Field Study Methodology

Advance Planning

Many monitoring locations were on privately owned properties (e.g., backyard of a house or patio of a restaurant). TTI researchers obtained written permission to use private property to record field measurements. TTI staff identified the property owners and their addresses from county tax assessor records. Right-of-entry forms were then mailed to the property owners.

Advanced notification was also sent to the local city police department advising of the team's general arrival time, locations of and planned activities, and vehicles being used for data collection.

Field Measurement Process

Sound level measurements and meteorological data were collected at each of the eight locations per study site. An example instrument setup is shown in Figure 11. Sound level measurements were recorded for 15-minute periods in each of the morning (7 a.m. to 9 a.m.), early afternoon (1 p.m. to 3 p.m.), and evening (5 p.m. to 7 p.m.) periods. Staff also collected traffic data from the highway main lanes during these periods. The traffic data collected were vehicle hourly volume, vehicle classification, and vehicle speed. Video data were used to collect volume and vehicle classification, or this information was requested from the operating agency. Speed data were collected using a handheld Doppler-radar gun.

Figure 11. View of Sound Level Meter and Weather Station Setup at Monitoring Location with Line of Sight to Highway.

Description of Field Monitoring Equipment

Sound Level Meter

The Brüel & Kjær Type 2250 Sound Level Meter (SLM) was used to obtain the noise level measurements.

Weather Station

Meteorological data were collected using a Vantage Vue manufactured by Davis Instruments. It consists of an Integrated Sensor Suite (ISS) and a wireless console. The ISS measures temperature, relative humidity, dew point, wind speed, wind direction, highest wind speed (gust), gust direction, wind chill, heat index, barometric pressure, total rain, and rain rate, and it records the values for each of these variables at one-minute intervals.

Section 5. Field Study Site Descriptions

This section describes the three field study sites selected. These field study sites were selected to represent a variety of projects of both TxDOT and toll road authorities spread throughout the state (not concentrated in one area). Brief descriptions of the roadways are provided in this section, and additional information is provided in Appendix J. In addition, facts from the projects' environmental documents are presented to relay the number of modeled receivers and types of land uses, if existing noise was modeled or measured, and information about recommended walls. Google Maps™ was used to collect ground-level views of the walls and some 3D models of the land uses behind the walls. Table 11 presents an abbreviated summary of the three selected locations.

Table 11. List of Field Study Locations.

Roadway	County	Authority	Ambient Noise Levels	No. Noise Walls	No. Study Receivers	Facility Open
SH 99 (Grand Parkway) Segment G	Harris	TxDOT	Yes	7	165	2016
US 183A	Williamson	CTRMA	Yes	4	26	2007
Pres. George Bush Turnpike Eastern Extension	Dallas	NTTA	Yes	5	14	2011

SH 99 (Grand Parkway) Segment G

This study site (Figure 12) is located in Harris and Montgomery Counties. The section is a new-location, four-lane, controlled-access facility with discontinuous frontage roads and varying grades to adjacent properties between I-45 near the city of Spring and I-69 in the city of New Caney (approximately 13.7 mi). Segment G connects completed sections of a loop to the west of the study site. The roadway was built and is operated under the authority of TxDOT. The facility fully opened to traffic in 2016 (*26*).

The final environmental impact statement documents the ambient noise levels and results of the TNM analysis. The noise analysis evaluated 165 noise receiver sites (163 residential, one recreation, and one school land use) along the preferred alignment. The results of those noise level projections are recorded in Table 4-21 of the Final Environmental Impact Statement (FEIS). Seven noise walls were proposed for the project, as summarized in Table 12. The values presented are taken directly from the environmental documentation and reflect estimated costs.

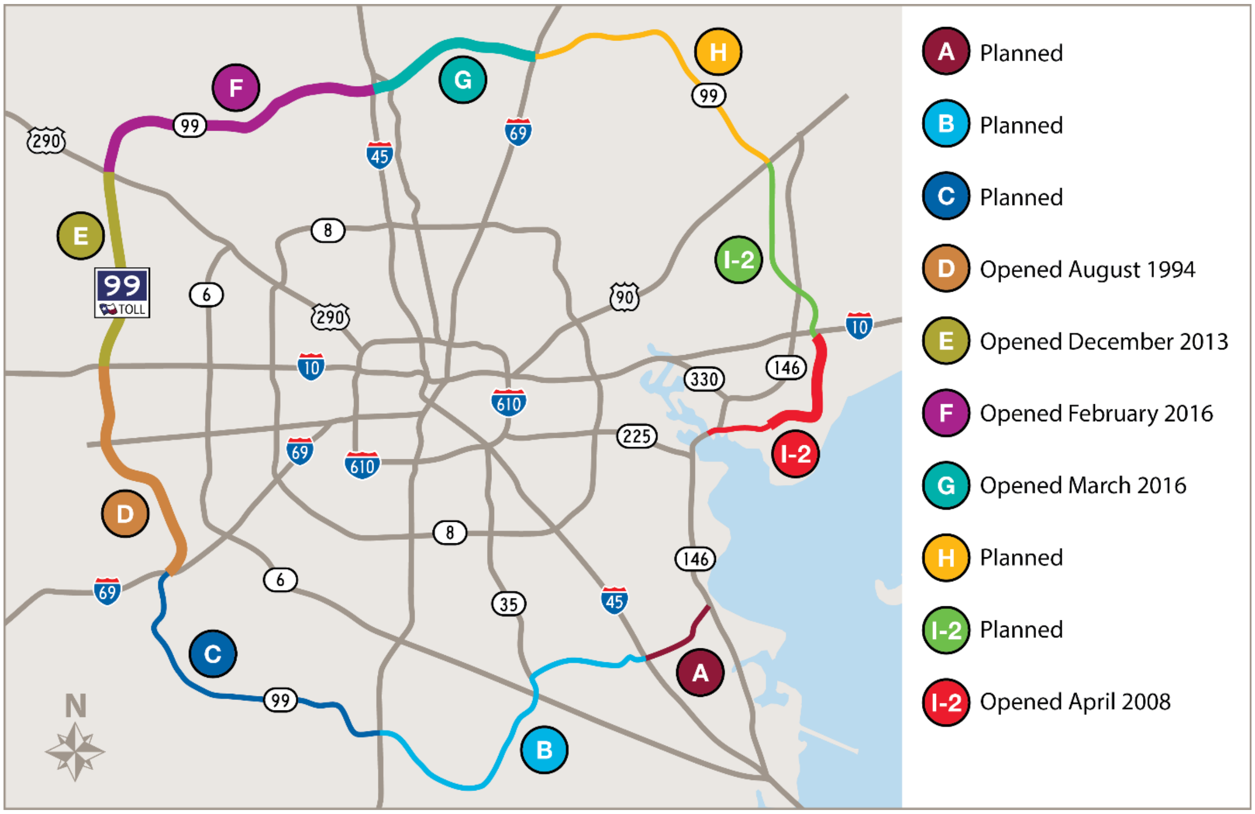


Figure 12. SH 99 (Grand Parkway) System Map.

Table 12. Noise Walls Proposed on SH 99 Segment G.

Barrier	Impacted Representative Receivers	Preliminary Dimensions		Total Cost	# Benefiting Receivers	$/Benefiting Receivers
		Length	Height			
1	1, 4, 5, 14, 15, 16, 18, 19, 21, 23, 24, 25	5,547	16	$1,331,280	34	$18,438
	*1, 4, 6, 13, 14, 15, 16, 18, 19, 21, 23, 24, 25			$1,597,536*	68*	$23,493*
2	32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48	3,322	16	$797,280	39	$20,443
3	49, 50, 51, 52, 55, 57, 58, 60, 61, 64	2,482	16	$595,680	31	$21,617
4	65, 66, 67, 68	1,166	16	$279,840	12	$23,320
5	98, 99, 100, 103, 104, 105, 106	1,970	16	$472,800	21	$22,514
8	127, 128, 129, 130, 131	2,079	16	$498,960	26	$19,191
9	140, 141, 142, 145, 146, 147, 148, 149, 153, 154	3,014	10	$452,100	19	$23,795

* Change as recorded in 2012 reevaluation document.
Source: (*27*, *28*).

US 183A

This study site (Figure 13) is located in the cities of Cedar Park and Leander in Williamson County. The new-location section is a six-lane divided toll facility with discontinuous, non-tolled frontage roads at varying grades to adjacent properties between the US 183/SH 45 interchange and the South San Gabriel River (approximately 4.1 mi). The roadway was built (under a design-build contract) and is operated under the authority of the Central Texas Regional Mobility Authority. The facility fully opened to traffic in March 2007.

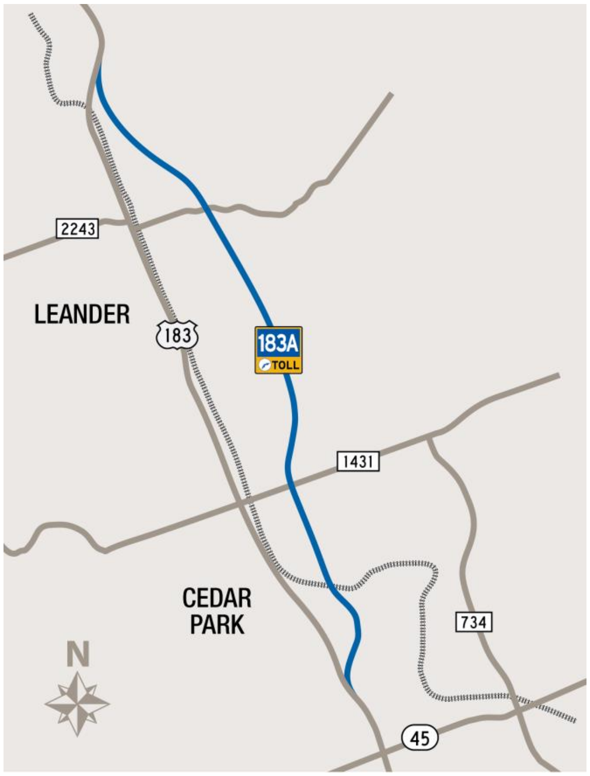
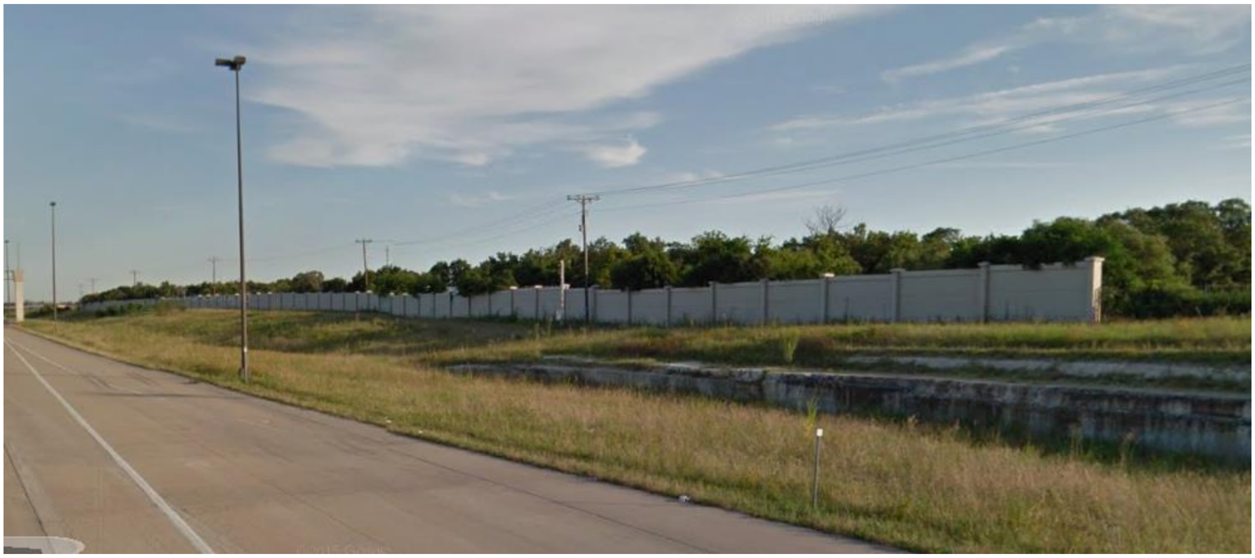


Figure 13. US 183A System Map.

This project was originally modeled with the STAMINA 2.0 noise model, the current noise model at the time of the analysis. Later project reevaluations used the TNM since reevaluations required noise analysis from vertical or horizontal alignment changes.

Based on the original noise analysis, four noise walls were recommended and constructed to benefit 144 properties. For Receiver 2, two walls were proposed to benefit 71 residences. Wall 1 proposed was 3,000 ft long and 12 ft high at an estimated cost of $756,000, or $22,909 per benefited receptor. Wall 2 proposed was 600 ft long and 12 ft high at an estimated cost of $151,200, or $16,800 per benefited receptor. For Receiver 3, two walls were proposed to benefit 73 residences. Wall 3 proposed was 2,250 ft long and 12 ft high at an estimated cost of $567,000, or $21,808 per benefited receptor. Wall 4 proposed was 2,000 ft long and 12 ft high at an estimated cost of $504,000, or $20,160 per benefited receptor. A noise wall constructed for this project is displayed in Figure 14.



Source: (*29*).

Figure 14. Noise Wall on Southbound US 183A between E Park St and Brushy Creek Rd.

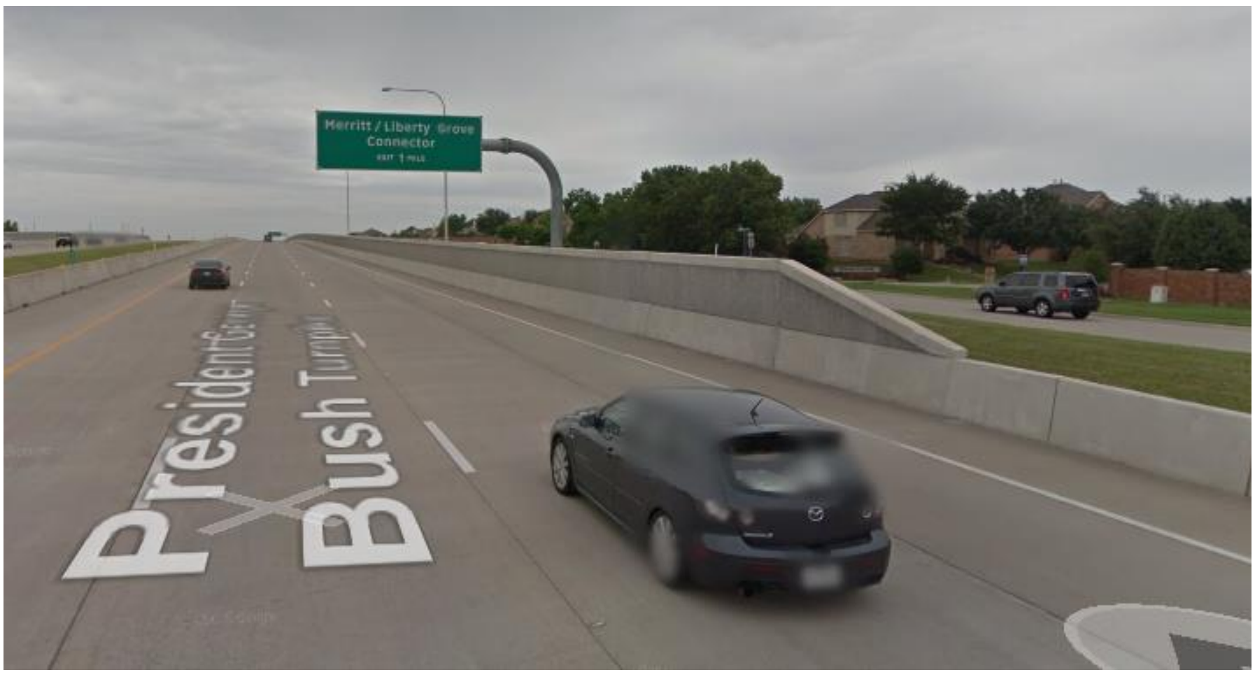
President George Bush Turnpike (PGBT) Eastern Extension

This study site (Figure 15) is located in the cities of Garland, Sachse, and Rowlett in Dallas County. The section is a new-location, six-lane divided facility with varying grades to adjacent properties between SH 78 and I-30 (approximately 9.9 mi). The roadway was built and is operated under the authority of the North Texas Tollway Authority. The facility fully opened to traffic in December 2011.

Figure 15. President George Bush Turnpike Eastern Extension.

The original FEIS identified four walls that were feasible and reasonable. Wall 1 proposed was 2,900 ft in length with an average height of 12 ft benefiting 26 receivers for an estimated cost of $626,400, or $24,092 per benefited receptor. Wall 2 proposed was 1,100 ft in length with an average height of 10 ft benefiting nine receivers for an estimated cost of $198,000, or $22,000 per benefited receptor. Wall 3 proposed was 2,600 ft in length with an average height of 10 ft benefiting 35 receivers at an estimated cost of $468,000, or $13,371 per benefited receptor. Wall 4 proposed was 2,900 ft in length with an average height of 10 ft benefiting 34 receivers at an estimated cost of $522,000, or $15,353 per benefited receptor.

A reevaluation published in 2008 changed the design year from 2025 to 2030. The analysis results proposed a fifth wall and reduced the barrier height of the previous four walls to 8 ft. A noise wall constructed for the project is displayed in Figure 16.



Source: (*29*).

Figure 16. Noise Wall Located on Northbound PGBT South of Liberty Grove Rd.

Section 6. Field Study Results

This section presents and discusses the results of the three field studies at SH 99 Segment G in Houston, US 183A in Cedar Park/Leander, and President George Bush Turnpike Eastern Extension in Garland, Sachse, and Rowlett. Appendix K provides additional details on field study notes.

The section begins with a presentation of a simple assessment that determined if the noise walls blocked or obscured the line of sight between receiver and noise source (highway). This is followed by a presentation of data comparing traffic data collected against the modeled future-year traffic volumes and vehicle mix. Information on the pavements is presented. A visual comparison of satellite imagery between the year the environmental documentation was published and 2016 is presented. Finally, results from the sound level measurements are presented. Additional details of the analysis are provided in Appendix L. The appendix provides additional discussion on the quality checks that researchers performed on the TNM inputs received for analysis.

Line of Sight

The literature review presented information stating that noise walls that block the line of sight between the receiver and noise source typically reduce noise levels by 5 to 10 dB(A). The line of sight between the highway and this study's measured receivers was evaluated. The following observations were made:

- All noise walls at the SH 99 Segment G study site blocked the line of sight between this study's measured receivers and the highway.
- All noise walls at the US 183A study site blocked the line of sight between this study's measured receivers and the highway. However, inspection of Google Street View™ images from east of the highway show that the line of sight is not always broken, such as in Figure 17, which shows a view looking west from the intersection of Darkwoods Dr and Cashew Ln where a heavy truck traveling northbound is in the image view.
- The noise wall located adjacent to Site 8 at the President George Bush Turnpike Eastern Extension study site did not block the line of sight between the receiver and the noise source. Figure 18 displays a photograph taken from this site. In the photograph, the sound level meter and weather station are shown in the foreground. In the background, a heavy truck can be seen toward the right side of the image. The truck above the height of the tires is clearly visible, allowing noise from the engine and the exhaust to travel directly to the receiver site.

Source: (*29*).

Figure 17. Unobstructed Line of Sight to Noise Source at US 183A at Intersection of Darkwoods Dr and Cashew Ln.

Figure 18. Unobstructed Line of Sight to Noise Source at President George Bush Turnpike Eastern Extension Site 8.

Traffic Data

The traffic data collected at each of the field study sites consisted of main lane traffic volumes and vehicle classification. These data were converted into design hourly volumes (DHVs) and were compared to the field study site's design year DHV used in the TNM analysis.

Traffic Volumes

Table 13 displays a comparison of traffic volumes represented by the DHV used as an input to the TNM. A design hourly volume is the result of factoring an annual average daily traffic volume by a K-factor typically representing the 30th highest hourly volume and a directional split, where 0.5 represents an equal balance in volume by direction. The Environmental TNM DHV column represents the DHV taken from the TNM modeling inputs used to prepare the official environmental document. The 2016 Traffic Data DHV column represents the DHV applying the same K-factor and direction factors as documented in the study site's TNM inputs but applied to the measured 2016 average daily traffic for this study.

The SH 99 Segment G and US 183A study sites have −27 percent to −83 percent less traffic than the design year forecast. The President George Bush Turnpike Eastern Extension, however, has traffic that is +41 percent to +113 percent higher than the design year forecast. TTI researchers suspect that the design year DHV was estimated low due to the application of a directional split on what appears to be a directional annual average daily traffic.

Table 13. Comparison of Design Hourly Volumes between 2016 Traffic Volumes and TNM Input for Environmental Documentation.

Study Site	Design Year	Direction	Environmental TNM DHV (Min–Max)	2016 Traffic Data DHV	2016 Traffic Difference from TNM Maximum	% 2016 Difference from TNM Maximum
SH 99 Seg G	2025	WB/NB	1,770–3,162	619	−2,543	−80
		EB/SB	1,400–3,354	580	−2,774	−83
US 183A	2020	WB/NB	476–4,288	2,205	−2,083	−48
		EB/SB	2,162–2,656	1,940	−716	−27
PGBT-EE	2030	WB/NB	987–1,389	2,963	+1,574	+113
		EB/SB	1,506–2,154	3,047	+893	+41

Vehicle Classification

Table 14 displays a comparison of the vehicle classification from the TNM analysis used for environmental documentation with measured 2016 vehicle classification distributions. Trucks and motorcycles are typically associated with higher noise; generally, more trucks and motorcycles will lead to higher noise levels. This table shows that at SH 99 Segment G and President George Bush Turnpike Eastern Extension, the combined truck, bus, and motorcycle volumes are higher than modeled in the environmental documentation—2.1 to 3.4 times more trucks for SH 99 Segment G and 2.1 to 3.7 times more trucks for President George Bush Turnpike Eastern Extension. Medium trucks at SH 99 were observed to be two to three times greater than modeled. At the President George Bush Turnpike Eastern Extension site, heavy trucks were observed to be three to four times greater than modeled, and medium trucks were two to three times greater than modeled. At US 183A, the 2016 vehicle classification data were consolidated to the heavy truck classification since that was the only truck classification used in the TNM input for the environmental documentation. Truck volumes at the US 183A study site were observed to be lower (3 percent observed versus 5 percent modeled).

Table 14. Comparison of Vehicle Classification in Design Hourly Volumes between 2016 Traffic Volumes and TNM Input for Environmental Documentation.

Study Site	Design Year/ Current Year	Direction	Percentage				
			Auto	Heavy Truck	Medium Truck	Buses	Motorcycles
SH 99 Seg G	2025	WB/NB	95	3	2	0	0
		EB/SB	95	3	2	0	0
	2016	WB/NB	87.7	5.1	6.9	0	0.3
		EB/SB	91.4	3.2	4.2	0	0.4
US 183A	2020	WB/NB	95	5	0	0	0
		EB/SB	95	5	0	0	0
	2016	WB/NB	97	3	0	0	0
		EB/SB	97	3	0	0	0
PGBT-EE	2030	WB/NB	96.7	0.7	2.7	0	0
		EB/SB	96.7	0.7	2.6	0	0
	2016	WB/NB	91.1	2.7	5.8	0.1	0.3
		EB/SB	88.0	2.0	9.7	0.1	0.3

Pavement

FHWA directs that an average pavement type be modeled. The average pavement represents the averaged sound generation from Portland cement concrete and dense-graded asphaltic concrete. However, all three study sites had Portland cement concrete pavement main lanes.

Land Use Changes

Development that has occurred near the study sites since the environmental assessments (EAs) were prepared likely contribute to an increase in the ambient noise. The research team reviewed satellite images of the study sites since the EAs were prepared and found moderate growth in residential and commercial development at the US 183A and President George Bush Turnpike Eastern Extension study site corridors. Both of these corridor study sites show development of the land use around the corridor. Additional development can contribute to additional background noise and greater traffic volumes on roadways meeting the demands of these developed properties. Researchers did not find measurable growth at the SH 99 study site. This lack of growth is likely due to the recent opening of this new facility and the lack of advance development anticipating its opening.

Sound Level Measurements

The sound level measurements are presented in Table 15 through Table 17 and are compared against both the sound levels published in the project's environmental documentation (without and with noise barriers) and against a 2016 modeled sound level represented with 2016 traffic data.

The SH 99 Segment G results are shown in Table 15. At this field study location, the field sound levels recorded were higher than the predicted design year sound levels with a noise barrier at three out of seven locations, where the measured increases were +9 dB(A), +3 dB(A), and +1 dB(A). In contrast, four out of seven locations measured sound levels less than the predicted design year levels, ranging from −1 dB(A) to −10 dB(A). Running the TNM with 2016 main lane traffic volumes, vehicle classification, and speed data showed little difference (0 to −1 dB[A]) compared to the design year predicted noise levels with and without barrier.

The US 183A results are shown in Table 16. At this field study location, the field sound levels recorded were higher than the predicted design year sound levels with a noise barrier at one of two locations, where the measured increases were +3 dB(A). In contrast, one location measured sound levels less than the predicted design year by −3 dB(A). Running the TNM with 2016 main lane traffic volumes, vehicle classification, and speed data showed a moderate difference (ranging from −1 dB(A) to −4 dB[A]) compared to the design year predicted noise levels with and without barrier. This study site was unique in that the sound levels were predicted originally using the STAMINA noise model, which has since been replaced by TNM. A later environmental reevaluation did use the updated TNM v2.1 model for analysis. Also, the sound modeling for the environmental documentation revealed that (a) only automobiles and combined trucks were modeled instead of greater refinement of the truck classifications, and (b) the design volumes were modeled in a single lane instead of equally dividing them across the available lanes (i.e., one lane versus three lanes).

The President George Bush Turnpike Eastern Extension results are shown in Table 17. At this field study location, the field sound levels recorded were higher than the predicted design year sound levels with a noise barrier at four out of six locations, where the measured increases were +5 dB(A), +10 dB(A), +7 dB(A), and +6 dB(A). Site 1 and 1B were located behind the same noise wall, were adjacent properties, and had data collected on two different days. The results showed that Site 1 recorded a sound level higher than the design year predicted noise level, whereas the adjacent property on the next day did not record a noise level higher than the design year predicted level. It is also noted that Site 6 was measured at an area between two private properties after the right-of-entry request was denied. This location may be influenced by additional sound reflection between the exterior walls of the two residences. In contrast, two of six locations measured sound levels less than the predicted design year by −2 dB(A) and −7 dB(A). Running the TNM with 2016 main lane traffic volumes, vehicle classification, and speed data showed little difference (0 dB[A] expect for one location with a +1 dB[A]) compared to the design year predicted noise levels with and without barrier.

Table 15. Sound Level Measurement Results Comparison for SH 99, Grand Parkway.

TTI Location	Wall?	Name in Environmental Document	2025 TNM Results (Leq, dBA) No Barrier	2025 TNM Results (Leq, dBA) With Barrier	2016 TNM Results (Leq, dBA) No Barrier	2016 TNM Results (Leq, dBA) With Barrier	2016 Observed (Leq, dBA)	Time Period	Diff. from 2025 with Barrier Leq, dBA
1A	Yes	Receiver 9 NGXN	58	54	58	53	63	AM	+9
							60	Midday	+6
							62	PM	+8
2	Yes	Receiver 19 NGXS	64	57	64	57	56	AM	−1
							54	Midday	−3
							56	PM	−1
3A	Yes	Receiver 38 SPRING TRAILS	58	56	57	56	60	AM	+4
							57	Midday	+1
							60	PM	+4
4	Yes	Receiver 49 Fox Run	66	59	66	58	60	AM	+1
							58	Midday	−1
							60	PM	+1
5A	Yes	Receiver 65 Lockeridge	66	65	65	64	54	AM	−9
							54	Midday	−9
							55	PM	−10
7	Yes	Receiver 145 Timberland S	66	58	66	58	52	AM	−6
							53	Midday	−5
							54	PM	−4
8	Yes	Receiver 153	64	59	64	59	53	AM	−6
							52	Midday	−7
							56	PM	−3

Note: Cell shading indicates that observed values exceeded 2025 TNM results with barrier.

Table 16. Sound Level Measurement Results Comparison for US 183A.

TTI Location	Wall?	Name in Environmental Document	2020 TNM Results (Leq, dBA)		2016 TNM Results (Leq, dBA)		2016 Observed (Leq, dBA)	Time Period	Diff. from 2020 with Barrier Leq, dBA
			No Barrier	With Barrier	No Barrier	With Barrier			
5	Yes	R2	72	65	70	61	68	AM	+3
							62	Midday	−3
							64	PM	−1
6	Yes	R3	72	66	70	65	57	AM	−9
							57	Midday	−9
							63	PM	−3

Note: Cell shading indicates that observed values exceeded 2030 TNM results with barrier.

Table 17. Sound Level Measurement Results Comparison for President George Bush Turnpike Eastern Extension.

TTI Location	Wall?	Name in Environmental Document	2030 TNM Results (Leq, dBA) No Barrier	2030 TNM Results (Leq, dBA) With Barrier	2016 TNM Results (Leq, dBA) No Barrier	2016 TNM Results (Leq, dBA) With Barrier	2016 Observed (Leq, dBA)	Time Period	Diff. from 2030 with Barrier Leq, dBA
1	Yes	R1	65	61	65	62	59	AM	−2
							66	Midday	+5
							60	PM	−1
1B	Yes	R1B	65	63	65	63	59	AM	−4
							57	Midday	−6
							61	PM	−2
2	Yes	Receiver 3	70	64	70	64	62	AM	−2
							56	Midday	−8
							58	PM	−6
4	Yes	Receiver 5	70	65	70	65	57	AM	−8
							56	Midday	−9
							58	PM	−7
5	Yes	Receiver 9	66	59.	66	59	69	AM	+10
							64	Midday	+5
							64	PM	+5
6	Yes	Receiver 10	62	59	62	59	66	AM	+7
							63	Midday	+4
							64	PM	+5
8	Yes	Receiver 12A	71	63	71	63	68	AM	+5
							67	Midday	+4
							69	PM	+6

Note: Cell shading indicates that observed values exceeded 2030 TNM results with barrier.

Sound level measurements were taken at 16 locations behind noise walls at three study sites. Sound levels that exceeded the design year predicted sound level were measured at eight of these locations. Of these eight locations not meeting the noise abatement prediction, five locations exceeded the predicted sound level with a noise wall for all three time periods, one location exceeded the predicted sound level with a noise wall for two time periods, and two locations exceeded the predicted sound level with a noise wall for one time period. In contrast, sound levels were measured below the design year predicted sound level at eight of these locations.

Table 18 presents a summary of the highest recorded sound measurements for all 16 locations over the three time periods compared to the predicted sound level for that location, in absolute values. Under-prediction is associated with higher measured sound levels and under-predicted model levels. In contrast, over-prediction is associated with lower measured sound levels and over-predicted model levels. The sound models are evenly split between over- and under-prediction.

Table 18. Sound Model Performance Compared to 2016 Measured Sound Levels.

Model Performance Compared to 2016 Sound Level Measures	Frequency of Locations' Absolute Value from Predicted Sound Level			
	1–2 dB(A)	3–5 dB(A)	6–10 dB(A)	Total
Under-prediction	1	3	4	8
Over-prediction	3	3	2	8

Possible Reasons for Higher Measured Sound Levels versus Predicted Sound Levels

Measured sound levels may be higher than predicted sound levels for a variety of reasons. Some of these reasons are presented and briefly discussed below. These reasons are not presented in any particular order of importance or effect.

- The noise wall did not break the line of sight (present at two study sites).
  Discussion: Noise walls are most effective when they break the line of sight between the noise source and the receiver. When the line of sight is maintained, the effectiveness of the noise wall is greatly diminished.

- Total current volume of traffic is higher than traffic TNM volume inputs (present at one study site).
  Discussion: Traffic noise modeling depends on inputs from many sources. One input is the predicted traffic volume since the sound is directly related to traffic volumes. Predicted traffic volumes are derived within the transportation planning process from the application of travel demand models used to forecast regional traffic demand across the transportation network.

- Percent trucks are higher than the truck traffic TNM inputs (condition present at two study sites).
  Discussion: Truck engines and exhausts are higher in elevation compared to automobiles and pickup trucks. These vehicles also are typically associated with higher noise levels from their engines and exhaust systems.

- Actual pavements used in the corridor result in higher noise levels (e.g., Portland cement concrete) than the average pavement type used in the TNM (present at all study sites).
  Discussion: The FHWA TNM guidance directs analysts to use an average pavement type. However, Portland cement concrete pavements are typically associated with higher noise levels than other pavement types. It is common for Portland cement concrete to receive a surface treatment (tining) that applies slight grooves perpendicular to the vehicle travel path, which can generate greater sound than other available texturing methods. A more conservative modeling approach would assume the worst noise pavement surface.

- Unknowable and unpredictable changes occur in the built environment beyond and adjacent to noise walls placed along right-of-way lines.
  Discussion: Development along the corridor may contribute to raising ambient noise levels as measured in the pre-construction environmental documentation. However, the increase in ambient noise level should be expected to be very minimal. The traffic noise modeling only predicts sound generation from the proposed project. The noise analysis does not account for other sources such as side streets, airports, and industrial areas.

- Differences between measured location and modeled location exist since exact coordinates were not available or right of entry was not granted (Site 6 in PGBT Field Study was located between two houses).
  Discussion: Measured noise levels from a different location introduce different sound travel pathways for noise across different surfaces, resulting in different noise levels.

Section 7. Findings

This section summarizes the research team's findings from the literature, interviews, and field study results. The findings are presented in relation to the questions posed by HB 790.

Sound Mitigation Process, Methodology, and Implementation

The federal noise guidelines are straightforward in terms of criteria and process. States produce their own guidelines that echo the process and requirements of the federal process. Toll authorities typically follow the same process as their state DOT's noise guidelines. TxDOT follows federal guidelines and relies on the prescribed FHWA TNM to predict noise levels in future years. Interviews conducted with toll authority agencies indicate they generally follow TxDOT established guidelines for the analysis and implementation of noise mitigation measures on Texas highways.

Noise along highways is predicted using the acoustics modeling software developed by the FHWA known as TNM Version 2.5. The TNM is a three-dimensional model that predicts sound levels from traffic on a roadway to surrounding properties. Noise mitigation measures are evaluated within the noise model to determine if any reduction in noise may be obtained.

Federal and Texas guidelines require the use of TNM when a noise analysis is performed. When noise analyses are performed, the results are included in the project's environmental assessment documentation. If project changes occur (e.g., horizontal and vertical alignments) after the environmental documentation has been approved, a reevaluation of the environmental assessment's traffic noise analysis is required using the most recent TNM version.

Currently, for noise mitigation measures to be placed as treatments, the mitigation action must meet two criteria—feasibility and reasonableness. The feasibility criterion is achieved if there is a predicted noise reduction of at least 5 dB(A) at greater than 50 percent of the first-row impacted receptors (abutting specific or representative noise-sensitive properties defined in FHWA's noise abatement criteria).

The reasonableness criterion must meet a combination of social, economic, and environmental factors. All three reasonableness factors must be met. The three reasonableness factors are as follows:

- First, the estimated cost per benefited receptor must be at or under a defined cost threshold. These thresholds are set by states and vary. In Texas, the cost-effectiveness threshold is $25,000 per benefited receptor, as established in the 1990s. The noise wall costs are estimated at $18.00 per square foot, also established in the 1990s. As confirmed by several agencies, the actual cost to construct noise walls exceeds the estimated costs used in the environmental process. Costs are determined for the noise wall placement only and typically do not include right-of-way, utility relocation, etc. TxDOT is currently evaluating the state's noise barrier costs used in the environmental analysis process.

- The second factor is based on predicted future noise levels with and without noise abatement. States may set these noise abatement design goals, and in Texas, the noise design goal is that at least one first-row receptor must achieve a reduction of at least 7 dB(A).
- The third and final factor is that the preferences of those individuals affected by the placement of the noise abatement measure (the benefited receptors) are included. States address individual benefited receptors' preferences through noise workshops and balloting. In Texas, ballots cast by property owners are the only ones that count toward determining if an abatement measure is built. Texas acknowledges the viewpoints of non-owning residents, but their ballots do not count toward an approval vote. Texas requires a majority vote (50 percent + 1) to favor the noise abatement measure for it to be advanced.

Federal regulations require consideration of viewpoints of both tenants and property owners. Some states include viewpoints of tenants in the balloting process. Florida, Illinois, and Washington consider both owner and resident opinions in balloting. Also in those states, second-row receivers are considered and given different balloting weights. Like TxDOT, toll agencies welcome the public to participate in noise workshops. Also, like TxDOT, toll agencies only count ballots from affected first-row property owners in the process to determine noise wall implementation.

Direct Field Sound Measurement Studies on Highways

Direct field measurements are conducted **before** a noise assessment and as inputs into the TNM for new-location roadways. These measurements are referred to as ambient noise measurements. Generally, there are no routine direct field measurements made **after** the highway, or noise abatement, has been constructed. After measurements are very rare.

Sound Mitigation Process and Method Efficacy

Noise modeling and noise mitigation methods and processes are inherently complicated. The process and methods used by TxDOT follow similar feasibility criteria as Florida, Illinois, California, Washington, and New York (1 dB[A] lower than the value set by the federal NAC) for each activity. Washington and Illinois have tier-based, cost-effectiveness criteria to address higher noise levels, or larger sound level increases, whereas California, Florida, New York, and Texas have a fixed value.

Based on the results of the literature search, interviews, and field measurement tasks, several observations have emerged. The results of the literature search point to the following observations:

- The federal regulations published in July 2010 state that "the highway agency shall reanalyze the allowable cost for abatement (cost-effectiveness criteria) on a regular interval, not to exceed 5 years" (*7*). This statement was not in earlier federal regulations, and it only mandates a recurring analysis but does not require the criteria to be changed. TxDOT has used the same $25,000 cost-effectiveness criterion since 1992. The cost effectiveness was last analyzed in 1999. Researchers were unable to determine when this initial value was set.

- The definition of the first-row receiver varies throughout the peer states. In Texas, first-row receivers are the owners and residents of noise-sensitive land uses who are adjacent to proposed noise barriers, whereas in California and Washington, the definition depends on topography and highway geometrics.
- In Texas, only the opinions of the benefited property owners adjacent to a proposed abatement measure are considered for the reasonableness criteria, whereas Florida, Illinois, and Washington consider both owner and resident opinions. Also in those states, second-row receivers are considered and given different weights.
- Most of the peer states have a cost-effectiveness criterion tied to the construction cost index.
- The land use activity area definitions used by all peer state highway agencies are consistent with each other, and they are consistent with those listed in the current federal regulations.
- Federal guidelines state the development and implementation of Type II projects are not mandatory requirements. Currently, TxDOT, FDOT, and IDOT do not participate in a Type II (retrofit) program.

The results of the interviews point to the following observations:

- The toll authority agencies generally follow TxDOT established guidelines for the analysis and implementation of noise mitigation measures on Texas highways.
- FHWA's TNM Version 2.5, the most current version available, is used for traffic noise modeling and analysis by the agencies.
- Most of the agencies use an average pavement type for noise analysis, as specified by FHWA. FHWA averages the sound levels associated with both Portland cement concrete and dense-graded asphaltic concrete. Noise levels do vary between changes in pavement types and tire size interaction.
- Costs for noise wall mitigation are determined using the TxDOT guidelines of $25,000 per benefited receiver and $18.00 per square foot of noise wall. Costs are determined by the noise wall placement only and typically do not include right-of-way, utility relocation, etc. These costs are typically less than the actual cost to build a wall.

- The public is welcome to participate in noise workshops; however, consistent with TxDOT guidelines, only benefited property owners cast votes in the process to determine noise wall implementation.
- Only one of the queried agencies has conducted noise measurement analysis after the construction of the noise wall measure.
- Social media, such as email, Twitter, and websites, is becoming an additional useful tool for the dissemination of upcoming workshop and public meeting announcements.

Effectiveness of Sound Mitigation Measures

The sound measurement results at 16 receivers behind noise walls across the three study locations show that the sound levels behind eight of these walls exceeded the TNM predicted sound level with a noise barrier in place for one or more of the time periods observed. Of these eight locations, measured sound levels exceeded the TNM modeled sound levels with a noise barrier at five walls during all three time periods observed. The measured sound levels at four locations exceeded the TNM predicted sound levels by 6 to 10 dB(A). In contrast, the measured sound levels at two locations were 6 to 10 dB(A) less than the TNM model prediction.

TTI researchers found that material used in barrier construction that has a transmission loss of at least 25 dB(A) or greater is desired and would always be adequate for a noise barrier. The research team developed the following conclusions based on the evidence found through the literature review process:

- The criteria for selection of noise barrier material in order of decreasing importance are as follows: durability, acoustical properties, material and installation cost, maintenance, aesthetics, public opinion, and graffiti resistance.
- Precast concrete, earthen berm, and block barriers are commonly used noise wall materials that have proven cost effectiveness. Mostly concrete and metal (steel and aluminum) barriers can provide transmission loss of 25 dB(A) or greater, as desired, from adequate noise barriers.
- Wooden barriers most frequently have problems related to warping, rotting, weathering, and UV degradation, whereas concrete barriers can have UV degradation, cracking, and spalling.

- The average unit cost across the nation combining all materials and barrier types from 2011–2013 was $33.81 per square foot, whereas between 2004 and 2013, it was $35.46 per square foot.[2]
- Additional research is needed to investigate the performance and life-cycle costs of asphalt pavement to mitigate highway noise.

[2] According to an FHWA source, there may be non-uniformity in the data due to differences in individual state DOT definitions of barrier components and the respective component costs that the DOTs include in the report as the overall noise barrier cost.

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Appendix A. Definitions

A-Weighted Sound Level	A-weighted decibels, abbreviated dBA, dB(A), dBa, or dB(a), are an expression of the relative loudness of sounds in air as perceived by the human ear. In the A-weighted system, the decibel values of sounds at low frequencies are reduced, compared with unweighted decibels, in which no correction is made for audio frequency.
Existing Noise Levels (Before)	The noise, resulting from the natural and mechanical sources and human activity, considered to be usually present in a particular area.
Insertion Loss (IL)	The difference in the level of sound before and after noise wall insertion.
L10	The sound level that is exceeded 10 percent of the time (the 90th percentile) for the period under consideration.
L10(h)	The hourly value of L10.
Leq	The equivalent steady-state sound level, which in a stated period of time contains the same acoustic energy as a time-varying sound level during the same period.
Leq(h)	The hourly value of Leq.
Noise Abatement Criteria	A traffic noise impact occurs when the predicted levels approach or exceed the noise abatement criteria or when predicted traffic noise levels substantially exceed the existing noise level, even though the predicted levels may not exceed the NAC. This definition reflects the FHWA position that traffic noise impacts can occur under either of two separate conditions: (1) when noise levels are unacceptably high (absolute level); or (2) when a proposed highway project will substantially increase the existing noise environment (substantial increase). In order to adequately assess the noise impact of a proposed project, both criteria must be analyzed. While the FHWA noise regulations do not define approach or exceed, all state highway agencies must establish a definition of approach that is at least 1 dB(A) less than the NAC for use in identifying traffic noise impacts in traffic noise analyses.

Type I Projects	A proposed federal or federal-aid highway project for the construction of a highway on new locations or the physical alteration of an existing highway that significantly changes either the horizontal or vertical alignment or increases the number of through traffic lanes.
Type II Projects	A proposed federal or federal-aid highway for noise abatement on an existing highway.

Appendix B. HB 790 Language

AN ACT

relating to a study on the implementation and effectiveness of sound mitigation measures on certain highways.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS:

SECTION 1. (a) The Texas A&M Transportation Institute shall conduct a study assessing the implementation and effectiveness of sound mitigation measures on highways that are part of the state highway system and toll roads or turnpikes under the jurisdiction of a toll project entity as defined by Section 372.001, Transportation Code. The study must include:

(1) an analysis of the process and methodology used by the Texas Department of Transportation or toll project entity for selecting and implementing sound mitigation measures, including factors that affect the process and how outcomes are determined;

(2) an analysis of whether any kind of live testing is conducted at any point to determine the actual traffic noise level for neighboring properties;

(3) an evaluation of the effectiveness of the process and methodology described by Subdivision (1) of this subsection in reducing the traffic noise level for neighboring properties; and

(4) an evaluation of the effectiveness of implemented sound mitigation measures in reducing the traffic noise level for neighboring properties.

(b) Not later than November 1, 2016, the Texas A&M Transportation Institute shall submit a report on the results of the study and any recommendations to the governor, the lieutenant governor, the speaker of the house of representatives, and the presiding officer of each standing committee of the legislature with jurisdiction over transportation matters.

(c) This Act expires August 31, 2017.

SECTION 2. This Act takes effect immediately if it receives a vote of two-thirds of all the members elected to each house, as provided by Section 39, Article III, Texas Constitution. If this Act does not receive the vote necessary for immediate effect, this Act takes effect September 1, 2015.

President of the Senate

Speaker of the House

I certify that H.B. No. 790 was passed by the House on May 15, 2015, by the following vote: Yeas 133, Nays 6, 2 present, not voting.

Chief Clerk of the House

I certify that H.B. No. 790 was passed by the Senate on May 26, 2015, by the following vote: Yeas 30, Nays 1.

Secretary of the Senate

APPROVED: ______________________

Date

____

Governor

Appendix C. State-of-the-Practice Review of Sound Mitigation Measures and Costs

Noise Barrier Material

There are no federal requirements related to the selection of material types in the construction of highway traffic noise barriers (*1*). Individual state highway agencies select the material types when building their barriers. Typically, highway agencies make this selection based on several factors including aesthetics, durability, maintenance, cost, public comments, and others. FHWA does not specify the type of material to use for noise barrier construction, but the material type chosen must meet state specifications approved by FHWA. The material chosen should be rigid and of sufficient density (approximately 4 lb/sq ft minimum) to provide a transmission loss of 20 dB(A) or greater (*1*).

Concrete

Almost half of the noise walls constructed in North America are made of concrete. It is a mixture produced by combining Portland cement, coarse and fine aggregates, and water. Specific additives may also be added to the mix to modify curing rate, air entrainment, strength, fluidity, and porosity. Concrete is considered one of the most durable materials currently used for many highway products, including noise barriers, if the concrete mix is designed, cast (precast or cast-in-place), and cured properly. It is rugged and able to withstand severe temperatures, intense sunlight, moisture, ice, and salt. Its versatility allows shaping, molding, and texturing to take on the appearance of anything from weathered wooden boards to rock face to stone blocks or any sculpted design imaginable. Its mass, even at a thickness of only 12 mm (0.5 inch), is well within any sound transmission class requirement (*2*).

The versatility of concrete also extends to the shape and the size with which the panels can be manufactured (e.g., precast stacked panels [see Figure 19(a)]), cast-in-place and precast full height panels, and precast concrete block). Concrete also allows for a complete range of installation techniques including post and panel (see Figure 19[b]), post integral with the panel, freestanding (see Figure 19[c]), continuous footings, traffic barriers, and retaining walls (see Figure 19[d]). Cast-in-place concrete walls have been typically used on bridges and retaining walls because of their flexibility of design, high structural strength, and resistance to vehicle impact damage.

Source: (*3*)

(a) Precast Stacked Panels

Source: (*4*)

(b) Concrete Post and Panel Sound Wall

Source: (*5*)

(c) Concrete Tilted Post and Panel Sound Wall

Source: (*6*)

(d) Freestanding (Precast) Sound Wall

Figure 19. Versatile Uses of Concrete-Based Sound Wall.

Wood

Typically, wood noise walls are constructed of pressure preservative treated lumber, plywood, and glue laminated products. Several different species of wood may be used as a noise barrier product, but the performance and effectiveness may vary. Some species, such as pines, respond well to pressure treatment. On the other hand, it may be difficult to obtain a deep, uniform penetration of the preservative in spruces. Some of the more common species of wood used are the following:

- Pacific Coast Douglas Fir.
- Interior Douglas Fir.
- White Fir.
- Western and Eastern Hemlock.
- Western Larch.
- Jack Pine.
- Red Pine.

- Ponderosa Pine.
- Eastern White Pine.
- Lodgepole Pine.
- Western White Pine.
- Southern Yellow Pine.
- Red Spruce.
- White Spruce.
- Poplar.
- Red Alder.

Panels can be quickly assembled either piece by piece in the field or partially at the manufacturer. An advantage of wood barriers is they can be easily dismantled if future highway modifications are needed. Other benefits of this material are that it blends well with natural or residential background and that it does not conduct electricity. However, warping or shrinking leaves open cracks between joints, especially if they have not been properly processed, resulting in less-effective sound walls.

Brick or Masonry Block

Brick is typically manufactured using a clay and sand mix that is fired in a kiln to make it strong and durable. Bricks are of varying sizes, but the most common size is 2 × 3¾ × 8 inches. Masonry block is manufactured using a dry-cast concrete mix. These blocks can be produced in any size but with the most common dimensions in the range of 8 to 12 inches thick by 8 to 10 inches high and 14 to 18 inches long.

Both brick and masonry block walls can be either hand laid or preassembled by machine. Hand-laid walls have greater versatility in their ability to conform to the variety of ground contours matching the curvature and elevation of the road than do the preassembled panels with their fixed panel sizes and heavy equipment requirements. Preassembled panels have an advantage in speed of construction if the construction site allows for easy maneuvering of the necessary cranes and transport vehicles. All brick and masonry walls, whether they are hand or machine laid, require a continuous concrete foundation (Figure 20). The wall must be anchored to the foundation with reinforcing bars. Vertical and horizontal reinforcing bars are also needed in the wall itself to provide structural strength. Preassembled panels usually must be braced while the supporting concrete gains its strength. In most cases, scaffolding is needed to install brick and masonry block noise walls. Cranes may be used to install prefabricated panels, but crews still need scaffolding to fasten the panels to the posts and framework. There needs to be room and a solid foundation for scaffolding. These types of walls require a considerable amount of effort and time to construct (*7*).

Source: (*8*).

Figure 20. Brick Sound Wall.

Metals

Noise walls can be built out of three metals: steel, aluminum, and stainless steel. Steel is the least expensive and most common of all metals used in construction. Most steel panels, posts, and girts are coated with plastisols, bonded powders, enamel paints, or galvanizing material. Aluminum is preferred because of its light weight, whereas stainless steel is highly durable and corrosion resistant.

Bridges and retaining walls are ideal locations for the use of these lightweight types of panels (*7*). Care should be taken to ensure that differing metals that come in contact with each other do not have an adverse effect on one another. This is especially true for aluminum coming in contact with steel. The aluminum acts similarly to the zinc in the galvanizing material where it is the sacrificial element and will eventually disintegrate over a short period. Most metal sheeting materials do not meet the typical minimum panel weight and/or sound transmission class required in typical noise barrier specifications. However, adding corrugations or ribs to the profile of the panel material tends to improve the sound transmission class of the panel (*7*).

Transparent Panels

The typical transparent noise wall (see Figure 21) may use panel material made of either glass or a clear plastic product such as Plexiglas, butacite, surlyn, Lexan, or acrylic. Glass panels are commonly made of single-tempered or laminated-tempered glass sheets. Both plastics and glass can be tinted, etched, or given a frosty appearance.

Source: (*9*).

Figure 21. Noise Wall with Transparent Panels.

Tempering of glass is a heat-treating process that strengthens the glass and produces a much more shatter-resistant product. When it does shatter, the shards are small and granular, with pieces typically not larger than 0.5 inch. This glass is much safer than the long, knife-like shards produced from shattering common non-heat-treated glass. In addition to the tempering, the glass panels may also be laminated. This type of glass panel is produced by adhering two sheets of tempered glass with a clear, rubbery type flexible sheeting in between the two glass sheets. When this type of glass panel is shattered, the glass will break into small granular-like pieces, where the pieces will remain adhered to the sheeting. This panel is similar to a typical vehicle windshield. Transparent barriers are typically only built for three reasons:

- To prevent obstructing the scenic view for the driving public.
- To prevent obstructing the scenic view for the residents adjacent to the roadway.
- To prevent obstructing the view of retail establishments for the driving public.

Transparent noise walls may cost as much as 20 times that of common concrete or steel panels, so the decision to use transparent noise walls should be made carefully (*7*). Other possible reasons for their use would be to improve safety or to retrofit existing structural elements without much additional weight. Opaque noise barrier walls may have an adverse effect on stopping sight distance, visibility in merge areas, lighting, and shading (*7*).

Plastics

There are several types of plastic materials available for use as wall material, including polyethylene, PVC, and fiberglass (see Figure 22). The most unique features of plastic products are their versatility and moldability. This material can be produced to appear the same as almost any construction material on the market today. Its light weight allows for ease of handling both in the plant and in the field. Most of these products are also recyclable. Plastic noise wall panels can be installed in almost any situation. However, due to their light weight, they are particularly suitable for structure-mounted applications.

Source: (*10*).

Figure 22. Post and Plastic Panel Sound Wall.

Recycled Rubber

The application of recycled rubber from tires in products used for roadway construction has been under investigation for many years by numerous government agencies worldwide. The results of these efforts indicate widely varying success in trying to adapt this type of material into a usable product (see Figure 23).

Recycled rubber can be incorporated into a wide range of products, made from an equally wide range of rubber compounds. In practice, the rubber waste stream comes mainly from scrap tires. Tire trim and off-spec tires from tire production and buffings from rubber product manufacturers are two other significant sources. Although the weight of the panels may be sufficient to meet general requirements for minimum sound transmission class ratings, it may not be sufficient when produced as a porous panel. Even when stiff backers or cores are used, this material may require the cores or backers to be extensively perforated to promote bonding.

Source: (*11*).

Figure 23. Recycled Rubber Used in Noise Wall Applications.

Composites

Composite noise barrier materials are defined as any product composed of two or more primary materials, such as plywood with a fiberglass skin or wood mixed with concrete and then layered onto concrete. Since the possibilities are almost endless, agencies considering the use of these sections will need to carefully consider and evaluate their safety, durability, and performance.

Noise Berm

Noise barriers constructed from natural earthen materials such as soil, stone, rock, rubble, etc. in a natural, unsupported condition are termed noise berms (Figure 24). These types of barriers are typically constructed with surplus materials available on the construction site or from materials transported from an off-site location. The source and availability of such materials are factors that can significantly affect the cost of such construction.

Noise berms generally require more right-of-way than a wall type of barrier. This is mainly due to the sloping sides of the berms, which must be gradual enough to maintain stability of the structure. For most berms, side slopes of 2:1 (2 ft horizontal to 1 ft vertical) are typical, although steeper slopes (1.5:1) may be acceptable occasionally. For berms constructed from rock (in an unsupported condition), side slopes as steep as 1:1 may be acceptable (*2*). The top of the berm may be of minimal width (with normal slope rounding), or it can be designed with a relatively wide plateau. While the wider, level plateau area results in more space required to construct the berm, it allows more room for maintenance of the berm and offers an area for placement of such features as plantings, a fence, or a noise wall (Figure 24) that could be used for improving the acoustical effectiveness by increasing the height of the barrier system (*2*).

Source: (*12*).

Figure 24. Combination of Earth Berm and Sound Wall for Traffic Noise Abatement.

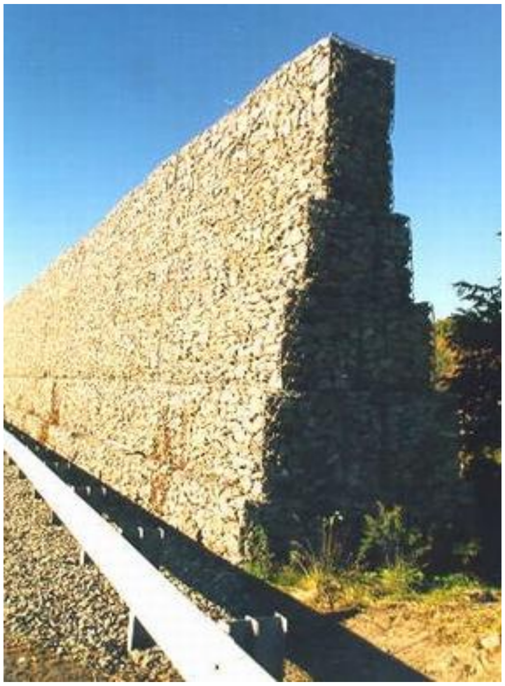
Stone Crib Noise Wall

Berms may be constructed from rock in a supported condition. This type of barrier system (also referred to as a gabion system) is comprised of crushed rock contained in large rectangular baskets made of heavy wire mesh (see Figure 25). These wires can be coated with vinyl, which is available in various colors for aesthetic purposes. The baskets are stacked on top of each other in a pyramid fashion to obtain the required barrier height and stability. The baskets are typically placed on well-draining, compacted ground. Their structure is flexible enough to allow for some settlement. This type of system is only feasible if sufficient quantities of suitable rock material are readily available close to or on the construction site. Little, if any, plant life can be expected to grow on or within this barrier system. The system is applicable to rolling topography (*2*).

Planted Type Barrier

These systems obtain their stability from a type of structural shell. This shell is typically made from concrete, wood, or plastic and is filled with soil and then planted (see Figure 26). Some form of continuous concrete leveling pad or footing often supports these systems. Depending on the design and the type of plantings, these systems may also be set directly on top of the existing ground with little or no preparation other than minor leveling.

Careful consideration needs to be given to the type of planting selected and to the means for providing adequate irrigation of the plant material during all seasons (*2*). Maintenance requirements can be significant on such systems, particularly with items such as weeding, removing large saplings that grow from blown-in weed seeds (if not removed, they can adversely affect the structural integrity of the barrier), and replacing pockets of washed-out soil. Safety, security, and liability issues such as the ability to climb the steps of the planted wall also should be considered (*2*).



Source: (*2*).

Figure 25. Stone Crib Noise Wall.

Source: (*2*).

Figure 26. Planted Type Noise Barrier.

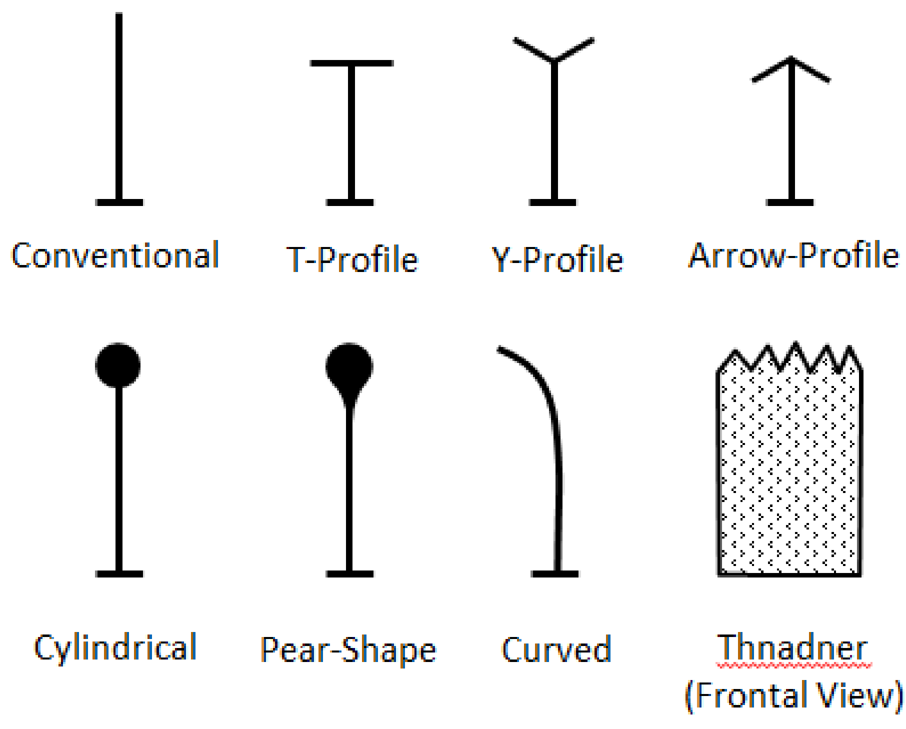
Advances in Noise Abatement Measures

Realistically, typical noise barriers can achieve a noise reduction of up to approximately 5 to 10 dB(A). If a larger effect is desired, it will be necessary to use very high barriers, vary the shape of the top of the wall, or undertake a total or partial covering of the road (*13*).

Noise Wall Top Shape Variations and Curvature

There has been research into varying the shape of the top of a wall (see Figure 27) to shorten the wall height and possibly attain the attenuation function of a taller wall. The technical rationale is that attenuation may be heightened by increasing the number of diffractions occurring at the top of the barrier (*2*).

The curved top or entire wall heightens attenuation by not only increasing diffractions but also changing the angle of those diffractions over a larger surface area (see Figure 28 and Figure 29). Shorter wall heights could minimize the impact and improve the aesthetics of communities and motorists by preserving more of the view. These special barrier tops or wall curvatures provide some acoustical and aesthetic benefits, but the cost of constructing these shapes typically outweighs the cost of building a conventional noise wall with increased height and similar acoustic attenuation capacity.



Source: (*2*).

Figure 27. Special Tops of Noise Walls.

Source: (*14*).

Figure 28. Steel Noise Barrier in Vienna, Austria, Bending over the Highway to Increase the Noise Reduction.

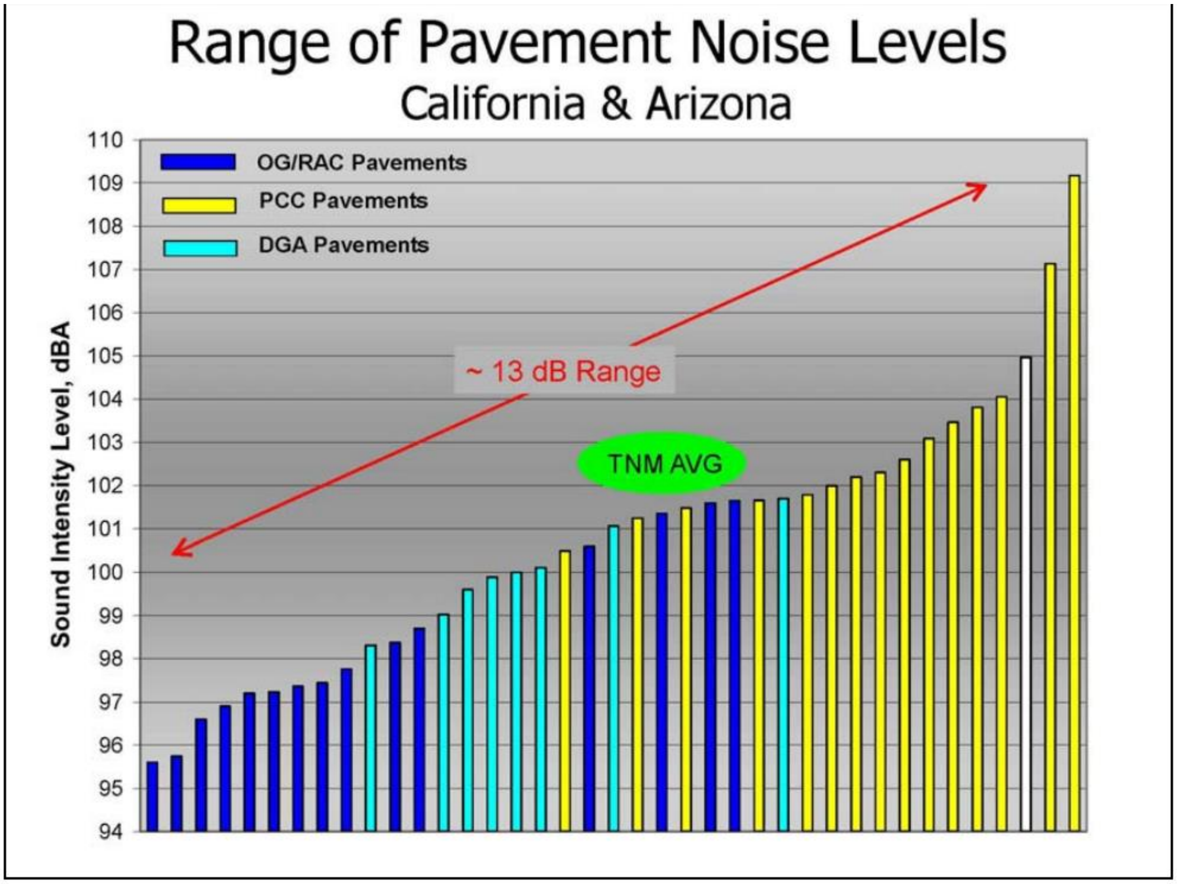
Source: (*14*).

Figure 29. Depressed Highway Partly Covered at the Road Sides and with White Concrete Noise Barriers.

Quiet Pavements

The common response to road traffic noise in the United States has been the use of noise barriers. However, noise barriers can be expensive, do not reduce noise at the source (reduce noise as it propagates), and are not always feasible (*15*). A potential cost-effective solution is a combination of noise barrier and quiet pavement or pavement treatment.

At highway speeds (above 50 mph), the tire-pavement noise dominates the noise emissions from all types of vehicles. Studies from California and Arizona indicate that there is a large range of noise performance for different pavements (see Figure 30)—a range of about 13 decibels (from 95 dB to 109 dB) (*15*). However, it is difficult to reach a design goal of a 7-dB reduction compared to TNM average pavement with quieter pavement alone. In some cases, long barriers will not be feasible or reasonable unless combined with quiet pavement. There can be times when abatement is not going to happen unless pavement is part of the solution with a barrier. Consideration of quiet pavement extends the potential for noise reduction in areas with low receptor density or where barriers already exist but cannot be made higher (*15*).



Note: OG/RAC = open-graded asphalt; PCC = Portland cement concrete; DGA = dense-graded asphalt.
Source: (*15*).

Figure 30. Range of Pavement Noise Levels, California and Arizona.

Various studies have realized significant noise reduction benefits by replacing traditional pavements with quieter pavements. For example, on Highway 101 in Marin County, California, when an old dense-grade asphalt concrete was replaced with an open-grade asphalt concrete, noise dropped about 10 to 11 dB from previous measures when measured 60 ft away from the highway at two different heights. Typically, good barrier performance is 10 dB, so the pavement improvement offered about the same noise reduction as a barrier.

In another project, replacement of dense-grade pavement overlaid with open-grade asphalt on Interstate 80 near Davis, California, led to reduction of about 5 dB with the overlay, which would be a noticeable change for a neighborhood. In the Arizona Quiet Pavement Pilot Program, when a transverse tine PCC was overlaid with rubberized asphalt, a 9-dB reduction was seen. Relative to the TNM, which uses an average pavement for noise prediction, the new pavement was about 8 dB quieter than what would be predicted for assessing noise impact (*15*).

Quiet pavement offers substantial savings over barrier erection in terms of initial costs (*15*); however, its main drawback is acoustic longevity. Over time, quiet pavement will get noisier, and therefore the cost benefit degrades with time (*16*). The studies done in Arizona and California show that quieter asphalt degrades about 0.3 to 0.8 dB per year (*15*), whereas concrete degrades at a lower rate (i.e., about 0.1 to 0.35 dB per year). This also depends on average traffic density—the more traffic, the higher the rate of degradation. Maintaining performance means doing rehabilitation by either overlaying or grinding concrete, whereas noise barriers need less maintenance to keep up their performance.

Different Types of Quiet Pavement

The following types of asphalts are mentioned in a published report on quiet pavements (*15*):

- **Hot-mix asphalt** includes dense-graded asphalt, stone matrix asphalt, and open-graded asphalt. For quieter pavements, there is a range of materials and mixes.
- **Stone matrix asphalt** can be one of the quieter options. With a smaller stone size, modified binder, and filler of manufactured sands and minerals, it can have a more negative texture, reducing inputs to the tire and producing less noise.
- **Rubberized asphalt,** first used in Europe, is a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. Rubberized asphalt is becoming common in Arizona, California, Nevada, and Texas.
- **Open-graded asphalt** is the most common quieter pavement. It allows some relief of noise via reduced air pumping and reduced horn effect. With voids in the pavement, air and water can penetrate it, and splash and sprays can be reduced since water can drain through the pavement. Some European countries use double-layer asphalt pavement—a top layer that is a relatively fine aggregate to minimize the surface texture and a larger aggregate below to maximize drainage through the pavement.
- **Concrete** includes jointed plain concrete pavement and continuously reinforced concrete pavement (the most common types) and jointed reinforced concrete pavement and precast concrete pavement (the less common types). Joints in the concrete can add to noise. One quieter pavement texture is longitudinally tined pavement, which is currently

recommended by FHWA, instead of noisier transverse tine. Adding longitudinal tines is a good solution because anytime a cement surface is poured, texture must be added, so it is inexpensive to add texture that reduces noise.

- **Diamond grinding** is probably the quietest concrete surface texture available. This is a surface added after the pavement is down and initially textured in some other manner. It is often used for pavement maintenance to reduce tire inputs at joints that can be caused by the pavement slabs warping. It can also improve skid performance of pavements that have become polished.
- A newer, next-generation concrete surface involves a specialized grinding technique often done in two or three passes over the surface. Fine-textured grinding is done in between wider-spaced grooves. Several states have had success with this type of surface for reducing noise and addressing safety concerns (*15*).

Effectiveness of Noise Barrier Materials

Sound Transmission Loss Values

As mentioned earlier, any material weighing 4 lb/sq ft or more has a transmission loss (TL) of at least 20 dB(A). These materials would also be adequate for a noise reduction of at least 10 dB(A) due to diffraction. Note that a weight of 4 lb/sq ft can be attained by having a lighter and thicker material or a heavier and thinner material. The greater the density of the material, the thinner the material may be. TL also depends on the stiffness of the barrier material and frequency of the sound source (*17*).

In most cases, the maximum noise reduction that can be achieved by a barrier is 20 dB(A) for thin walls and 23 dB(A) for berms. As a result, a material that has a TL of at least 25 dB(A) or greater is desired and would always be adequate for a noise barrier. Table 19 gives approximate TL values for some common materials as tested for typical A-weighted highway traffic frequency spectra. These values may be used as a rough guide in acoustical design of noise barriers. Agencies should consult material test reports by accredited laboratories for accurate values.

Table 19. Approximate Sound Transmission Loss Values for Various Materials.

Material	Thickness (inches)	Weight (lb/sq ft)	Transmission Loss (dB[A])
Concrete Block, 8" x 8" x 16", lightweight	8	31	34
Dense Concrete	4	50	40
Light Concrete	6	50	39
Light Concrete	4	33	36
Steel, 18 ga	0.05	2	25
Steel, 20 ga	0.0375	1.5	22
Steel, 22 ga	0.0312	1.25	20
Steel, 24 ga	0.025	1	18
Aluminum, Sheet	0.0625	0.9	23
Aluminum, Sheet	0.125	1.8	25
Aluminum, Sheet	0.25	3.5	27
Wood, Fir	0.5	1.7	18
Wood, Fir	1	3.3	21
Wood, Fir	2	6.7	24
Plywood	0.5	1.7	20
Plywood	1	3.3	23
Glass, Safety	0.125	1.6	22
Plexiglas	0.25	1.5	22

Source: (*2*).

Pros and Cons of Noise Wall Material

Material and type of sound wall selected depends on various factors. According to the National Cooperative Highway Research Program's (NCHRP's) *Guidelines for Selection and Approval of Noise Barrier Products* (*18*), the four most important of these factors are:

- Durability.
- Acoustical properties.
- Material and installation cost.
- Maintenance issues.

Table 20 shows the advantages and disadvantages of various materials used for sound walls and provide an insight of how these material qualities affect the material selection process. Currently, concrete and metal barriers are available as both absorptive and reflective. According to the NCHRP report (*18*), most states have experienced problems with graffiti and with collision damage to noise barriers.

Table 20. Advantages and Disadvantages of Various Noise Wall Materials.

Material	Advantages	Disadvantages
Concrete	Very durable materials May be molded and textured Minimal maintenance	Material may not be easily available in rural areas or is available at a considerably higher cost
Brick and Masonry Block	Hand-laid walls allow conforming to ground contours Preassembled panels allow faster construction May be textured	In most cases, scaffolding is needed for installation, and it needs ample room, a solid foundation, and a considerable amount of work and time to install
Metal	Due to its light weight, this material is ideal for bridges and retaining walls	Rusting panels may stain adjacent concrete Different metals coming into contact may create a destructive chemical reaction Liability due to walls being climbable Susceptible to glare Electrically conductive
Wood	Panels are light and power nailers allow for quick assembly Material blends well with natural terrain and residential application May easily dismantle	Toxic if burned Fasteners should be non-corroding and not reacting to pressure treating chemicals Wood products tend to warp/shrink Color fades due to sunlight
Transparent Panels	Prevents obstruction of scenic view for the driving public and for the residents adjacent to the roadway Prevents obstruction of the view of retail establishments for the driving public Lightweight Easier to remove graffiti compared to other materials	Needs replacement if vandalized May be sensitive to sunlight Susceptible to shattering and damage from airborne debris Susceptible to glare Costs up to 20 times more than other materials Need to be washed on a regular basis If damaged, entire panel needs replacement

Material	Advantages	Disadvantages
Plastics	Versatile and moldable Lightweight Suitable for structure-mounted applications due to their light weight	Toxic if burned Material tends to shrink May be sensitive to sunlight Vulnerable to vandalism Susceptible to shattering and damage from airborne debris If damaged, entire panel needs replacement Susceptible to glare
Recycled Rubber	The recycling process removes scrap rubber products, mainly tires, from landfills	Toxic if burned Additives in product may be toxic Not rigid enough to be noise barrier without backing

Source: (*2*).

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Appendix D. Cost of Noise Barriers in the United States

FHWA has comprehensive noise barrier data that it receives from the state DOTs (*1*). The cost data shown in Table 21 represent the best estimates from state DOTs for barrier construction. There may be non-uniformity in the data due to differences in individual state DOTs' definitions of barrier components and the respective component costs the DOTs included in the report as the overall noise barrier cost. Additionally, California did not provide data from 1999 through 2004 and provided limited data for the 2005 through 2007 inventory update. Since California's reported noise barrier quantity comprises approximately 16 percent of total U.S. noise barrier quantities by area, this lack of information affects the quality of data for these years. Researchers are only listing data between 2008–2010 by material type (newest available). Although used primarily in single-material barriers, many noise materials can be used in combination, such as wood and concrete, metal and concrete, brick and concrete, metal and wood, and earthen berms with concrete, wood, or metal.

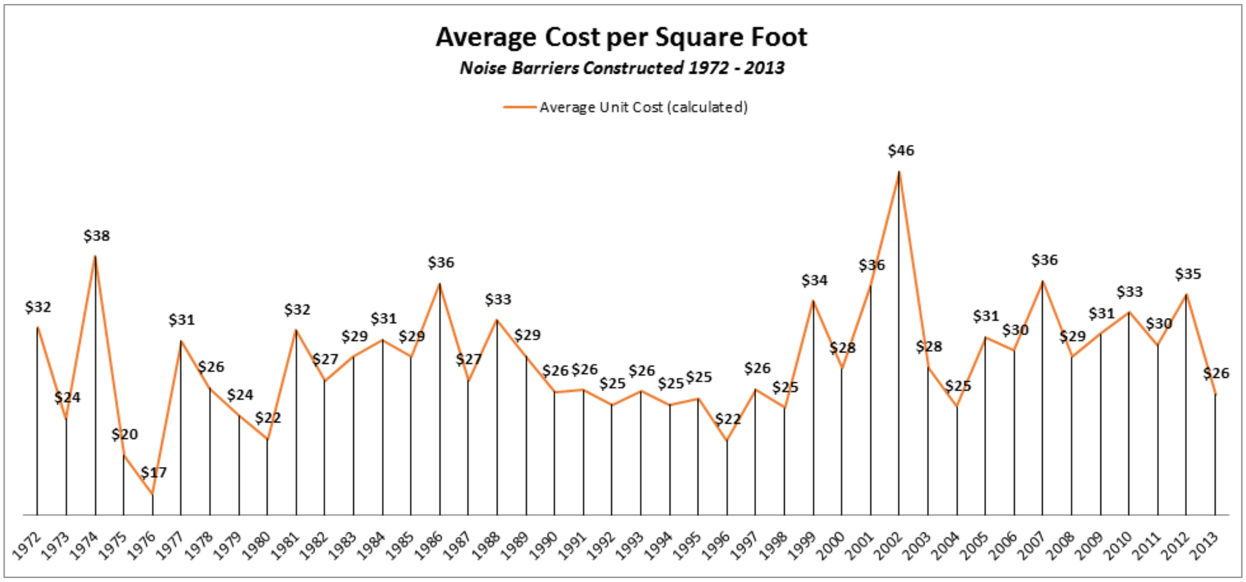
Table 21. Noise Wall Material Average Unit Cost in 2010 $/sq ft.

Year	2008	2009	2010
Concrete	$30	$30	$33
Block	$29	$25	$31
Wood	NA	NA	$19
Metal	$15	NA	$52
Earthen berm	NA	$17	$24
Brick	NA	NA	NA
Combination	$25	$34	$27

Note: NA indicates that this material was not used for this particular year.
Source: (*1*).

According to FHWA, the average unit cost combining all materials and barrier types was the following (as shown in Figure 31):

- From 2011–2013, it was $33.81/sq ft.
- From 2008–2010, it was $35.14/sq ft.
- From 2004–2013, it was $35.46/sq ft.
- From 1963–2013, average unit costs varied by state, from a low of $11/sq ft in North Dakota to a high of $75/sq ft in Delaware.



Source: (*1*).

Figure 31. Average Cost of Noise Barriers in the United States.

The 2008 NCHRP *Guidelines for Selection and Approval of Noise Barrier Products* (*2*) also provides unit costs, obtained from barrier manufacturing companies. Table 22 presents the generalized cost range results reported in this study; however, caution must be exercised because many manufacturers and distributors did not divulge detailed information. The basis for the per-square-foot costs was not consistent among the companies. Transportation costs were included with some estimates but not with others. Also, some firms reported a cost range for an assumed range of quantities, while others provided only one figure. For a specific noise barrier project, the actual cost to the state will be the installed cost of the barrier (post, panel, and foundation) at the unit cost applicable to the actual quantity installed.

Table 22. Summary of Barrier Material Unit Costs.

Material Type	Reflective/Absorptive	Generalized Cost Range (per sq ft)
Concrete—Precast	Absorptive	$10–$23
Concrete—Precast	Reflective	$16–$19
Concrete—Machine	Reflective	$12
Metal	Absorptive	$10–$40
Metal	Reflective	$10–$40
Wood	—	No products reported

Source: (*3*).

Noise Wall Material Usage in the United States

Table 23 shows the national noise wall material average area use for years 2008, 2009, and 2010. As the table shows, concrete and block have been the most popular materials used for the construction of noise walls in the United States. Since FHWA started to collect these data in 1963, the state DOTs have used various materials and tested their applications. The versatility and durability of concrete and block proved itself early, and the use of other materials for noise walls declined. Table 23 shows that just in 2008–2010, the use of wood, metal, and brick declined to very low usage or none.

Table 23. Noise Wall Material Average Area Use by Year (10,000 sq ft).

Noise Wall Material*	2008	2009	2010
Concrete	252	546	498
Block	72	72	161
Wood	NA	NA	4
Metal	18	NA	7
Earthen berm	NA	3	1
Brick	NA	NA	NA
Combination	62	64	7

Note: NA indicates that this material was not used for this particular year.
* Square feet of noise barriers constructed with other materials was 1,946,829, costing approximately $34 sq ft.
Source: (*3*).

Since 1963, noise walls constructed with a single material make up 86 percent of the number of walls. The material use distribution in these noise walls is presented in Figure 32 and Figure 33.

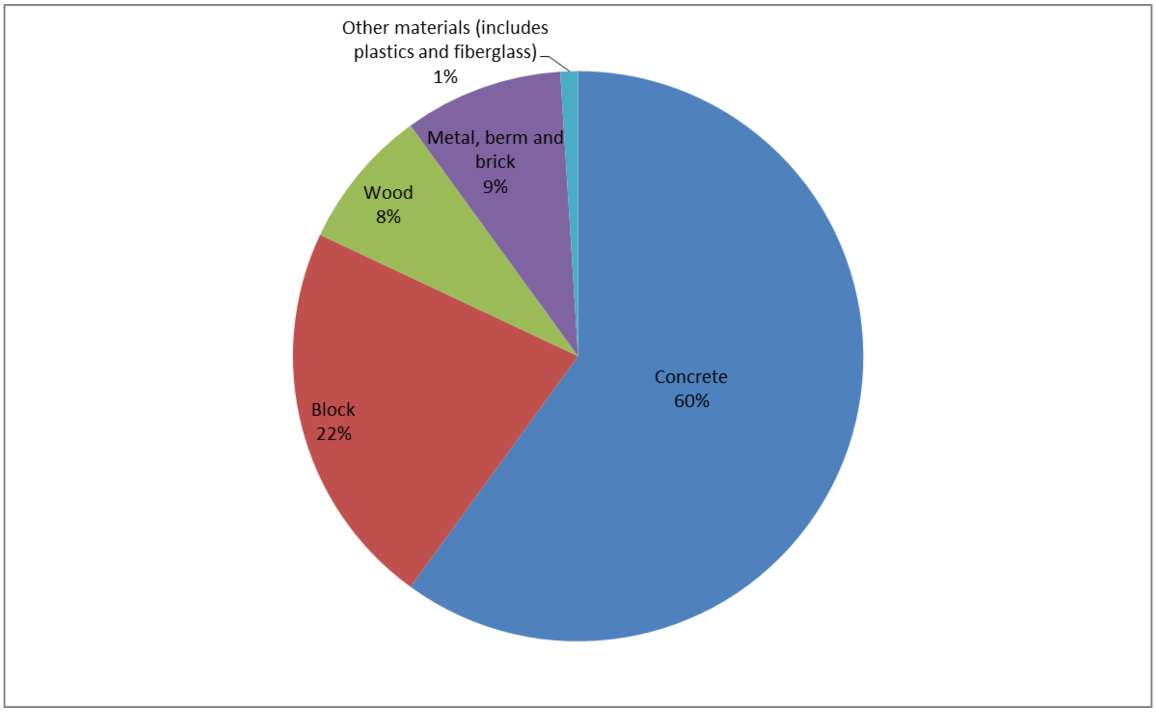
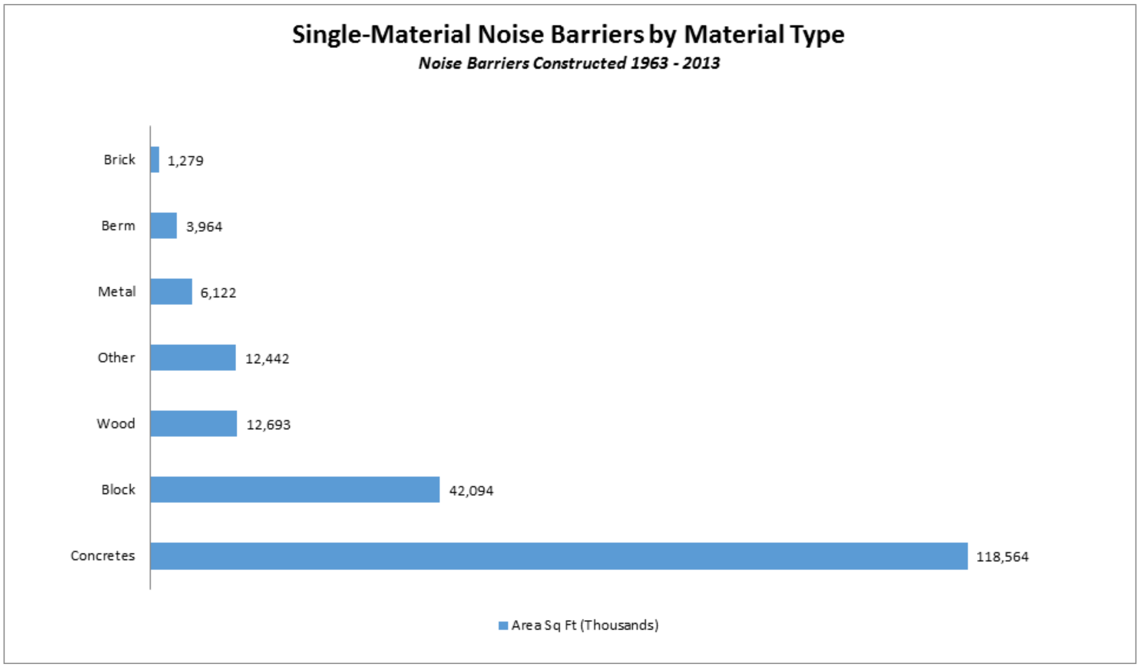


Figure 32. Distribution of Material Used in All Noise Walls.



Source: (*3*).

Figure 33. Installation of Noise Barriers in the United States by Material Type.

Noise Wall Construction Cost and Material Use in Texas

Table 24 shows average costs for noise wall construction in the United States (the average of all states) and Texas for the following time intervals: before 2001, 2001–2005, and 2006–2010. This table shows that TxDOT has followed the national trend of using different materials for building noise walls (before 2001) and eventually using only concrete for noise walls. These average unit costs of material are likely a function of the cost-effective reasonableness limit rather than the true costs set by state DOTs. The reader may compare between categories but should be careful when interpreting trends across years.

Table 24. Noise Wall Material Usage and Cost as Reported in FHWA Inventory.

	Before 2001				2001–2005				2006–2010			
	US		TX		US		TX		US		TX	
	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft
Berm	3,732	$7	73	$23	85	$16	NA	NA	67	$17	NA	NA
Block	30,029	$23	4	$22	4,313	$36	17	$50	4,140	$26	NA	NA
Combination	15,815	$21	82	$28	3,918	$13	NA	NA	3,788	$27	NA	NA
Concrete	60,565	$27	2,586	$25	26,843	$34	375	$21	25,811	$32	1,204	$13
Metal	2,671	$19	NA	NA	1,608	$18	NA	NA	713	$20	NA	NA
Wood	11,759	$20	3	$18	955	$19	NA	NA	58	$19	NA	NA

Note: NA indicates that either material was not used for these years or data are insufficient to develop average cost.
* During 2006–2010, the average cost of a concrete noise wall was $13/sq ft. TxDOT's statewide average low bid unit prices for various sound walls vary from $19.28/sq ft to $24.71/sq ft (last update: May 27, 2016).
Source: (*3*).

References

1. FHWA. Summary of Noise Barriers Constructed by December 31, 2013. Updated May 2016. http://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/. Accessed June 16, 2016.

2. Ernst, D., L. Biton, S. Reichenbacher, M. Zgola, and C. Adkins. *Guidelines for Selection and Approval of Noise Barrier Products.* NCHRP Project 25-25, Task 40, NCHRP, Washington, DC, 2008.

3. FHWA. Noise Barrier Construction Material Average Unit Cost by Year. 2010. http://www.fhwa.dot.gov /environment/noise/noise_barriers/inventory/summary/stable710.cfm. Accessed June 16, 2016.

Appendix E. WSDOT Reasonableness Allowances

Exhibit 11 – Reasonableness Allowances

Column A	Column B	Column C	Column D
Design Year Traffic Sound Decibel Level (dBA)	Noise level increase as a result of the project (dBA)[(2)]	Allowed Wall Surface Area Per Qualified Residence or Residential Equivalent	Allowed Cost Per Qualified Residence or Residential Equivalent[(1)]
66		700 Sq Feet	$36,127
67		768 Sq Feet	$39,636
68		836 Sq Feet	$43,146
69		904 Sq Feet	$46,655
70		972 Sq Feet	$50,165
71	10 (substantial, step 1) [(3)]	1,040 Sq Feet	$53,674
72	11 (substantial, step 1)	1,108 Sq Feet	$57,184
73	12 (substantial, step 1)	1,176 Sq Feet	$60,693
74	13 (substantial, step 1)	1,244 Sq Feet	$64,203
75	14 (substantial, step 1)	1,312 Sq Feet	$67,712
76	15 (substantial, step 2)[(4)]	1,380 Sq Feet	$71,222

(1) Current costs based on $51.61 per square foot constructed cost developed in 2011.

(2) If the noise level increases 10 dBA or more as the result of the project (Column B), follow the allowed wall surface and cost for the level of increase in Column C in lieu of the total design year sound decibel level in Column A. For total highway related sound levels at 76 or more dBA or the project results in an increase of 15 or more decibels, continue increasing the allowance at the rate provided in the table unless circumstances determined on a case-by case basis require an alternative methodology for determining allowance.

(3) Step 1 is when the noise levels are 10 to 14 dBA over Existing condition traffic noise as a result of the transportation project.

(4) Step 2 is when the noise levels are 15 or more dBA over Existing condition traffic noise as a result of the transportation project (or total highway related noise levels are between 76 and 79 decibels). Additional consideration for abatement may be considered under these circumstances.

Appendix F. Example of NYSDOT Feasibility and Reasonableness Worksheet

Highway traffic noise abatement for a project

PIN:			
Abatement Measure:			
		Yes	No
Feasibility			
Engineering Considerations	Can the measure be built?		
Noise Reduction (Acoustic Feasibility)	Does the proposed measure provide a reduction of at least 5 dB(A) to a majority of the impacted receptors?		
Reasonableness			
Viewpoints of Benefited Property Owners and Residents	Were responses obtained from at least half of the benefited property owners and residents?		
	Do a majority of the responses favor the measure?		
Cost Index	**If a berm:** Is the total estimated cost of the proposed berm less than $80,000 per benefited receptor?		
	If a barrier: Is the proposed barrier less than 2,000 square feet per benefited receptor?		
Noise Reduction Design Goal	Do a majority of the benefited receptors achieve the Noise Reduction Design Goal of 7 dB(A)?		
If all the questions can be answered "Yes," then the measure is considered reasonable and feasible.			

Appendix G. Review of Environmental Assessments to Review Costs and Cost-Effectiveness Results

TTI researchers reviewed 25 environmental assessment reports documenting 206 noise walls proposed and/or built after the year 2010 in the following counties: Bexar, Brazoria, Dallas, El Paso, Ellis, Galveston, Grimes, Harris, Hays, Hill, Kenedy, Kleberg, Montgomery, Nueces, Rockwall, Tarrant, Travis, Willacy, and Williamson. This appendix documents and compares the reported costs per benefited receptor for those walls determined to be feasible. The appendix also compares cost per benefited receptor of the Texas noise walls to the national average cost per unit to build a noise wall.

The research team developed the following conclusions based on the evidence found through the literature review process:

- 78 percent of reviewed noise walls were feasible and 62 percent (100) of these feasible noise walls were reasonable based on TxDOT cost-effectiveness criterion of $25,000 per benefited receptor.
- 75 percent of the non-reasonable noise walls (exceeds criterion of $25,000 per benefited receptor) that were feasible do not have a specifically reported cost per benefited receptor value in the environmental assessment report.
- All noise walls that met the reasonableness criteria reported cost per benefited receptor value.
- Sometimes when the individual cost per benefited receptor for a wall is higher than the $25,000 criterion, multiple walls are grouped together to bring the average cost down and qualify for the cost-effectiveness criterion.
- TxDOT's unit construction cost value of $18 per square foot that is used to calculate the cost-effectiveness criterion of $25,000 is well below the current national average cost for noise barriers (combining all materials and barrier types) of $33.81 per square foot. However, it is somewhat of an arbitrary value alone, only having value in the context of how it relates to the cost-effectiveness criterion and a resultant barrier area per benefited receiver.

Introduction

The review included a scan of 25 environmental assessment reports documenting 206 noise walls proposed and/or built after the year 2010 in the following counties: Bexar, Brazoria, Dallas, El Paso, Ellis, Galveston, Grimes, Harris, Hays, Hill, Kenedy, Kleberg, Montgomery, Nueces, Rockwall, Tarrant, Travis, Willacy, and Williamson. Researchers compared the cost per benefited receptor for reviewed noise walls and national average cost per unit to build a noise wall.

Database Development

A goal of this project was to review and build a database of available environmental assessment reports for noise walls built in various counties in urban districts such as Dallas, Houston, Fort Worth, and El Paso after the year 2010. TTI researchers first downloaded environmental assessment reports for various construction projects available online in public libraries (such as Hathi Trust Digital Libraries at Northwestern University). Researchers also contacted TxDOT staff to obtain a listing of environmental assessment reports for noise walls built or considered since 2010. TTI leveraged TxDOT's Environmental Compliance Oversight System to obtain recent environmental assessment reports using the project identification information provided by TxDOT staff. From all these available resources, researchers obtained 25 environmental assessment reports documenting 205 noise walls for projects proposed and/or built since 2010.

From these environmental assessment reports, researchers built a database that had necessary information for performing analysis of current cost-effectiveness criteria. The database had the following attributes (see Figure 34):

- Project and control section job number.
- Study name.
- Year and location.
- Project description.
- Impacted site or area.
- Site description.
- Feasibility and reasonableness of wall.
- Cost per benefited receptor.
- Number of benefited receptors.
- Length and height of wall.
- Total cost.
- Any other remarks about the noise wall.

Project #	CSJ	Study Year	Study Name and Location	Brief Project Description	County	District	Impacted Site Number/Soundwall Site	Site Description	Feasible	Reasonable (Cost)	Reasonable (Vote)	Survey Results (Desire to have Wall)	Cost ($) per benefitted receptor	Number of Benefitted Receptors	Length (feet)	Height (feet)	Total Cost	Remarks
Project 1	0092-01-052 0197-02-108 0092-14-081	2013		SM Wright Project with improvements to US HWY 175 from IH 45 to SH 310 NORTH	Dallas	Dallas	CF HAWN 1	South side of CF Hawn Fwy, at the intersection of SM	Yes	No		2013	$ 30,175.00	11	1620	8, 10, 12, 14, 16	$ 331,920.00	The proposed proj
			Task-2b-Lit-Review-Update		Dallas	Dallas	CF HAWN 2	North side of CF Hawn Fwy, at the intersection of SM Wright	Yes	Yes		2013	$ 23,209.00	17	1670	8, 10, 12, 14, 16	$ 394,560.00	
			References		Dallas	Dallas	CF HAWN 3	Along Hooper Street	Yes	Yes		2013	$ 17,100.00	4	380	10	$ 68,400.00	
			Recent Enviromental Doo		Dallas	Dallas	CF HAWN 4	NE intersection of CF hawn freeway and SM Wright	Yes	No		2013	$ 26,537.00	7	860	12	$ 185,760.00	
			Dallas		Dallas	Dallas	CF HAWN 4a		No	Yes		2013						The barriers that we
					Dallas	Dallas	CF HAWN 5	North of Anderson Lane	Yes	Yes		2013	$ 17,018.00	11	735	10, 12, 14, 16	$ 187,200.00	
					Dallas	Dallas	CF HAWN 6	Along Bluitt Ave, North of CF Hawn	Yes	Yes		2013	$ 17,550.00	8	595	10, 12, 14, 16	$ 140,400.00	at some walls were c
					Dallas	Dallas	CF HAWN 7	Parallel to Bethurum Ave , South of CF Hawn	Yes	Yes		2013	$ 18,000.00	12	750	16	$ 216,000.00	
					Dallas	Dallas	CF HAWN 8	Parallel to Anderson St, North of CF Hawn	Yes	Yes		2013	$ 17,400.00	12	725	16	$ 208,800.00	
					Dallas	Dallas	IH 45 1	Reaches from Holmes St to Lenway St	Yes	Yes		2013	$ 12,803.00	32	2030	8, 10, 12	$ 12,803.00	
					Dallas	Dallas	IH 45 1a		No	Yes		2013						
					Dallas	Dallas	IH 45 2	Northside of 45, from Cooper to Lenway st	Yes	Yes		2013	$ 19,710.00	8	730	12	$ 19,710.00	
					Dallas	Dallas	IH 45 3	Along Spence St	Yes	Yes		2013	$ 17,010.00	4	270	14	$ 17,010.00	
					Dallas	Dallas	IH 45 4	Warren Ave to Panama Pl	Yes	No		2013	$ 35,280.00	2	140	14	$ 35,280.00	
					Dallas	Dallas	IH 45 5		Yes	Yes		2013	$ 13,860.00	2	55	14	$ 13,860.00	
					Dallas	Dallas	IH 45 6	Warren Ave, Covering MLK Elementary	Yes	Yes		2013	$ 21,870.00	4	270	18	$ 21,870.00	
					Dallas	Dallas	IH 45 7	Pennsylavnia Ave to PeaBody Ave	Yes	Yes		2013	$ 21,420.00	2	170	14	$ 21,420.00	
					Dallas	Dallas	IH 45 8		Yes	Yes		2013	$ 23,940.00	2	190	14	$ 23,940.00	
2	0014-16-179 0014-16-268	2012	state.tx.us/pub/txdot-info/ftw/ih35	Interstate hwy 35W From HWY 820 to Hwy 30	Tarrant County	Fort Worth	R4		No									R4,R18, R21, R22 Would require gaps to satisfy access requir
							R6		Yes	No								
							R8		Yes	No								R6,R8,R9,R10,R24,R25 - Due to topography nois
							R9		Yes	No								R30 - Has existing noise barrier so becau
							R10		Yes	No								
							R12											o meaningful noise
							R13											
							R14	Noise Barrier 1, West of IH 35W	Yes	Yes		2012	$ 23,733.82	11	1,036	14	$ 261,072	
							R15											
							R16											
							R18		No									
							R19	Noise barrier 2, South of SH 121	Yes	Yes		2012	$ 11,176.36	11	683	10	$ 122,940	
							R20	Noise Barrier 3, North of SH 121	Yes	No		2012	$ 57,602.57	7	1,474	15, 16	$ 403,218	
							R21		No									
							R22		No									
							R24		Yes	No								
							R25		Yes	No								

Figure 34. Example of the Database Developed from Reviewing the Environmental Assessments.

Reasonableness Criteria Analysis

The sample of 205 noise walls from environmental assessment reports of 25 projects that were proposed and/or built since 2010, although not randomly selected, is still a representative sample of available environmental reports. Therefore, the conclusions drawn in this section may not uniformly apply to all noise walls in Texas but are a valid general assessment of the reasonableness criteria adopted by TxDOT.

Comparison of Feasibility and Reasonableness of Reviewed Noise Walls in Texas

Figure 35 shows that of the reviewed 206 noise walls, around 78 percent (161) of the noise walls were found to be feasible and 62 percent (100) of these feasible noise walls were reasonable based on TxDOT cost-effectiveness criterion of $25,000 per benefited receptor. A noise wall must be both feasible and reasonable to meet noise abatement measure criteria for Type 1 federally funded projects. Forty percent (61) of these feasible noise walls did not meet the cost-effectiveness criterion set forth by TxDOT. Of these 40 percent of feasible but non-reasonable walls (exceeds criterion of $25,000 per benefited receptor), 75 percent (46) did not explicitly mention cost per benefited receptor in the environmental assessment report (see Figure 36). Instead, a general statement was provided about walls exceeding TxDOT's reasonableness criteria. For example, the FEIS on Grand Parkway Segments H and I-1 (SH 99 from US 59 (N)/I-69 to I-10 (E) in Montgomery, Harris, Liberty, and Chambers Counties, Texas) states that "receivers represent 30 residences along the south side of the preferred alternative, [and] a traffic noise barrier approximately 4,000 ft long and 14 ft high along the ROW would achieve the minimum feasible reduction of 5 dB(A) and the noise reduction design goal of 7 dB(A) for at least one of the 7 residences; however, it would exceed the reasonable, cost-effectiveness criterion of $25,000" (*1*).

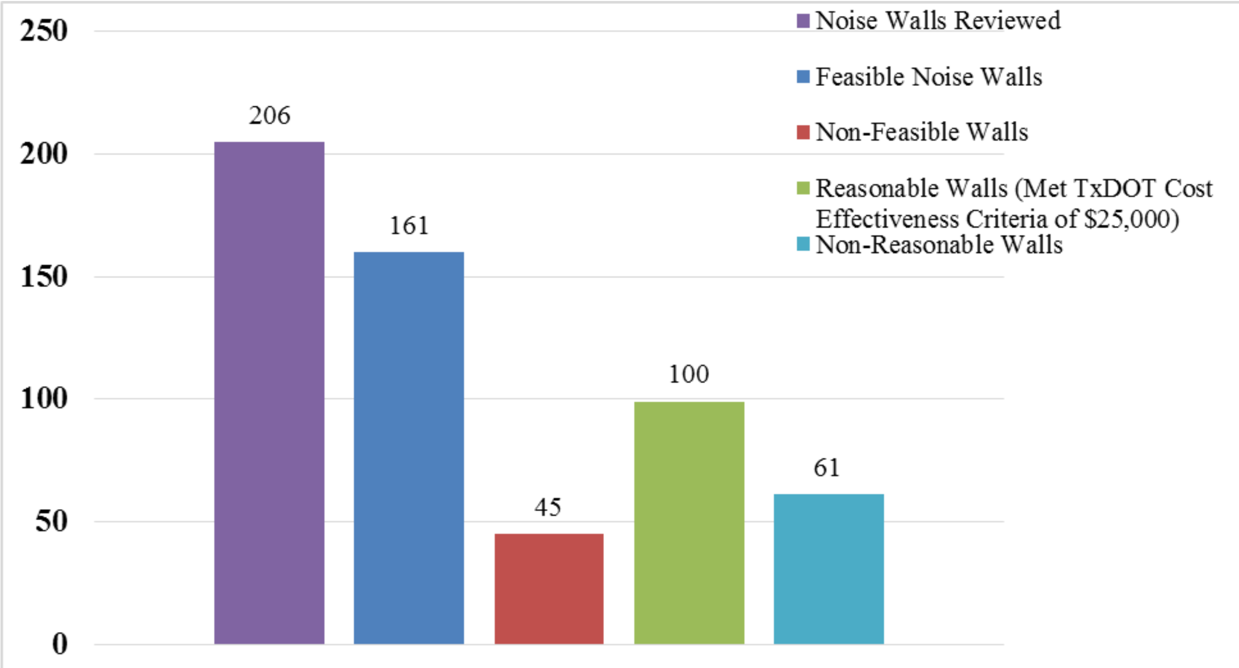


Figure 35. Comparison of Number of Feasible and Reasonable Noise Walls.

Further, from the total sample of 206 noise walls, around 56 percent (115) had cost per benefited receptor value.[3] To ensure transparency within the environmental process, the specific estimated cost per benefited receptor should be mentioned in every environmental assessment report instead of using a blanket statement. This is especially desired for noise walls that do not meet the cost-effectiveness criterion of $25,000 so that public trust is maintained by demonstrating due diligence.

[3] All noise walls that met the reasonableness criteria had cost per benefited receptor value.

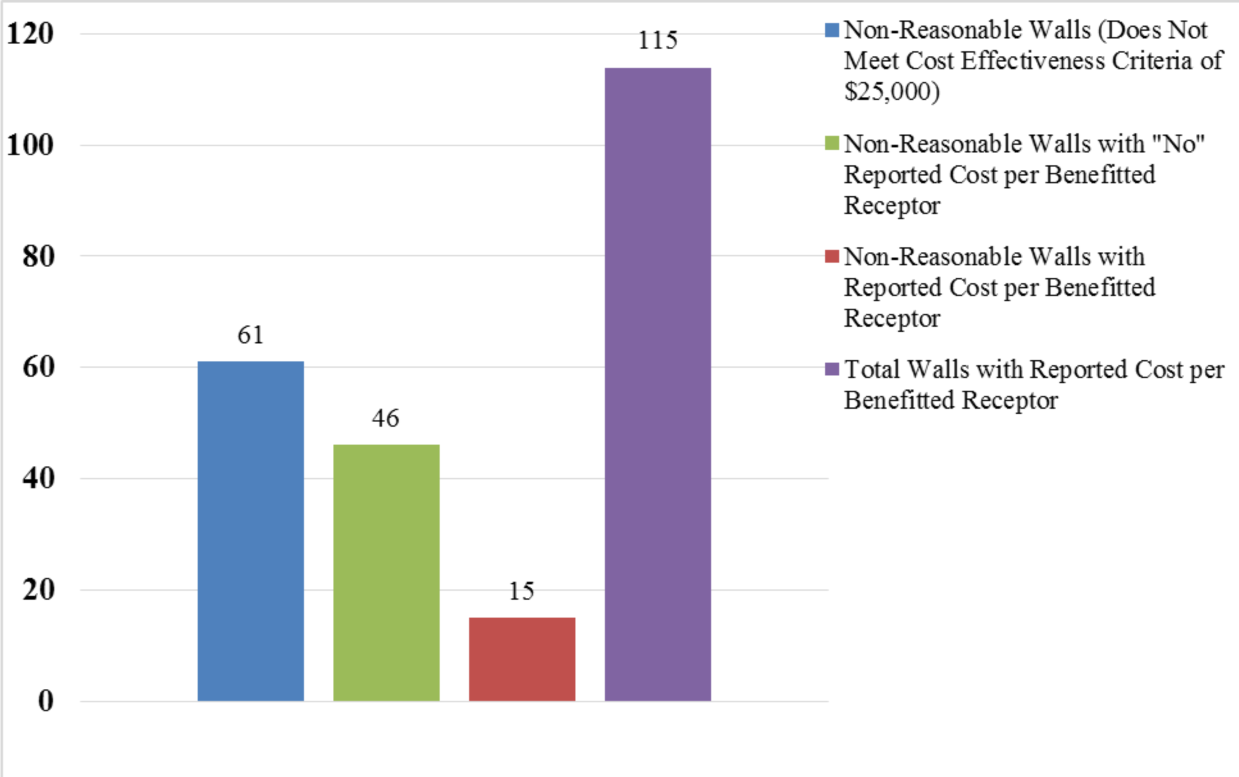


Figure 36. Assessment of Number of Noise Walls That Fail to Meet Reasonableness Criteria.

Next, TTI researchers plotted cost per benefited receptor for noise walls since 2010, as shown in Figure 37. There were no noise wall data for the year 2011. The cost per benefited receptor is in semi-logarithmic scale to capture all data points and prevent clustering. As mentioned above, around 75 percent (46) of non-reasonable noise walls (above the cost-effectiveness criterion of $25,000) had no cost information; thus, researchers had to rely on data in the remaining 25 percent (15 walls) to show data above the cost-effectiveness criterion. In addition, of the 100 noise walls that met the cost-effectiveness criterion, the cost information for some walls was grouped into one in the environmental assessment reports, leaving 90 cost per benefited receptor values (90 data points). It was observed that this might have been done to bring the average cost below the cost-effectiveness criterion since the individual cost per benefited receptor for these walls was higher than the criterion.

The graph in Figure 37 shows that five walls were just $500 below the criterion. In the available data, one wall was $200 above the criterion; however, due to the lack of cost-effectiveness values for 75 percent of the total non-reasonable noise walls, it is difficult to interpret how many walls that did not meet the cost-effectiveness criterion were also close to the threshold.

Figure 38 draws a comparison between the cost benefited per receptor in 2016 dollars, number of benefited receptors, and number of built walls. A general observation is that the higher number of benefited receptors have the potential to bring down the cost of the wall and more chances of being reasonable and subsequently built.

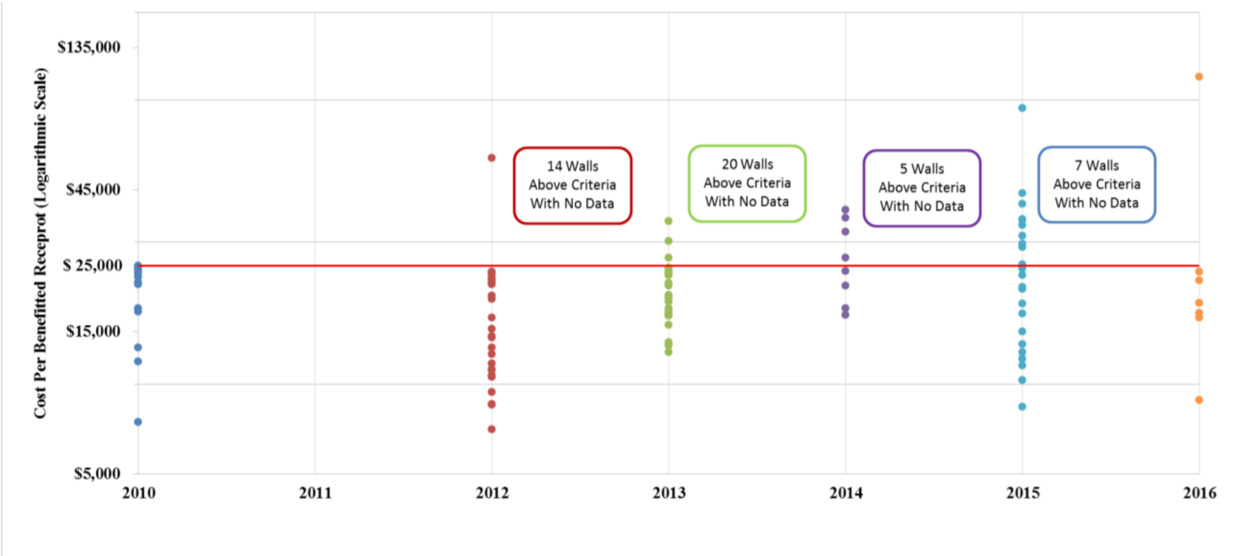


Figure 37. Cost per Benefited Receptor for Noise Walls from Reviewed Reports.

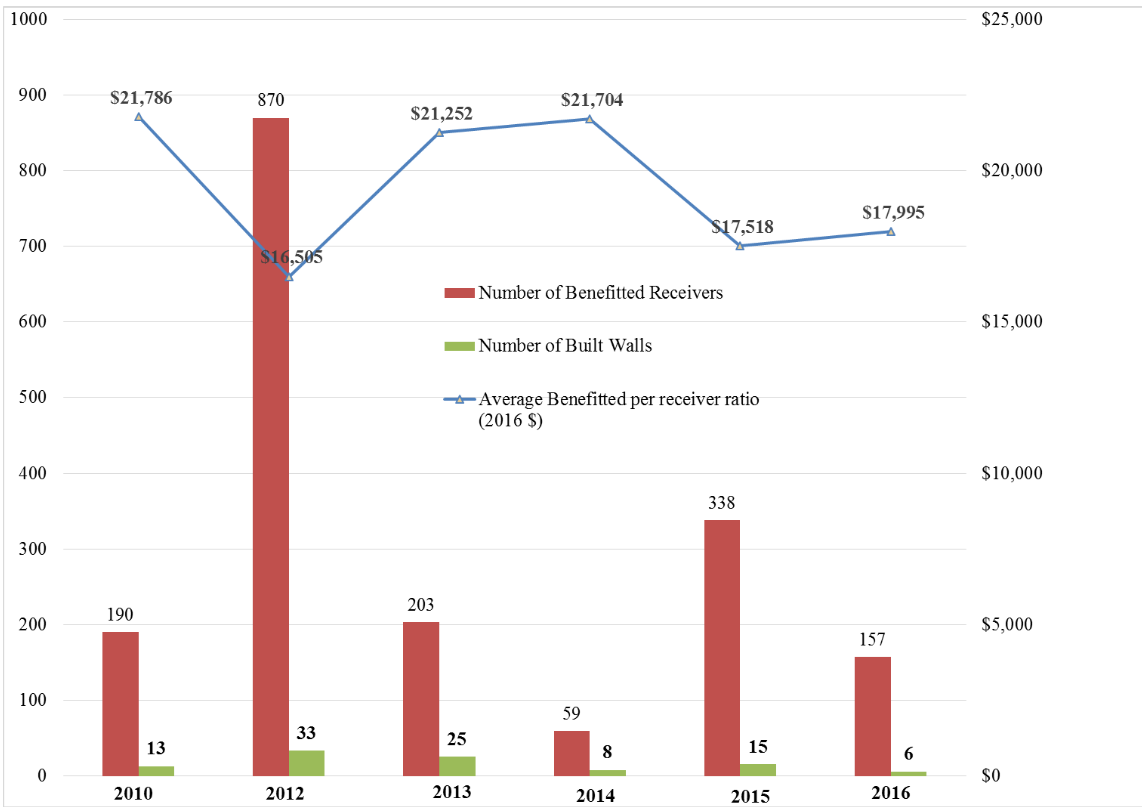
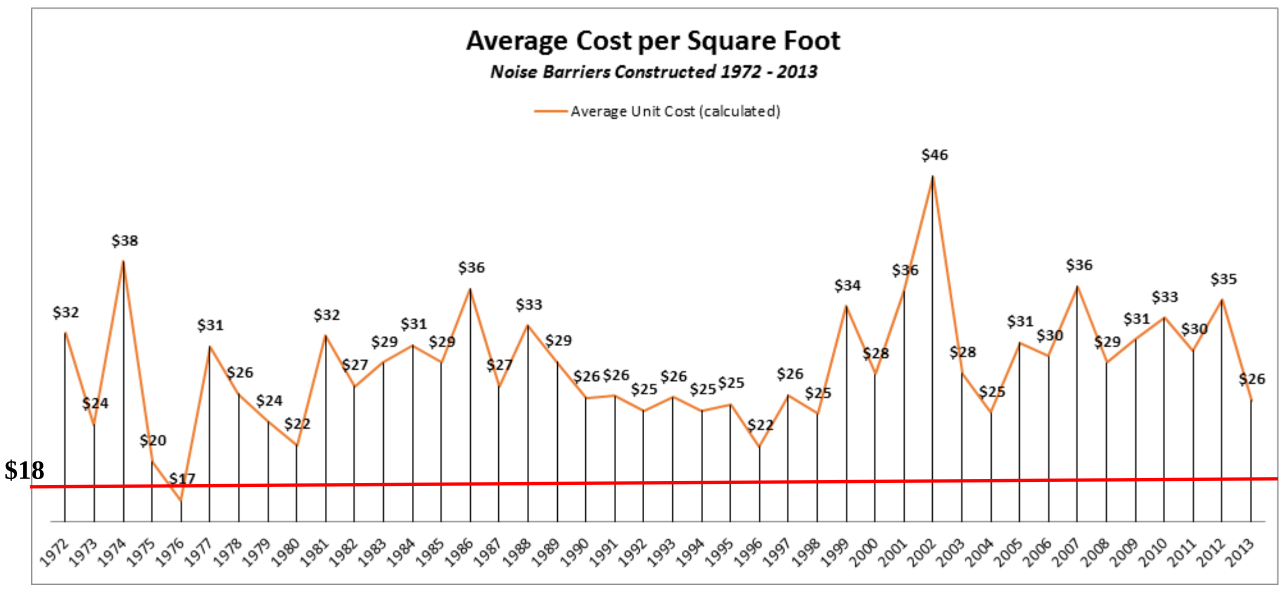


Figure 38. Comparison of Cost per Benefited Receptor with Benefited Receptors and Noise Walls Built.

Comparison with National Cost

TxDOT uses a construction cost of $18 per square foot to calculate the cost-effectiveness criterion of $25,000, and that only includes the cost of construction of a noise barrier and not the cost of any additional right-of-way or utility adjustments (*2*). The yearly national average cost per square foot for noise barriers (combining all materials and barrier types) as published by FHWA is shown in Figure 39 (*2*). This cost is based on the data supplied by 52 state highway agencies (including Washington, DC, and Puerto Rico) between 1963 and 2013. According to FHWA, the national average unit cost from 2011–2013 was $33.81 per square foot for Type I projects. This cost was $35.14 per square foot from 2008–2010, and $35.46 per square foot from 2004 to 2013. From 1963 to 2013, the average cost per square foot varied by state, from a low of $11 per square foot in North Dakota to a high of $75 per square foot in Delaware.

An important caveat for Figure 39 is that the listings are approximate due to varying state practices for estimating costs and individual state highway agency (SHA) definitions of barrier information and project features. Further, these average unit costs are likely a function of the cost-effective reasonableness used by various state DOTs that may limit the upper bounds. Nevertheless, the current per unit construction cost used by TxDOT ($18/sq ft) seems low compared to the national average, as illustrated in Figure 39.



Source: (*2*, *3*).

Figure 39. Average Cost of Noise Barriers in the United States.

TTI also used the available noise wall inventory data from FHWA to develop an assessment of noise walls built by material type and average per unit cost. This assessment is based on the most recent published data by material type that was available on the FHWA website (*2*). Table 25 shows average construction costs for different noise wall materials in the United States and Texas as reported in the inventory data for the following time intervals: before 2001, 2001–2005, and 2006–2010. As shown in Table 25, concrete is the most commonly used noise wall material in Texas, with reported average costs of around $13 per square foot for 2006–2010. Further, based on the state database, TxDOT's statewide average low bid unit prices for various sound walls vary from $19.28 per square foot to $24.71 per square foot. It is not clear whether the average unit cost reported in the FHWA inventory includes right-of-way acquisition or utility adjustments (*2*).

Table 25. Noise Wall Material Usage and Average Unit Cost in the United States and Texas as Derived from FHWA Inventory.

	Before 2001				2001–2005				2006–2010			
	US		TX		US		TX		US		TX	
	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft	1000 sq ft	$/sq ft
Berm	3,732	$7	73	$23	85	$16	NA	NA	67	$17	NA	NA
Block	30,029	$23	4	$22	4,313	$36	17	$50	4,140	$26	NA	NA
Combination	15,815	$21	82	$28	3,918	$13	NA	NA	3,788	$27	NA	NA
Concrete	60,565	$27	2,586	$25	26,843	$34	375	$21	25,811	$32	1,204	$13
Metal	2,671	$19	NA	NA	1,608	$18	NA	NA	713	$20	NA	NA
Wood	11,759	$20	3	$18	955	$19	NA	NA	58	$19	NA	NA

Note: NA indicates data not available.
Source: (*2*).

Comparison of Height and Length of Reviewed Noise Walls in Texas

TTI developed a height distribution of the noise walls reviewed from the environmental assessment reports and compared them to the national average. Figure 40 shows that the majority of noise walls (80 percent) that qualified under the cost-effectiveness criterion are not higher than 14 ft. Nationally, 56 percent of the noise walls are below 14 ft (Figure 41).

TTI also compared the cost (in terms of 2016 dollars) and length in linear miles for the noise walls in the reviewed environmental assessment reports. Figure 42 shows length and cost of reviewed noise walls in Texas by year. Figure 43 shows the national length and cost of all noise barriers constructed in the United States through 2013.

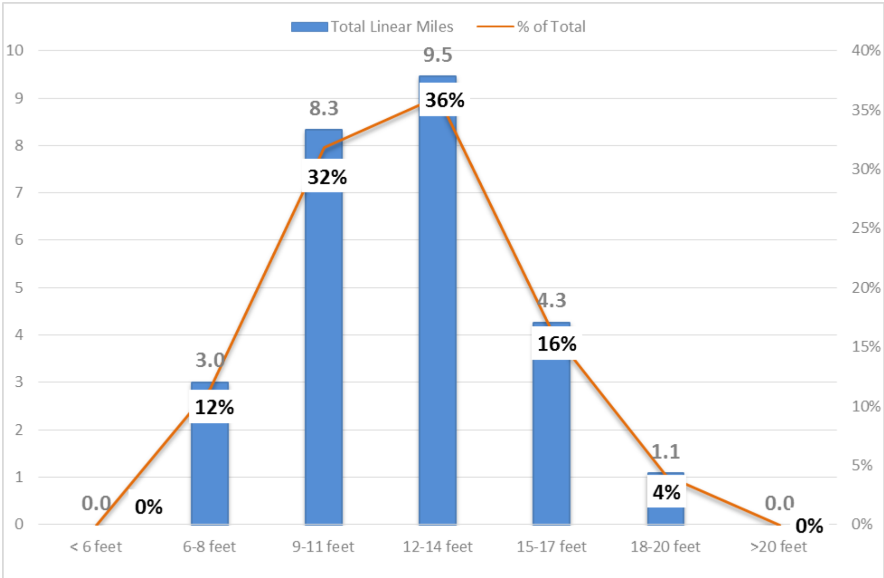
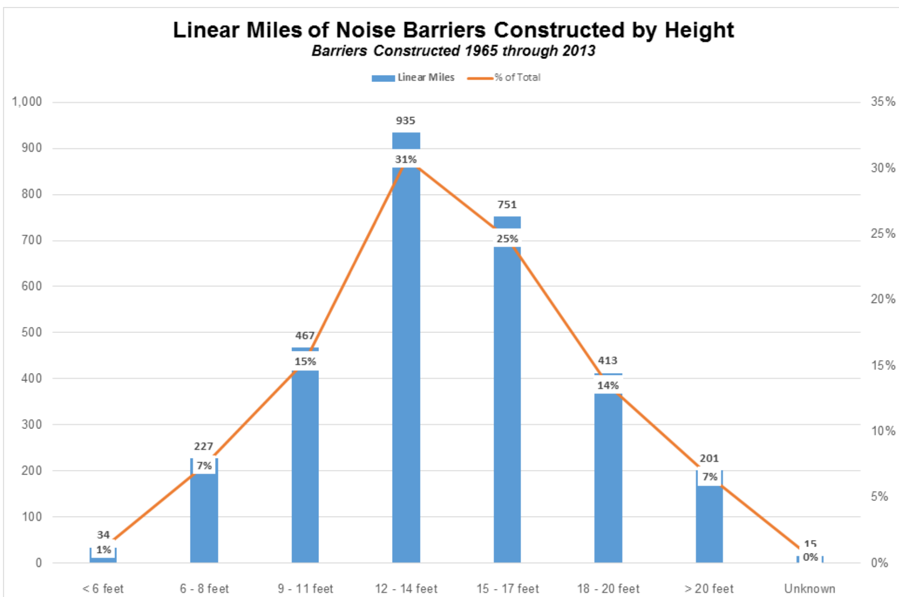


Figure 40. Height Distribution of Reviewed Noise Walls in Texas.



Source: (*4*).

Figure 41. Height Distribution of All Noise Barriers Constructed in the United States.

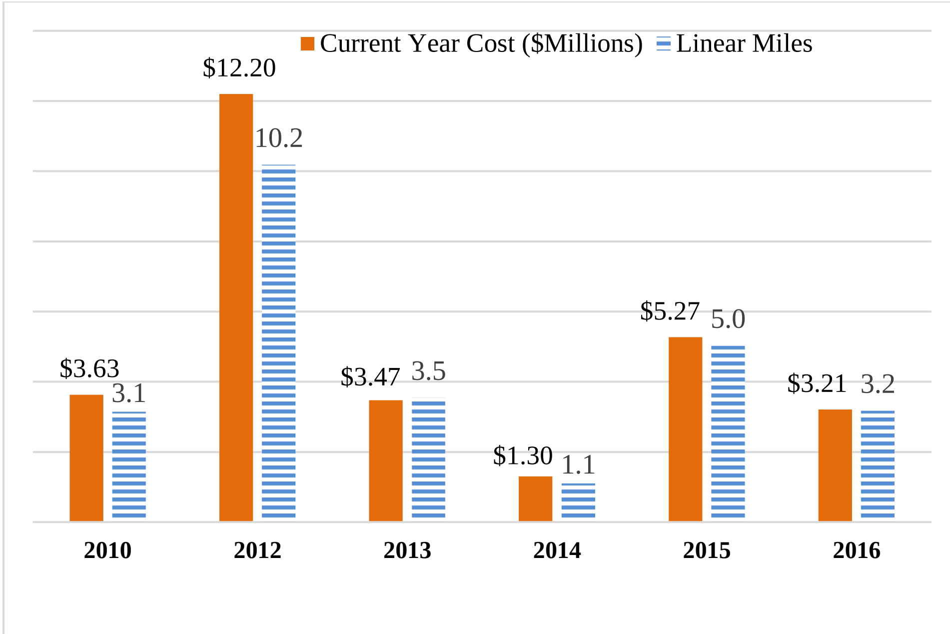
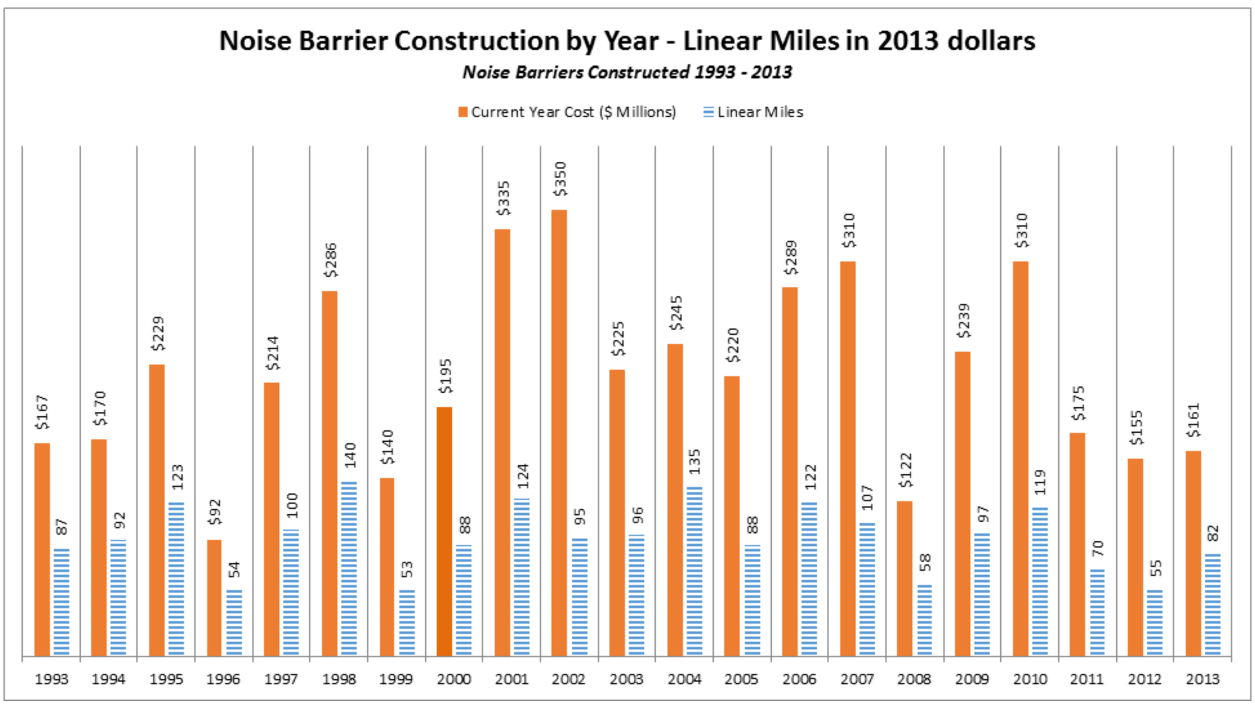


Figure 42. Length and Total Cost of Reviewed Noise Walls in Texas by Year in 2016 Dollars.



Source: (*4*).

Figure 43. Length and Cost of All Noise Barriers Constructed in the United States by Year in 2013 Dollars.

Conclusions

The research team developed the following conclusions based on the evidence found through the literature review process:

- 78 percent of reviewed noise walls were feasible and 62 percent (100) of these feasible noise walls were reasonable based on TxDOT cost-effectiveness criterion of $25,000 per benefited receptor.
- 75 percent of the non-reasonable noise walls (exceeds criterion of $25,000 per benefited receptor) that were feasible do not have a specifically reported cost per benefited receptor value in the environmental assessment report.
- All noise walls that met the reasonableness criteria reported cost per benefited receptor value.
- Sometimes when the individual cost per benefited receptor for a wall is higher than the $25,000 criterion, multiple walls are grouped together to bring the average cost down and qualify for the cost-effectiveness criterion.
- TxDOT's unit construction cost value of $18 per square foot that is used to calculate the cost-effectiveness criterion of $25,000 is well below the current national average cost for noise barriers (combining all materials and barrier types) of $33.81 per square foot. However, it is somewhat of an arbitrary value alone, only having value in the context of how it relates to the cost-effectiveness criterion and a resultant barrier area per benefited receiver.

References

1. FHWA. Volume I: Final Environmental Impact Statement and Exhibits—The Grand Parkway Segments H and I-1—SH 99: US 59 (N)/I-69 to I-10 (E). April 2014.
2. FHWA. Summary of Noise Barriers Constructed by December 2013. Updated May 2016. http://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/. Accessed July 16, 2016.
3. FHWA. Noise Barrier Construction Material Average Unit Cost by Year. 2010. http://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/summary/stable710.cfm. Accessed June 16, 2016.
4. FHWA. Noise Barrier Graphs. 2013. http://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/graphs.cfm. Accessed July 16, 2016.

Appendix H. Interview Questionnaire

Implementation and Effectiveness of Sound Mitigation Measures on Texas Highways (H.B. 790)

Task 3 – Interview TxDOT and Toll Authorities

DATE

DISCUSSION QUESTIONS

PLANNING

1. Describe your benefit/cost analysis?
    a. Fully define all inputs considered (dBA, receptor, IL, etc.).
    b. What B/C justification is required for projects?
    c. What costs are included in your total (e.g., right-of-way, materials, labor, etc.)?
    d. What is your cost-effectiveness threshold per benefitted receptor?
        i. When and how was this threshold determined?
    e. What is your cost-effectiveness threshold per square foot of wall?
        i. When and how was this threshold determined?
2. Define criteria used when evaluating cost/ft^2 of noise abatement, cost/receiver protected, etc. (i.e., when is a wall too expensive?).
3. What is the timeframe/process for re-evaluating the cost-effectiveness threshold per receptor?
4. What is the local government's role in funding noise abatement projects?
    a. Have there been opportunities to partner with local government for noise abatement?
    b. What prevents local government in funding noise abatement projects? Why?
5. Describe your experiences with third party cost-sharing.
6. At what stage in the project development process is the decision made to construct noise abatement?
    a. Are noise abatements constructed early, middle, or late in a construction project?
    b. Do you include provisions in the construction contract for when the abatement measures are constructed?
    c. How is the schedule determined for when the noise abatement measures are constructed?
7. Is highway noise abatement placement determined by the corridor adjacent land use?
    a. How do planners respond when new similar development occurs?
8. What type of noise measurement is used to determine the need for a noise abatement treatment?
9. What traffic noise prediction model is used?
    a. Is road surface noise introduced into the traffic noise prediction model? If so, describe.
    b. Identify and describe the source and the quality of the data used for the source model (e.g., traffic volume source, etc.)
10. What source height is used for noise abatement analysis?

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11. How are changes in traffic mix and volume, ground cover, weather, etc., accounted for when measuring IL?
12. Does your procedure differ from the federal requirements? If so, how?
13. Describe the procedures used in Before/After (IL) measurement analysis, including utilized, and descriptor (L_{10} or L_{eq}).
14. Are there cases when your agency collected After sound studies?
    a. Under what circumstances was the decision made to perform the After study?
    b. Where were the sound measurement receptors placed to measure the After sounds?
15. How does environmental justice influence if noise abatement treatments are needed?
    a. How does environmental justice impact the design of noise abatement treatments?

DESIGN

1. Do you solicit community input for design details?
    a. How are the participants identified?
    b. What methods are used to solicit community input?
2. What criteria are used to determine noise barrier height and length?
3. How do you define line of sight?
4. What do you typically design for (i.e., the highest critical receptor, most critical receptors, etc.)?
5. How do you determine lateral placement of noise barriers (i.e., close to source, close to receptor, etc.)? Why?
6. Have you used internal or external noise abatement materials on existing structures (i.e., sound insulated windows, absorbent panels, etc.) in lieu of a noise barrier?
7. Do you use a context sensitive solutions approach to barrier design and community involvement?

PUBLIC INOLVEMENT

1. What is your solution when a minority of adjacent property owners wants noise abatement?
    a. How do you reach a consensus?
    b. Do renters have a voice in the decision-making process?
    c. What voice do offset or second-line receivers have in the process?
    d. How are the opinions of multi-family residences heard?
    e. How are the opinions of renters balanced with property owners?
2. How are opinions of non-residential land uses heard in the design and voting processes?
3. Have you conducted community surveys regarding the perceived Before/After effectiveness of noise abatement placement?
    a. If so, what survey method was used?
    b. How deep into the community does the data extend? (1st row, 2nd row, etc.)

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c. Have your surveys shown any correlation between perceived effectiveness and
    i. Before L_{10} or L_{eq}
    ii. IL
    iii. Aesthetics
    iv. Barrier type/material
    v. Level of community involvement in the process
    vi. Other.

4. Does the public consider the barriers necessary?
    a. Cost vs perceived effectiveness
    b. Cost vs aesthetics
    c. Perceived effectiveness vs aesthetics
5. At what stage in the project life does community involvement begin?
6. Describe the community involvement techniques used (i.e., formal and informal public meetings, visual aids, computer simulations, etc.).
7. Provide examples of how community involvement input affects decision-making of noise abatement selection?
8. Have you had inquiries from the public about Type II projects?
9. Have you experienced any litigation regarding noise abatement?

POLICY AND PROCEDURE

1. Have you ever deviated from your standard policy/procedures? If so, what was the deviation and what was the justification for the deviation?
2. Are you currently considering any changes to your policy/procedures? What are the changes you are considering?

Appendix I. Summary of Interview Responses

Note: NA means not applicable.

Sound Mitigation Summary—Planning	
1. Describe your benefit/cost analysis.	
TxDOT	Uses TNM Version 2.5
CCRMA	TNM
CRRMA	Follows TxDOT
CTRMA	Follows TxDOT
FBCTRA	Follows TxDOT if using TxDOT money—perform environmental report
HCTRA	Not legally required to follow federal guidance but does Not much different from TxDOT guidance
MCTRA	Follows TxDOT Same as NEPA process
NETRMA	No projects required
NTTA	TNM
1a. Fully define all inputs considered.	
TxDOT	Roadway geometry—to create three-dimensional model Traffic inputs (TxDOT TPP and consultant data)—includes average daily traffic existing year and 20 year (design year) Average weather—standard default Pavement type—held constant (due to changes over time and constant reevaluation) Model for design speed limit and 30th highest vehicle volume hour
CCRMA	Typical model inputs
CRRMA	Follows TxDOT guidance
CTRMA	Follows TxDOT guidance
FBCTRA	Follows TxDOT guidance
HCTRA	Follows TxDOT guidance
MCTRA	Follows TxDOT guidance
NETRMA	NA
NTTA	Follows TxDOT guidance

1b. What benefit/cost justification is required for projects?	
TxDOT	Noise abatement criteria table Residential—equal or greater than 66-dB(A) impact, then must analyze for noise abatement
CCRMA	Follows TxDOT
CRRMA	Reasonable Feasible
CTRMA	Follows TxDOT guidance
FBCTRA	Follows TxDOT guidance
HCTRA	At least 50% of first row has 5-dB(A) reduction At least 1 receptor has 7-dB(A) reduction Maximum of $25,000 cost per receptor
MCTRA	Follows TxDOT guidance
NETRMA	NA
NTTA	Follows TxDOT guidance
1c. What costs are included in your total?	
TxDOT	Cost of wall only—$18/sq ft
CCRMA	Cost of wall only
CRRMA	Cost of wall only—may be instructed by TxDOT to adjust under circumstances
CTRMA	Cost of wall only—$18/sq ft
FBCTRA	Cost of wall only if put in ROW Any other costs incorporated into total
HCTRA	Cost of wall only—$18/sq ft
MCTRA	Cost of wall at $18/sq ft—TxDOT guidance
NETRMA	NA
NTTA	Follows TxDOT guidance
1d. What is your cost-effectiveness threshold per benefited receptor?	
TxDOT	$25,000 or less—guidelines reapproved in 2011 FHWA study
CCRMA	$25,000
CRRMA	$25,000—TxDOT guidance
CTRMA	$25,000—TxDOT guidance
FBCTRA	$25,000—TxDOT guidance
HCTRA	$25,000—TxDOT guidance
MCTRA	$25,000—TxDOT guidance
NETRMA	NA
NTTA	$25,000—TxDOT guidance

1e. What is your cost-effectiveness threshold per square foot of wall?	
TxDOT	Uses $18/sq ft—guidelines reapproved in 2011 FHWA study
CCRMA	NA—no threshold per receiver known
CRRMA	$18/sq ft—TxDOT guidance
CTRMA	$18/sq ft—TxDOT guidance
FBCTRA	$18/sq ft—TxDOT guidance
HCTRA	$18/sq ft—TxDOT guidance
MCTRA	$18/sq ft—TxDOT guidance
NETRMA	NA
NTTA	$18/sq ft—TxDOT guidance
2. Define criteria used when evaluating cost/square foot of noise abatement, cost/receiver protected, etc.	
TxDOT	Cost exceeds $25,000
CCRMA	Cost exceeds $25,000
CRRMA	Cost exceeds $25,000
CTRMA	Cost exceeds $25,000
FBCTRA	Cost exceeds $25,000—TxDOT guidance
HCTRA	Cost exceeds $25,000
MCTRA	Uses TxDOT bid line items to determine cost of wall May use more specific vender pricing if available
NETRMA	NA
NTTA	Cost exceeds $25,000
3. What is the time frame/process for reevaluating the cost-effectiveness threshold per receptor?	
TxDOT	FHWA 5-year cycle 2011 approved current $18/sq ft and effectiveness of 7 dB(A) 2016 performing cost study reevaluation
CCRMA	3 years if project has not moved forward unless change in project
CRRMA	Follows TxDOT guidance Design changes Traffic changes
CTRMA	Follows TxDOT guidance
FBCTRA	Never had one
HCTRA	Follows TxDOT guidance
MCTRA	Environmental assessment during schematic phase/start with TxDOT procedures May upgrade wall from $25,000 if constituent opposition to original proposal
NETRMA	NA
NTTA	Follows TxDOT guidance/not reevaluated

4. What is the local government's role in funding noise abatement projects?	
TxDOT	No third-party money included (for consistency and fairness) Third-party money considered for aesthetic purposes only
CCRMA	Project specific Usually 90/10% split for noise abatement; depends on funding program May be less if TxDOT participates
CRRMA	Project specific
CTRMA	Self-funded
FBCTRA	FBCTRA 100% self-funded No funding accepted from state or federal
HCTRA	HCTRA pay 100% of all costs TxDOT may provide right-of-way
MCTRA	100% local funded
NETRMA	NA
NTTA	Follows TxDOT guidance
4a. Have there been opportunities to partner with local government for noise abatement?	
TxDOT	No Aesthetics only
CCRMA	No
CRRMA	No
CTRMA	City of Austin—no funding provided
FBCTRA	No
HCTRA	No
MCTRA	100% local
NETRMA	NA
NTTA	No

4b. What prevents local government from funding noise abatement projects? Why?	
TxDOT	For fairness
CCRMA	Federal reimbursement item, so usually does not fund Probably does not want to set precedent
CRRMA	Nothing
CTRMA	Lack of money
FBCTRA	Nothing—if has funding will allow (must be safe and provide appropriate agreement)
HCTRA	Non-issue
MCTRA	NA
NETRMA	NA
NTTA	Nothing—needs funding and commitment
5. Describe your experiences with third-party cost sharing.	
TxDOT	Does not use
CCRMA	NA
CRRMA	None
CTRMA	NA
FBCTRA	NA
HCTRA	Not relevant
MCTRA	This has not occurred Would be receptive to idea
NETRMA	NA
NTTA	NA
6. At what stage in the project development process is the decision made to construct noise abatement?	
TxDOT	Early on/after EIS document completed and signed and at the conclusion of a noise workshop
CCRMA	After noise workshop if consensus (simple majority vote in favor) Design phase
CRRMA	After noise workshop/after full plans, specifications, and engineering
CTRMA	Environmental process has section for noise
FBCTRA	Early on/environmental process and coordinated with utilities One after project completed (Westpark)
HCTRA	In design for inclusion in construction package—does not always happen
MCTRA	Depends on phasing of project Typically middle to late phases
NETRMA	NA
NTTA	Environmental process

6a. Are noise abatements constructed early, middle, or late in a construction project?	
TxDOT	Early
CCRMA	NA—not done yet
CRRMA	Early—site specific
CTRMA	Prefers early—depends on constraints Does not want wall damaged during construction
FBCTRA	Lets contractor build when it needs to Early preferred
HCTRA	Depends on contractor No stipulation on contractor except by overall completion of project
MCTRA	Middle to late
NETRMA	NA
NTTA	Site specific
6b. Do you include provisions in the construction contract for when the abatement measures are constructed?	
TxDOT	Usually left up to contractor to decide Sometimes specified in contract
CCRMA	Unsure/uses a lot of design-build, so flexible
CRRMA	Yes
CTRMA	Yes
FBCTRA	Left up to contractor to decide
HCTRA	No
MCTRA	Part of phasing
NETRMA	NA
NTTA	If can, then will

6c. How is the schedule determined for when the noise abatement measures are constructed?	
TxDOT	Contract specific Contractor has latitude
CCRMA	NA
CRRMA	Site specific Phasing of the project
CTRMA	Contract specific Site specific
FBCTRA	Site specific
HCTRA	NA
MCTRA	Site specific Phasing that works best for construction and mobility during construction
NETRMA	NA
NTTA	If ability to put in schedule, then does
7. Is highway noise abatement placement determined by the corridor adjacent land use?	
TxDOT	Yes
CCRMA	Yes
CRRMA	Yes
CTRMA	Yes
FBCTRA	Yes
HCTRA	Yes, generally if residential (if commercial with driveways, then usually does not)
MCTRA	Yes
NETRMA	NA
NTTA	Yes

7a. How do planners respond when new similar development occurs?	
TxDOT	Based on building permits at time of analysis Noise wall is built contingent upon firm commitment that property owner is to develop plat
CCRMA	If after public meeting, then local entity responsibility
CRRMA	Initially reviews undeveloped lands/if permitted; then included After environmental assessment document completed; then not included
CTRMA	During environmental assessment—look at all plats Follows TxDOT guidance
FBCTRA	Wall included if adjacent land platted prior to environmental process completion Only builds later if agreement with developer or county
HCTRA	Does not do anything after design complete
MCTRA	Evaluates each access point on per-location basis May use overlapping wall measures
NETRMA	NA
NTTA	Active review with cities—per TxDOT guidance Rechecks plats before construction
8. What type of noise measurement is used to determine the need for a noise abatement treatment?	
TxDOT	Existing roadway—ambient measures/comparison of existing model to future model Future (new) roadway—includes any new, unusual sound sources (factory nearby)/future model only
CCRMA	Noise models Field measurements
CRRMA	If measure 66 dB(A), then model
CTRMA	TNM Version 2.5
FBCTRA	Follows TxDOT guidance
HCTRA	Does not generally perform noise measurements (only if new corridor) Will model current system and compare to model of future system
MCTRA	Runs a continuous noise meter for 24-hour period/sometimes more Weekday versus weekend separate
NETRMA	NA
NTTA	TNM Version 2.5

9. What traffic noise prediction model is used?	
TxDOT	FHWA TNM Version 2.5
CCRMA	TNM Version 2.5
CRRMA	TNM Version 2.5
CTRMA	TNM Version 2.5
FBCTRA	Not sure, whatever TxDOT uses
HCTRA	TNM Version 2.5
MCTRA	TNM Version 2.5
NETRMA	NA
NTTA	TNM Version 2.5
9a. Is road surface noise introduced into the traffic noise prediction model?	
TxDOT	Yes, average pavement (default)
CCRMA	Yes, varies with sections because bridges use average of concrete and asphalt
CRRMA	Yes, average pavement
CTRMA	Yes, uses pavement type per project design
FBCTRA	Yes, pavement type and future traffic volumes
HCTRA	Yes, average pavement (TxDOT guidance)
MCTRA	Yes, kept at default/FHWA recommendation
NETRMA	NA
NTTA	Yes, average pavement
9b. Identify and describe the source and the quality of the data used for the source model.	
TxDOT	TxDOT TPP data
CCRMA	TxDOT TPP data
CRRMA	TxDOT TPP data
CTRMA	TxDOT TPP—vehicle mix
FBCTRA	Houston-Galveston Area Council (H-GAC) model data Private consultant data
HCTRA	TxDOT travel forecast and HCTRA data
MCTRA	H-GAC traffic demand model Supplements with own traffic counts from outside vendor Varies by project
NETRMA	NA
NTTA	Existing, NTTA data Consultant projects future years with TPP approval

10. What source height is used for noise abatement analysis?	
TxDOT	FHWA-defined vehicle classification source height/uses heavy-duty trucks
CCRMA	3 ft for cars/8 ft for trucks
CRRMA	Roadway elevation/z-value
CTRMA	Average vehicle height
FBCTRA	Unknown
HCTRA	TNM standard—0 m, 1.5 m, 3.66 m (tire, exhaust, and heavy-truck exhaust)
MCTRA	Proposed surface of roadway elevations from plans
NETRMA	NA
NTTA	Heavy-vehicle exhaust height
11. How are changes in traffic mix and volume, ground cover, weather, etc., accounted for when measuring insertion loss?	
TxDOT	TxDOT TPP forecasts new traffic mix/model each lane Average weather—based on location Ground cover—default ground type/lawn Terrain—based on location Water sources (lake or pond) Existing barriers (real fencing [not including wood fence], buildings, etc.)
CCRMA	Uses directional distribution and volume Uses soft ground cover No change with traffic mix
CRRMA	All terrain features included in model—based on location TxDOT TPP traffic mix Average weather Water sources (pond) Existing barriers (rock walls, real fencing [not including wood fence], concrete traffic barrier, buildings, etc.)
CTRMA	Input as traffic model asks
FBCTRA	Unknown Very few trucks on toll roads
HCTRA	Same as TxDOT
MCTRA	Identifies in TNM what each one is Includes concrete traffic barrier
NETRMA	NA
NTTA	TxDOT standard with NTTA traffic mix

12. Does your procedure differ from the federal requirements? If so, how?	
TxDOT	FHWA has no guide document on how to model (FHWA provides a website) FHWA provides approved model for use
CCRMA	No
CRRMA	No, follows TxDOT guidance
CTRMA	No
FBCTRA	Follows TxDOT guidance
HCTRA	TxDOT matches FHWA/HCTRA follows TxDOT guidance
MCTRA	No
NETRMA	NA
NTTA	No
13. Describe the procedures used in before/after (IL) measurement analysis, including method used and descriptors (L_{10} or L_{eq}).	
TxDOT	Typically does not perform before/after measurements Only if complaint/uses FHWA guidance on how to perform
CCRMA	NA
CRRMA	Models existing traffic conditions and future (20-year) traffic conditions
CTRMA	Equivalent noise level (L_{eq})
FBCTRA	Unknown
HCTRA	L_{eq}
MCTRA	Unknown/defer to consultant
NETRMA	NA
NTTA	NA
14. Are there cases when your agency collected after sound studies?	
TxDOT	No
CCRMA	NA
CRRMA	No
CTRMA	No
FBCTRA	Not aware
HCTRA	Not for sound walls
MCTRA	No
NETRMA	NA
NTTA	Typically no—model to proposed traffic

14a. Under what circumstances was the decision made to perform the after study?	
TxDOT	Barrier complaint—performed reanalysis to check model accuracy (confirmed initial finding)
CCRMA	NA
CRRMA	NA
CTRMA	NA
FBCTRA	NA
HCTRA	NA
MCTRA	NA
NETRMA	NA
NTTA	One instance—NTTA Board of Directors said to do a sound study Followed TxDOT procedures—no further mitigation warranted
14b. Where were the sound measurement receptors placed to measure the after sounds?	
TxDOT	Followed FHWA standard guidelines/15-minute intervals and get average sound level
CCRMA	NA
CRRMA	NA
CTRMA	NA
FBCTRA	NA
HCTRA	NA
MCTRA	NA
NETRMA	NA
NTTA	Receptors along first row—topography was a concern Also looked at 3–4 rows back
15. How does EJ influence whether noise abatement treatments are needed?	
TxDOT	No consideration Indirectly works better for denser developed areas
CCRMA	Does not influence
CRRMA	Treats everyone same
CTRMA	Treats same
FBCTRA	Treats same
HCTRA	Not a factor
MCTRA	Everyone treated the same
NETRMA	NA
NTTA	Does not influence

15a. How does EJ impact the design of noise abatement treatments?	
TxDOT	No/considered a blind policy
CCRMA	Does not impact design
CRRMA	Treats everyone same
CTRMA	Treats same
FBCTRA	Uses standard wall look for highway side On property owner side, gives choices—paint, exposed aggregate, etc.
HCTRA	Standards are the same
MCTRA	Public outreach with businesses throughout construction
NETRMA	NA
NTTA	Does not impact

Sound Mitigation Summary—Design	
1. Do you solicit community input for design details?	
TxDOT	Not by policy Conducts noise workshops if abatement proposed (adjacent property owners can attend) Ballots can have aesthetic options (but do not have to) Uses landscape architects for aesthetics option development Majority vote of property owners rules decision
CCRMA	Yes
CRRMA	Yes, noise workshop for eligible noise wall voters (first-row receptors) Uses TxDOT packet that includes noise barrier brochure (pros/cons)
CTRMA	Yes, through community workshops
FBCTRA	Not on highway side—wants consistent look along entire toll road
HCTRA	Yes, partnership with TxDOT Lets local TxDOT district run meetings
MCTRA	Yes
NETRMA	NA
NTTA	No, NTTA has own design
1a. How are the participants identified?	
TxDOT	Property owners through tax appraisal roll Other residents welcome but have no vote
CCRMA	Property owners of first-row receptors
CRRMA	Property owners through tax appraisal district
CTRMA	Property owners through tax appraisal district
FBCTRA	NA
HCTRA	Property owners directly impacted Adjacent property owners
MCTRA	Stakeholder outreach from time of planning Specific outreach (hospitals, stores, businesses, and college system) Community meetings (chamber and rotary) General outreach (windshield survey) Montgomery County Commissioner
NETRMA	NA
NTTA	NA

1b. What methods are used to solicit community input?	
TxDOT	Letter mailed out stating workshop date—includes mail-in ballot
CCRMA	Noise workshops Mailers
CRRMA	During NEPA process, includes all inputs received/document in EIS Public meetings Noise workshop
CTRMA	More than what TxDOT requires Door hangers Other forms of outreach
FBCTRA	Unknown
HCTRA	Meetings Comments from public ballots
MCTRA	Public outreach Website Email blasts Public meetings One-on-one meetings
NETRMA	NA
NTTA	Public outreach—not about design
2. What criteria are used to determine noise barrier height and length?	
TxDOT	TNM—adjusts height/length to determine optimum performance
CCRMA	Insertion loss
CRRMA	TNM—adjusts to desired performance along lateral of wall/height and gets to within cost parameters
CTRMA	TNM—adjusts to desired performance
FBCTRA	Whoever puts together sound study
HCTRA	Whatever needed to achieve overall 5-dB(A) and one 7-dB(A) reduction benefits
MCTRA	Begins with 8-ft wall and varies up or down within TNM to achieve desirable
NETRMA	NA
NTTA	TNM—maximum results

3. How do you define line of sight?	
TxDOT	Breaking line of sight to give 5-dB(A) reduction
CCRMA	Height of receiver to source of noise
CRRMA	Line between noise source and receiver/unobstructed
CTRMA	Relies on TNM to determine
FBCTRA	Information from environmental report in terms of how high wall needs to be
HCTRA	Receptor "seeing" noise source—average height of standing person
MCTRA	From where the receptor location is defined to source It varies by areas used and impacted
NETRMA	NA
NTTA	Receiver can see sound source
4. What do you typically design for (i.e., the highest critical receptor, most critical receptors, etc.)?	
TxDOT	Design goal—one receiver to get 7-dB(A) reduction Feasible (reasonable) goal—greater than 50% getting 5-dB(A) reduction (more cost effective)
CCRMA	TxDOT guidelines—first story only
CRRMA	First models representative receivers based on land use category Then looks at highest critical receptor
CTRMA	Models the first row of receptors at 5.5 ft off ground
FBCTRA	Unknown—relies on environmental document
HCTRA	Maximum number of benefited
MCTRA	Depends on receptor area/each class has separate noise limit Number of receptors in an area benefited
NETRMA	NA
NTTA	Reasonable/feasible criteria as a whole

5. How do you determine lateral placement of noise barriers (i.e., close to source, close to receptor, etc.)? Why?	
TxDOT	Project specific—closer to receiver or closer to source (not in middle)
CCRMA	Close to the receptor/determined most effective
CRRMA	First tries to put on right-of-way line, then adjusts one way or other if needed
CTRMA	Closer to the receptor—sound bends over top of wall, so closer to receptor; then sound bends over top of house
FBCTRA	At right-of-way line—due to safety
HCTRA	Ideally on right-of-way line—close to source If not possible, then closer to receiver
MCTRA	Right of way and whether receptor wants to allow on property Typically TxDOT does not want wall off right of way/would then go to county or private easement for maintenance
NETRMA	NA
NTTA	Site specific—closer to receiver if possible
6. Have you used internal or external noise abatement materials on existing structures (i.e., sound insulated windows, absorbent panels, etc.) in lieu of a noise barrier?	
TxDOT	No—not aware of any use on TxDOT projects Property structure owner would have to maintain
CCRMA	NA
CRRMA	No
CTRMA	Considered but never used
FBCTRA	No—nothing done outside of right of way
HCTRA	No
MCTRA	No
NETRMA	NA
NTTA	No

7. Do you use a context-sensitive solutions approach to barrier design and community involvement?	
TxDOT	Yes, context-sensitive solutions are encouraged; districts decide whether to utilize
CCRMA	Yes
CRRMA	Yes, during NEPA process
CTRMA	Yes, try to match barrier wall with bridge work and retaining walls
FBCTRA	Has never come up before
HCTRA	Follow Houston master plan
MCTRA	No
NETRMA	NA
NTTA	Design guidelines are standardized for NTTA Information is provided completely/no lack of quality assurance

Sound Mitigation Summary—Public Involvement	
1. What is your solution when a minority of adjacent property owners wants noise abatement?	
TxDOT	Simple majority vote
CCRMA	Uses majority vote
CRRMA	Has not occurred/non-issue
CTRMA	Has not come up before
FBCTRA	NA
HCTRA	Follows TxDOT—51% must agree May accommodate end properties if they do not want wall
MCTRA	Listens to input Re-looks at benefit-cost analysis
NETRMA	NA
NTTA	Property owner only has vote
1a. How do you reach a consensus?	
TxDOT	Vote Presents pros/cons of barrier as neutral as possible Majority of first-row property owners determines outcome
CCRMA	Survey (vote)
CRRMA	NA
CTRMA	TxDOT—51% of vote Non-response treated as a “no” vote
FBCTRA	Does not know County commissioners receptive to helping out
HCTRA	On the vote Discusses at workshops and among itself at that time
MCTRA	Talks through Provides design details Majority vote
NETRMA	NA
NTTA	51% majority vote

1b. Do renters have a voice in the decision-making process?	
TxDOT	Viewpoints obtained They have no vote
CCRMA	NA
CRRMA	NA
CTRMA	No, property owners only
FBCTRA	Never had situation before Believes the answer is no
HCTRA	Only through property owner
MCTRA	Notices go to property owners Not specifically outreached
NETRMA	NA
NTTA	Comments only
1c. What voice do offset or second-line receivers have in the process?	
TxDOT	These receivers may be counted toward a barrier's benefits Their viewpoints are obtained They have no vote
CCRMA	They participate and give input only/no vote
CRRMA	NA
CTRMA	No voice, but takes into account second-row benefiters receiving 5-dB(A) reduction
FBCTRA	Never had situation before
HCTRA	They can attend public meeting They do not receive any invitation directly They have no vote
MCTRA	Public hearing Public meeting processes to provide comments and express concerns early
NETRMA	NA
NTTA	Comments only

1d. How are the opinions of multifamily residences heard?	
TxDOT	Viewpoints obtained They have no vote Owner of complex can vote
CCRMA	Property owner gets one vote
CRRMA	NA
CTRMA	Property owner only gets vote
FBCTRA	No multifamily located along corridor when built
HCTRA	Owner of property can vote
MCTRA	Opinions fed into environmental process and documents
NETRMA	NA
NTTA	Comments only
1e. How are the opinions of renters balanced with property owners?	
TxDOT	Only if owner pursues (opinions of renters may influence owner)
CCRMA	NA
CRRMA	NA
CTRMA	Anyone can attend noise workshop Only property owner can vote
FBCTRA	NA
HCTRA	Not included—only through property owner
MCTRA	NA Not treated differently
NETRMA	NA
NTTA	Refers to owner
2. How are opinions of non-residential land uses heard in the design and voting processes?	
TxDOT	Yes, average lot size is divided by number of impacted areas of property
CCRMA	NA/has not proposed noise wall where there is no residential
CRRMA	Owner of the property
CTRMA	Considered and in voting process
FBCTRA	Everyone has a vote
HCTRA	NA—would follow same procedures as residential if occurs
MCTRA	Same as residential
NETRMA	NA
NTTA	Same as residential

3. Have you conducted community surveys regarding the perceived before/after effectiveness of noise abatement placement?	
TxDOT	No
CCRMA	NA
CRRMA	No
CTRMA	No
FBCTRA	No
HCTRA	No
MCTRA	No
NETRMA	NA
NTTA	No
3a. If so, what survey method was used?	
TxDOT	NA
CCRMA	NA
CRRMA	NA
CTRMA	NA
FBCTRA	NA
HCTRA	NA
MCTRA	NA
NETRMA	NA
NTTA	NA
3b. How deep into the community do the data extend (first row, second row, etc.)?	
TxDOT	NA
CCRMA	NA
CRRMA	NA
CTRMA	NA
FBCTRA	NA
HCTRA	NA
MCTRA	NA
NETRMA	NA
NTTA	NA

3c. Have your surveys shown any correlation between perceived effectiveness and L_{eq}/IL/aesthetics/barrier type/community involvement?	
TxDOT	NA
CCRMA	NA
CRRMA	NA
CTRMA	NA
FBCTRA	NA
HCTRA	NA
MCTRA	NA
NETRMA	NA
NTTA	NA
4. Does the public consider the barriers necessary?	
TxDOT	No data/speculates yes (most want them)
CCRMA	NA
CRRMA	No feedback available
CTRMA	Believes public likes them, but they are expensive
FBCTRA	Thinks walls are best way to go Public does not understand cost
HCTRA	No data/mostly vote yes, so speculates they do
MCTRA	No
NETRMA	NA
NTTA	Typically like walls
4a. Cost versus perceived effectiveness?	
TxDOT	No data
CCRMA	NA
CRRMA	No feedback available
CTRMA	NA
FBCTRA	NA
HCTRA	No data
MCTRA	NA
NETRMA	NA
NTTA	NA

4b. Cost versus aesthetics?	
TxDOT	Not sure/district-level determination
CCRMA	NA
CRRMA	No feedback available
CTRMA	NA
FBCTRA	Aesthetics costs minor
HCTRA	No data
MCTRA	NA
NETRMA	NA
NTTA	NA
4c. Perceived effectiveness versus aesthetics?	
TxDOT	No data
CCRMA	NA
CRRMA	No feedback available
CTRMA	NA
FBCTRA	NA
HCTRA	No data
MCTRA	NA
NETRMA	NA
NTTA	NA
5. At what stage in the project life does community involvement begin?	
TxDOT	Early/environmental process
CCRMA	Public hearings/meetings Usually at final design
CRRMA	NEPA process Noise workshop Throughout entire process
CTRMA	Planning stage may hold public meeting and discuss, but has no hard data to share Early in process
FBCTRA	Environmental process Sometimes before or during design
HCTRA	Final design of roadway project/noise workshop Sometimes discusses during public meeting if design far enough along
MCTRA	Conceptualization/early
NETRMA	NA
NTTA	Day 1 through public outreach

6. Describe the community involvement techniques used (i.e., formal and informal public meetings, visual aids, computer simulations, etc.).	
TxDOT	Noise workshops—after environmental documents signed Public hearings—provides schematic of wall locations Visualization of aesthetics options for each neighborhood separate Aerial imagery Computer simulation for visualization of noise wall—on large projects
CCRMA	Will use most of the examples listed in the question
CRRMA	Formal and informal public meetings Newspaper Electronic presentations Poster boards and schematics Social media/project website, evolving to Twitter, Facebook, email, etc.
CTRMA	Electronic presentations Door hangers Public meetings Social media/websites, Twitter, etc.
FBCTRA	Formal public meetings Graphics/posters of planned wall design
HCTRA	Boards (presents illustrations for wall, texture, and colors) Electronic presentations
MCTRA	Formal and informal public meetings Newspaper Website and email blast/social media Poster boards, schematics, and artist renderings (early) Computer simulation (late)
NETRMA	NA
NTTA	Formal and informal public meetings Social media Visual aids Computer simulation Customizes techniques to different concerns Separate meetings of various business locations and each homeowner association

7. Provide examples of how community involvement input affects decision making of noise abatement selection.	
TxDOT	Municipal entity gets involved Aesthetics committees
CCRMA	NA, not done yet
CRRMA	NA
CTRMA	Voting process Asks opinion on several aesthetic examples or alternatives
FBCTRA	Discussions/input from residents of community not in first row of receptors
HCTRA	Community chooses finish on its side of wall—3 form liners and 2 paint colors Vote on ballot
MCTRA	Responses from meetings County commissioner relays information of constituents
NETRMA	NA
NTTA	NA
8. Have you had inquiries from the public about Type II projects?	
TxDOT	Yes, has had inquiries (TxDOT does not have a Type II program)
CCRMA	No
CRRMA	No
CTRMA	Yes
FBCTRA	Finished design/then looked at lightweight wall type/not crash-tested Did not use wall/changed pavement type to asphalt
HCTRA	Retrofit project in Jersey Village—original road had 16-ft wall Road expanded—performed noise model reevaluation; no change warranted
MCTRA	No
NETRMA	NA
NTTA	NA

Sound Mitigation Summary—Policy and Procedures	
1. Have you ever deviated from your standard policy/procedures? If so, what was the deviation, and what was the justification for the deviation?	
TxDOT	Re-vote on wall—normally one vote and process ends Expanded noise wall abatement off ROW—TxDOT will not maintain (needs 100% agreement to put in proposal)
CCRMA	No
CRRMA	No
CTRMA	Does not deviate but accommodates if needed
FBCTRA	No
HCTRA	Not aware of any
MCTRA	No, follows TxDOT procedures
NETRMA	NA
NTTA	No
2. Are you currently considering any changes to your policy/procedures? What are the changes you are considering?	
TxDOT	Current study to update costs May move to square foot model instead of cost basis model Feasibility to build to benefit at least two receivers Handbook to clarify noise mitigation procedures
CCRMA	No
CRRMA	No, follows TxDOT guidance
CTRMA	No, case-by-case basis/constructability
FBCTRA	No, follows TxDOT guidance
HCTRA	No
MCTRA	Not required when state/federal funding is not involved Whatever is required under the available funding source
NETRMA	NA
NTTA	No

Sound Mitigation Summary—Other	
Comments	
TxDOT	Community concept—extend wall to include end properties that may not actually benefit end properties but could provide benefit to other (second-row) receptors near end with one continuous wall (currently not in guidance) Cost averaging implemented fairly—receivers cannot be over two times cost such that if cost is $60,000, then cannot build
CCRMA	CCRMA has not done any noise mitigation yet In the process of proposing noise mitigation on its upcoming project at South Padre Island
CRRMA	Property owners' side would be given opportunity to choose from several aesthetics choices/have not used for CRRMA to date
CTRMA	On property owners' side of wall have vote on a uniform selection along lateral limits of wall
FBCTRA	Two toll roads: Westpark/F.B. Parkway Tollway and Grand Parkway South Keeps revenue separate for respective toll roads as required for Grand Parkway South
HCTRA	NA
MCTRA	IH 45 at FM 242 in The Woodlands Built north-to-west and west-to-south connectors Approved to build north-to-east connector
NETRMA	NA
NTTA	NA

Appendix J. Field Study Location Detailed Descriptions

SH 99 (Grand Parkway) Segment G

This study site (Figure 44) is located in Harris and Montgomery Counties. The section is a new-location, four-lane, controlled-access facility with discontinuous frontage roads and varying grades to adjacent properties between I-45 near the city of Spring and I-69 in the city of New Caney (approximately 13.7 mi). Segment G connects completed sections of the loop to the west of the study site. The roadway was built and is operated under the authority of TxDOT. The facility fully opened to traffic in 2016 (*1*).

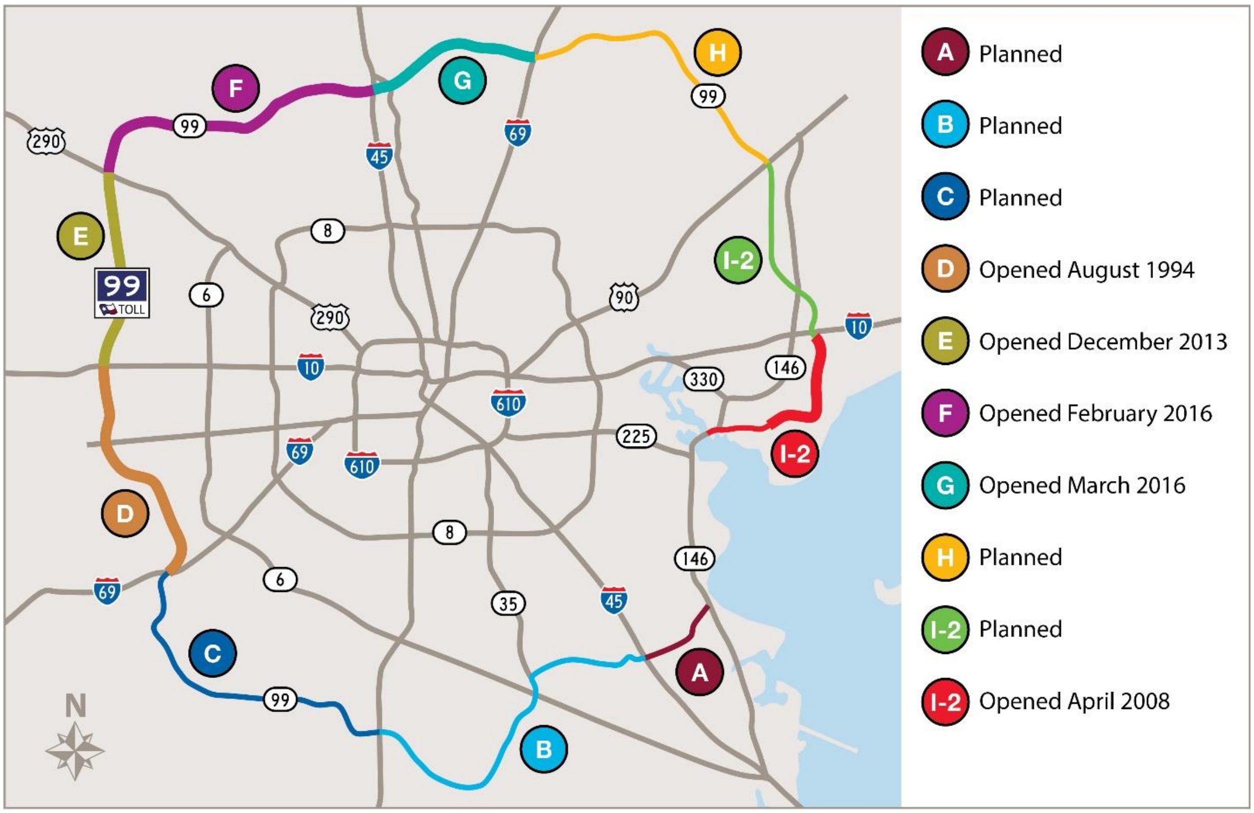


Figure 44. SH 99 (Grand Parkway) System Map.

An FEIS was published in 2009, and a record of decision was given by FHWA. The FEIS documents projected traffic volumes used in the analysis. Table 26 displays average daily traffic numbers cited in the FEIS in different sections. Note the forecasted volume differences within the analysis years.

Table 26. SH 99 Segment G Forecasted Future Traffic Volumes.

Year	Forecasted Average Daily Traffic (*3*)	ADT Roadway (*3*)
2015	**25,800**	**43,400**
2025	**53,700**	**64,500**

The FEIS states that a noise monitoring program was conducted to assess the ambient (existing) noise conditions within the project area. The FEIS states that this monitoring was performed in accordance with FHWA publication FHWA-PD-96-046, *Measurement of Highway-Related Noise*, in May 1996 (*4*), and FHWA guidelines (FHWA-DP-45-1R), *Sound Procedures for Measuring Highway Noise: Final Report* (*5*). The study was conducted September 5 and September 11, 2007. This monitoring program was conducted in accordance with short-term noise measurements of 15-minute durations at 14 sites along the preferred alignment using a Metrosonics db-308 Dosimeter/Analyzer (*3*). The analysis was performed for a future (design) year of 2025 using FHWA's TNM. No model version number was referenced in the FEIS or reevaluation documentation.

As documented in the FEIS, the noise analysis used 24-hour average daily traffic (ADT) volumes and vehicle speeds for the project-modeled roadways. The traffic noise analysis was performed for the peak hour (loudest) of the ADT as required by federal and state noise analysis guidelines. The FEIS states:

> *Typically, LOS C traffic volumes are considered to be the loudest operating condition for automobiles, because of the combination of relatively high volumes and constant speeds. With guidance from H-GAC, the traffic volumes selected to represent the peak-hour for the project-modeled roadways were 10.4 percent of their respective 24-hour ADT volumes, which is considered to be a close approximation to level-of-service (LOS) C conditions. Vehicle speeds on the project roadway mainline were modeled as a toll facility at 65 mph and frontage roads at 50 mph. The projected design year vehicle mix percentages used in the noise modeling analysis consisted of 95 percent automobiles (including vans, pickups, etc.), 2 percent medium trucks (two axles and six tires), and 3 percent heavy trucks (three or more axles).*

Table 27 shows the ambient noise levels recorded before the project was constructed. The design year (2025) ADT and peak-hour volumes for Segment G are shown in Table 28.

Table 27. SH 99 Segment G Ambient Noise Levels.

Site Number	Site Location	Description	Noise Level (dBA Leq)
MG-A	Residential area in Northgate Crossing on Westgate Village Drive located north of proposed Segment G approximately 1,500 ft east of IH 45	Residential Home	50
MG-B	Residential area in Northgate Crossing on Merrimac Ridge Lane located north of proposed Segment G approximately 3,800 ft east of IH 45	Residential Home	50
MG-C	Residential area in Northgate Crossing on North Bridge Terrance Court located south of proposed Segment G approximately 2,500 ft east of IH 45	Residential Home	49
MG-D	Residential area in Northgate Crossing on North Bridge Terrance Court located south of proposed Segment G approximately 3,500 ft east of IH 45	Residential Home	49
MG-E	Residential area in Spring Trails on Ryansbrook Lane located south of proposed Segment G approximately 575 ft southeast of Riley Fuzzel Road	Residential Home	46
MG-F	Residential area in Spring Trails in Misty Cliff Lane located south of proposed Segment G approximately 400 ft southeast of Riley Fuzzel Road	Residential Home	51
MG-G	Residential area in Lockeridge Farms on Lockeridge Bend located south of proposed Segment G approximately 125 ft southeast of Riley Fuzzel Road	Residential Home	52
MG-H	Residential area in Legends Ranch on Fuller Bluff Drive located north of proposed Segment G approximately 1,300 ft northwest of Riley Fuzzel Road	Residential Home	48
MG-I	Residential area in Benders Landing on East Benders Landing Boulevard located south of proposed Segment G approximately 210 ft southeast of Riley Fuzzel Road	Residential Home	47
MG-J	Residential area in Creekside Village on Little River Court located north of proposed Segment G approximately 125 ft northwest of Riley Fuzzel Road	Residential Home	51
MG-L	Residential area in Cumberland Crossing on Hammer Lane located south of proposed Segment G approximately 650 ft east of FM 1314	Residential	52
MG-L	Residential area in Timberland Estates at the intersection of Timberland Boulevard and Alyssa Drive	Residential	51
MG-M	Residential area in Timberland Estates on Hallie Lane	Residential	50
MG-N	Residential area in Valley Ranch at the intersection of Dave Canyon and Dove Haven Court approximately 3,400 ft west of US 59	Residential	49

Source: (*3*).

Table 28. Projected 2025 Traffic Volume Data for SH 99 Segment G Noise Analysis.

Location	Design Year ADT	Peak-Hour Volume
IH 45 to Hardy Toll Road	43,888	4,564
Hardy Toll Road to Riley Fuzzel	64,173	6.673
Riley Fuzzel to Rayford Sawdust	64,511	6.709
Rayford Sawdust to Benders Landing Blvd	61,112	6.355
Benders Landing Blvd to FM 1314	61,564	6.402
FM 1314 to US 59	45,657	4.748

Source: (*3*).

The noise analysis evaluated 165 noise receiver sites (163 residential, one recreation, and one school land use) along the preferred alignment. The results of those noise level projections are recorded in Table 4-21 of the FEIS. Seven noise walls were proposed for the project, as shown in Table 29.

Table 29. Noise Walls Proposed on SH 99 Segment G.

Barrier	Impacted Representative Receivers	Preliminary Dimensions		Total Cost	# Benefiting Receivers	$/Benefiting Receiver
		Length	Height			
1	1, 4, 5, 14, 15, 16, 18, 19, 21, 23, 24, 25 *1, 4, 6, 13, 14, 15, 16, 18, 19, 21, 23, 24, 25	5,547	16	$1,331,280 $1,597,536*	34 68*	$18,438 $23,493*
2	32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48	3,322	16	$797,280	39	$20,443
3	49, 50, 51, 52, 55, 57, 58, 60, 61, 64	2,482	16	$595,680	31	$21,617
4	65, 66, 67, 68	1,166	16	$279,840	12	$23,320
6	98, 99, 100, 103, 104, 105, 106	1,970	16	$472,800	21	$22,514
8	127, 128, 129, 130, 131	2,079	16	$498,960	26	$19,191
9	140, 141, 142, 145, 146, 147, 148, 149, 153, 154	3,014	10	$452,100	19	$23,795

* Change as recorded in 2012 reevaluation document.
Source: (*3*, *6*).

A reevaluation was submitted to FHWA in 2012 and received concurrence on May 22, 2012 (*6*). The reevaluation was prepared for two minor design modifications, five outfall channels, 10 stormwater detention basins, and one floodplain fill mitigation basin. The reevaluation assessed how the additional ROW required for the proposed detention facilities would affect the previous environmental impacts analysis. TxDOT's noise analysis and abatement guidelines were updated in April 2011. The reevaluation included a review of the noise analysis and updated findings consistent with the updated noise guidelines. As a result of the reevaluation, one receiver's NAC was changed. Receivers 1–28 were modeled to reevaluate impacts due to a change in elevation at the Union Pacific Railroad grade separation near the existing Hardy Toll Road. These receivers are one recreation facility and 27 single-family residences. The reevaluation used the same traffic volumes and speeds used in the FEIS.

Another reevaluation prepared in 2013 (*7*) did not update the noise analysis because there were no impacts to the roadway profile, traffic capacity, or mobile sources of noise. That reevaluation stated that the analysis of the FEIS and 2012 reevaluation remained valid.

Because of the newness of this project, no ground-level photography or 3D renderings were available through Google Maps.

US 183A

This study site (Figure 45) is located in the cities of Cedar Park and Leander in Williamson County. The new-location section is a six-lane divided toll facility with discontinuous, non-tolled frontage roads at varying grades to adjacent properties between the US 183/SH 45 interchange and the South San Gabriel River (approximately 4.1 mi). The roadway was built (under a design-build contract) and is operated under the authority of the Central Texas Regional Mobility Authority. The facility fully opened to traffic in March 2007.

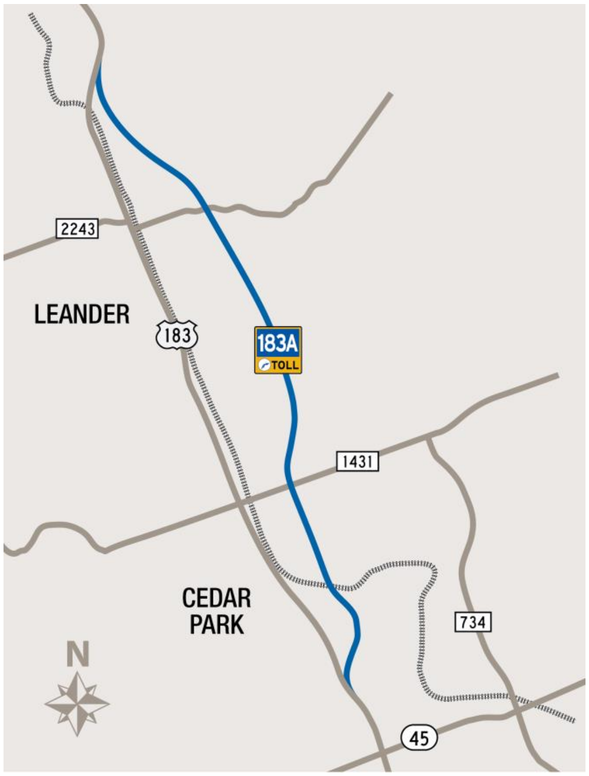


Figure 45. US 183A System Map.

An FEIS for two alternative alignments was published in 2001, and a record of decision was given by FHWA in July 2001.

Table 30 displays an excerpt of the forecasted average daily traffic volumes for the 2020 design year.

Table 30. US 183A Forecasted Year 2020 Traffic Volumes.

Segment		Forecasted 24-hour, Two-Way Traffic Volume
Begin	End	
RM 620	Davis Springs Rd	126,500
Davis Springs Rd	Brushy Creek Rd	116,200
Brushy Creek Rd	Park St	109,200
Park St	FM 1431	106,300
FM 1431	New Hope Rd	105,200
New Hope Rd	CR 272	87,200
CR 272	FM 2243	67,000
FM 2243	Existing US 183	46.900

Source: (*8*).

The FEIS (*8*) states that a noise monitoring program was conducted to assess the ambient (existing) noise conditions within the project area. The noise analysis measured existing noise levels using a Metrosonics db-308 Sound Level Dosimeter/Analyzer at 10 locations for the two alternative alignments, with five locations along or very near the preferred alignment that was constructed. Table 31 displays the ambient noise measurements before the roadway was constructed and at associated modeled receiver sites. Figure 46 maps these ambient noise measurement locations within the corridor.

Table 31. US 183A Reported Existing Noise Levels at Selected Sites within Study Documentation.

Noise Monitoring Site	Associated Receptor Site	Original Location Description	dBA
B	13	CR 271 @ bend in road	61
C	12	FM 2243 @ Fort Leer Baptist Church	53
G	None	Sunset Street	65
H	2	Darkwoods @ Tallow Trail	56
I	3, 4	Buffalo @ Colt	63
J	None	Williamson County Park @ the Pavilion	59

Source: (*8*).

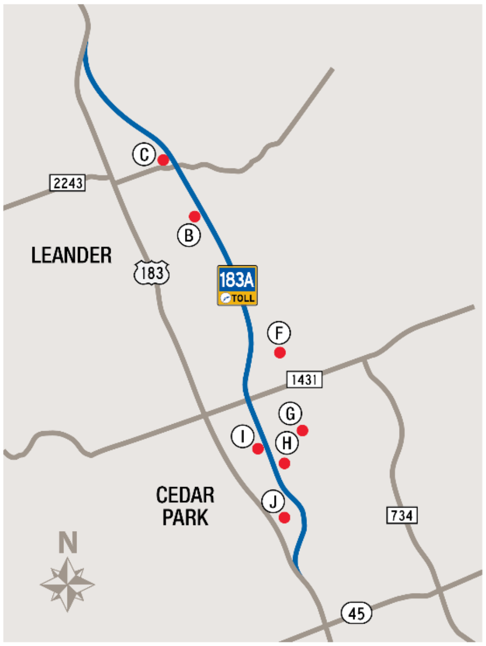


Figure 46. Corresponding Locations for Ambient Noise Measurements at US 183A.

The FEIS identified 130 noise receptors along the preferred alternative. The noise analysis modeled 26 representative sites. These receivers modeled were one park, one health center, one office, three commercial, and 20 residences. The noise analysis was performed using

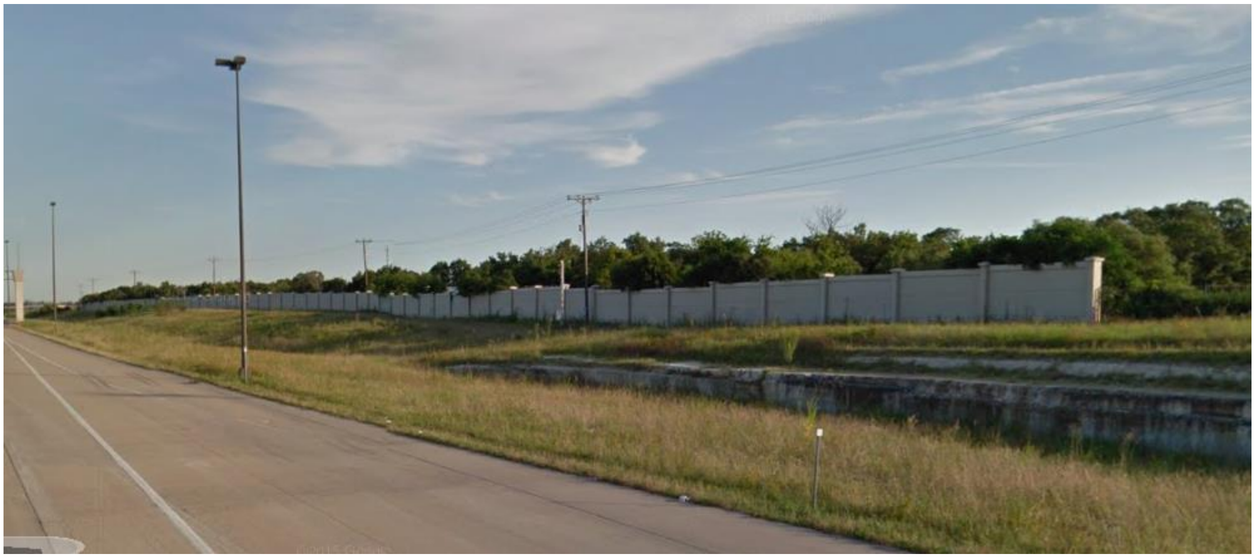
STAMINA 2.0, the current noise analysis model at the time of evaluation, with forecasted traffic for the 2020 design year.

Four noise walls were recommended and constructed to benefit 144 properties. For Receiver 2, two walls were proposed to benefit 71 residences. Wall 1 proposed was 3,000 ft long and 12 ft high at an estimated cost of $756,000, or $22,909 per benefited receptor. Wall 2 proposed was 600 ft long and 12 ft high at an estimated cost of $151,200, or $16,800 per benefited receptor. For Receiver 3, two walls were proposed to benefit 73 residences. Wall 3 proposed was 2,250 ft long and 12 ft high at an estimated cost of $567,000, or $21,808 per benefited receptor. Wall 4 proposed was 2,000 ft long and 12 ft high at an estimated cost of $504,000, or $20,160 per benefited receptor. The noise walls constructed are displayed in Figure 47 through Figure 50.

Environmental reevaluations were performed in 2006, 2008, and 2009. The 2006 reevaluation was initiated because several proposed design changes related to drainage required additional properties. The design changes did not result in additional traffic or additional travel lanes and did not change the roadway alignments analyzed in the FEIS. No noise analysis was required.

The 2008 reevaluation was initiated because of a design change for an at-grade intersection of the US 183A frontage road with County Road 274 as an interim project that would be replaced with a US 183A overpass at CR 274. The design changes did not result in additional traffic or additional travel lanes and did not change the roadway alignments analyzed in the FEIS. No noise analysis was required.

The 2009 reevaluation was initiated because of a proposed design change for a grade-separated intersection at US 183A and County Road 269. This reevaluation documented the use of the TNM, the current noise analysis model at the time of the reevaluation, because the alignment of the roadway had changed with the elevation of the US 183A main lanes (*9*). The reevaluation noise analysis resulted in a decrease of the 66-dB(A) noise contour from the edge of the US 183A right-of-way from 171 ft to 140 ft due to a design change and the TNM's "more realistic characterization of predicted noise levels" (*9*). The analysis was performed for a design year of 2020.



Source: (*10*).

Figure 47. Noise Wall on Southbound US 183A between E Park St and Brushy Creek Rd.

Source: (*10*).

Figure 48. 3D View of Noise Walls on US 183A between E Park St and Brushy Creek Rd.

Source: (*10*).

Figure 49. Noise Wall on Southbound US 183A between E Whitestone Blvd and E Park St.

Source: (*10*).

Figure 50. 3D View of Noise Walls on US 183A between E Whitestone Blvd and E Park St.

President George Bush Turnpike Eastern Extension

This study site (Figure 51) is located in the cities of Garland, Sachse, and Rowlett in Dallas County. The section is a new-location, six-lane divided facility with varying grades to adjacent properties between SH 78 and I-30 (approximately 9.9 mi). The roadway was built and is operated under the authority of the North Texas Tollway Authority. The facility fully opened to traffic in December 2011. This study site is located in HB 790 author Rep. Burkett's district.

Figure 51. President George Bush Turnpike Eastern Extension.

The FEIS (*11*) was published in 2004. Table 32 displays the forecasted average daily traffic for the 2025 design year.

Table 32. President George Bush Turnpike Eastern Extension Forecast 2025 Average Daily Traffic Volumes.

Location along PGBT-EE	Average Daily Traffic
West of SH 78	125,000
Between SH 78 and Northeast Pkwy	69,000
Between Northeast Pkwy and Miles Rd	75,000
Miles Rd to Liberty Grove Rd	67,000
Between Liberty Grove Rd and SH 66	72,000
Between SH 66 and Miller Rd	61,000 to 74,000
Miller Rd to Lake Ray Hubbard	67,000
Lake Ray Hubbard to IH 30	71,000

Source: (*11*).

Sensitive noise receivers were selected through aerial photographs to identify possible noise receivers, and field investigations were conducted to verify the receivers for residential and commercial properties. Ambient noise measurements were taken at 27 representative sites—one high school, one elementary school, one park, two places of worship, one commercial, three multifamily residential, and 18 single-family residential (see Table 33).

The FEIS states that the 2025 forecasted traffic was used for noise analysis. The document does not state the vehicle classification mix used in the analysis. The analysis proposed four walls that were feasible and reasonable. Wall 1 proposed (for Receiver 12) was 2,900 ft in length with an average height of 12 ft benefiting 26 receivers for an estimated cost of $626,400, or $24,092 per benefited receptor. Wall 2 proposed (for Receiver 13) was 1,100 ft in length with an average height of 10 ft benefiting nine receivers for an estimated cost of $198,000, or $22,000 per benefited receptor. Wall 3 proposed (for Receiver 21) was 2,600 ft in length with an average height of 10 ft benefiting 35 receivers at an estimated cost of $468,000, or $13,371 per benefited receptor. Wall 4 proposed (for Receiver 22) was 2,900 ft in length with an average height of 10 ft benefiting 34 receivers at an estimated cost of $522,000, or $15,353 per benefited receptor.

Table 33. President George Bush Turnpike Eastern Extension Summary of Ambient Noise Levels.

Receiver	Location	Measured Noise Level (dBA Leq)
R-1 Single-Family Residential	Northside of Creek Meadow Dr	56
R-2 Single-Family Residential	Southside of Pleasant Valley Rd	66
R-3 Single-Family Residential	Northside of Old Miles Rd	60
R-4 Single-Family Residential	Northside of Pleasant Valley Rd	61
R-5 Single-Family Residential	Eastside of Merritt Rd	70
R-6 Single-Family Residential	Southside of Castle Rd	50
R-7 Single-Family Residential	Southside of Hickox Rd	47
R-8 Single-Family Residential	Northside of Hickox Rd	51
R-9 Place of Worship	Northside of Hickox Rd	61
R-10 Single-Family Residential	Westside of Merritt Rd	50
R-11 Single-Family Residential	Northside of Liberty Grove Rd	63
R-12 Single-Family Residential	Northeast corner of Baffin Bay St and Copano Bay St	47
R-13 Single-Family Residential	Southwest corner of Liberty Grove Rd and Baffin Bay St	59
R-14 Commercial	Southeast corner of SH 66 and Kirby Rd	66
R-15 Place of Worship	Northside of Main St	66
R-16 Park	Southside of Main St	51
R-17 Single-Family Residential	Southwest corner of Main St and Kirby Rd	64
R-18 High School	Southeast corner of Main St and Kirby Rd	65
R-19 Single-Family Residential	Eastside of Mistletoe Dr	51
R-20 Elementary School	Northside of Miller Rd	59
R-21 Single-Family Residential	Westside of Alexandria Dr	50
R-22 Single-Family Residential	Eastside of Brittany Dr	64
R-23 Multifamily Residential	North of IH 30 at Lakeway Apartments	62
R-24 Multifamily Residential	North of IH 30 at Lakeview Apartments	63
R-25 Single-Family Residential	Northside of Zion Rd	55
R-26 Single-Family Residential	Southwest corner of Zion Rd and Bayberry	60
R-27 Multifamily Residential	North of IH 30 at Lakeway Forest Apartments	51

Source: (*11*).

A reevaluation was published in 2008. The reevaluation was initiated because of design changes requiring additional right-of-way and easement requirements, and the implementation of electronic toll collection. A new noise analysis was performed based on forecasted traffic volumes for 2030; however, no 2030 forecasted traffic volumes were presented in the environmental document. The reevaluation noise analysis documented 14 noise receivers. These receivers were one multifamily, one high school, and 12 single-family residential. These receivers were not referenced back to the original noise analysis. The reevaluation results proposed a fifth wall and reduced the barrier height of the previous four walls to 8 ft. Five noise walls were recommended and constructed to benefit 93 properties. Wall 1 proposed (for Receiver 3 and 4, or Receiver 12 in the FEIS) was 2,900 ft long and 8 ft high benefiting 22 structures. Wall 2 proposed (for Receiver 5, or Receiver 13 in the FEIS) was 1,100 ft long and 8 ft high benefiting 13 structures. Wall 3 proposed (for Receiver 10, 11, and 12, or Receiver 22 in the FEIS) was 2,900 ft long and 8 ft high benefiting 22 structures. Wall 4 proposed (for Receiver 9, or Receiver 21 in the FEIS) was 2,600 ft long and 8 ft high benefiting 25 structures. Finally, Wall 5 proposed (for Receiver 1) was 1,400 ft long and a varying height of 8, 10, and 12 ft benefiting 11 structures.

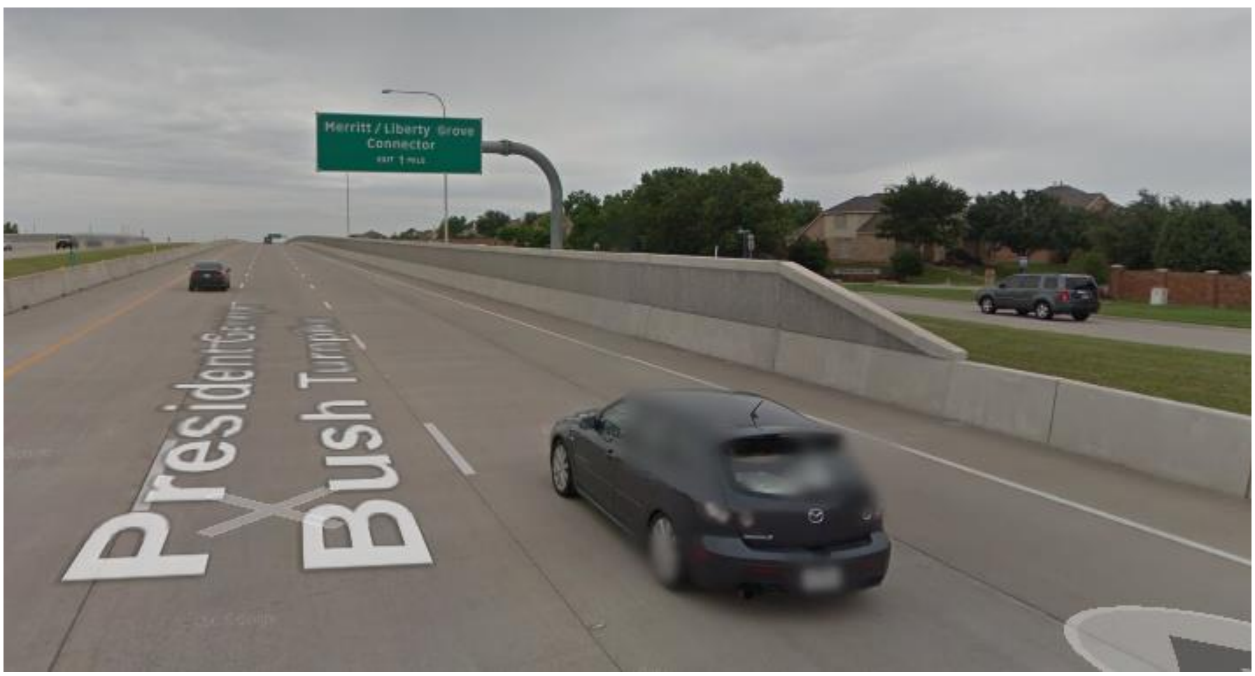
The noise walls constructed within the study site are displayed in Figure 52 through Figure 58.

Source: (*10*).

Figure 52. Noise Wall Located on Eastbound Entrance Ramp from Firewheel Pkwy and along Eastbound Lanes.

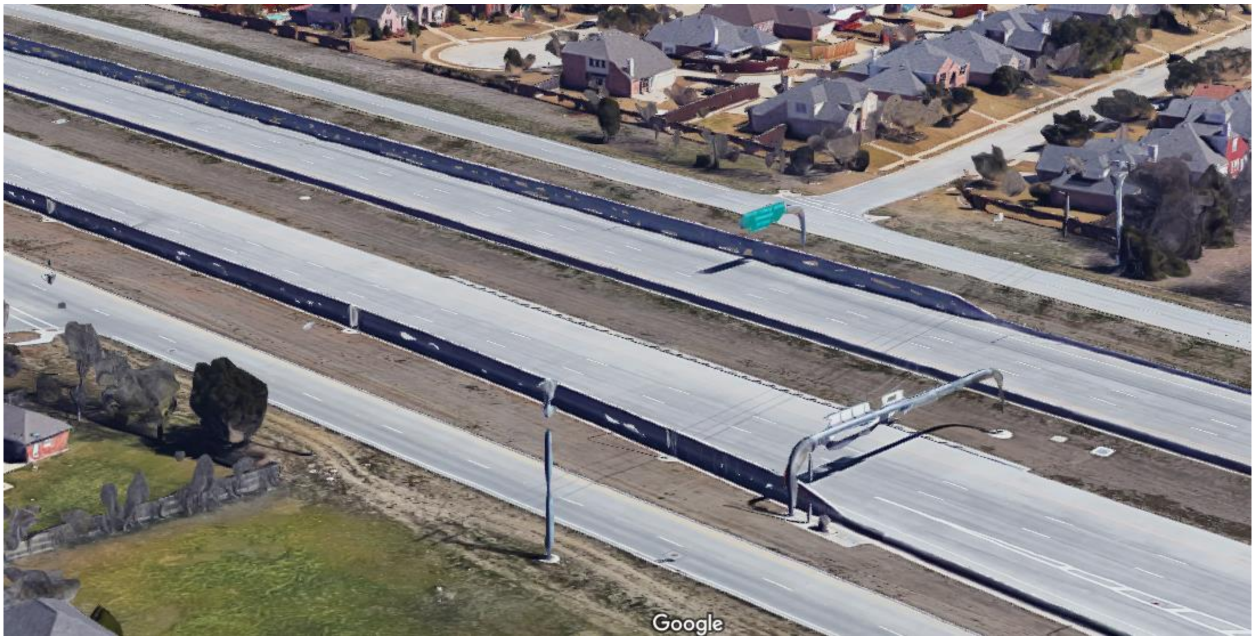
Source: (*10*).

Figure 53. Noise Wall Located on Southbound PGBT South of Liberty Grove Rd.



Source: (*10*).

Figure 54. Noise Wall Located on Northbound PGBT South of Liberty Grove Rd.



Source: (*10*).

Figure 55. 3D View of Noise Walls Located on Northbound and Southbound PGBT South of Liberty Grove Rd.

Source: (*10*).

Figure 56. Noise Wall Located on Northbound PGBT Frontage Road South of Miller Rd.

Source: (*10*).

Figure 57. Noise Wall Located on Southbound PGBT Frontage Road South of Miller Rd.

Source: (*10*).

Figure 58. 3D View of Noise Walls Located on Northbound and Southbound PGBT Frontage Roads South of Miller Rd.

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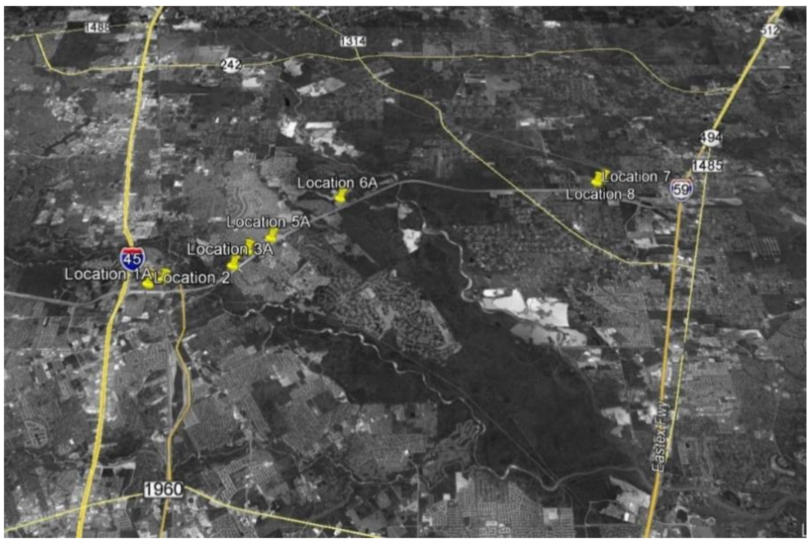
Appendix K. Field Study Notes

SH 99 Segment G

Field data were collected at eight different locations along SH 99 (see Figure 59). Field data were collected at four locations (Locations 2, 4, 7, and 8) on Tuesday, July 12, and the other four locations (Locations 1A, 3A, 5A, and 6A) on Wednesday, July 13.

TTI did not receive permission to enter the SH 99 right-of-way until the evening of Tuesday, July 12. Locations 2, 4, 7, and 8 were all on private property, so the study team was able to collect noise data and weather data at these locations; however, since the study team did not have permission to be on the SH 99 right-of-way, no video data or speed data were collected on Tuesday, July 12.



Source: (*1*).

Figure 59. Aerial View of Field Locations at SH 99 in Houston.

Noise and Weather Data

Location 1A

Location 1A was located on a public right-of-way between the sound wall and the private property fence. The study team requested permission to enter the private property, but the request was either denied or not responded to. The study team used aerial images and field reconnaissance to select this alternate location to be close to the originally requested location. The study team was able to collect noise data and weather data at this location for all three time periods (AM, midday, and PM) at this location.

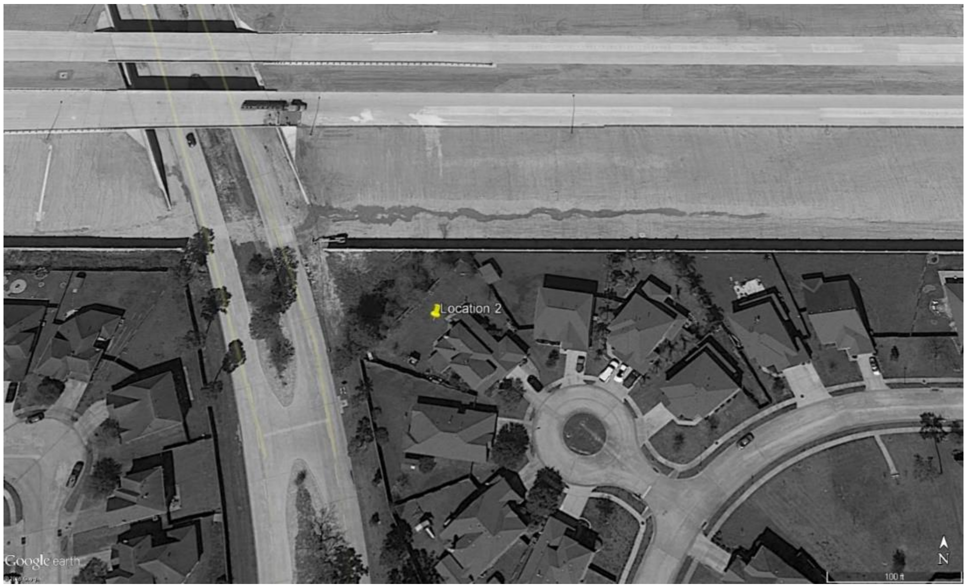
Source: (*1*).

Figure 60. Aerial View of Location 1A, SH 99 Segment G.

Figure 61. Field Photo of Equipment Setup at Location 1A, SH 99 Segment G.

Location 2

Location 2 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained prior to collecting data at this location. The study team was able to collect the noise data and weather data successfully for all three time periods at this location.



Source: (*1*).

Figure 62. Aerial View of Location 2, SH 99 Segment G.

Figure 63. Field Photo of Equipment Setup at Location 2, SH 99 Segment G.

Location 3A

The original location for the data collection was on private property (backyard of a house). A right-of-entry permit was requested, but the request was denied or not responded to. The study team used aerial images and field reconnaissance to choose an alternate site close to the original site for data collection. The study team used an opening in the sound wall to walk behind the sound wall and get closer to the private property fence to collect noise and weather data. The study team was able to collect noise data and weather data successfully for all three time periods at this location.

Source: (*1*).

Figure 64. Aerial View of Location 3A, SH 99 Segment G.

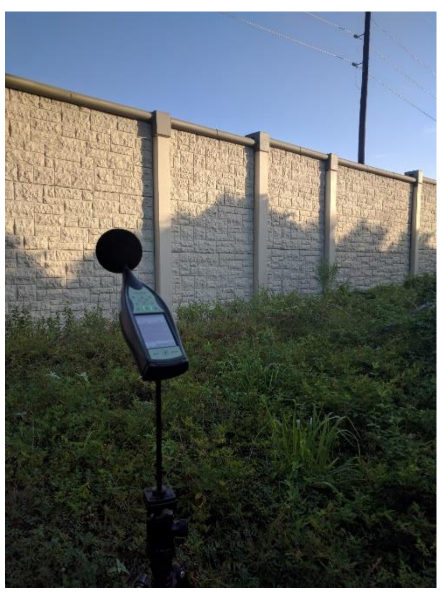


Figure 65. Field Photo of Equipment Setup at Location 3A, SH 99 Segment G.

Location 4

Location 4 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. Figure 66 shows two locations. The study team erroneously entered the backyard of the wrong private property (marked as Location 4 AM and afternoon) and realized the mistake after the afternoon readings were done. The study team apologized for the mistake to the house owner and entered the correct property (marked as Location 4 PM) for the evening period.

Since the original location was a neighboring location and the two were not more than 100 ft apart, the results were not affected by the change of location. The study team was able to collect noise data and weather data successfully at this location for all three time periods.

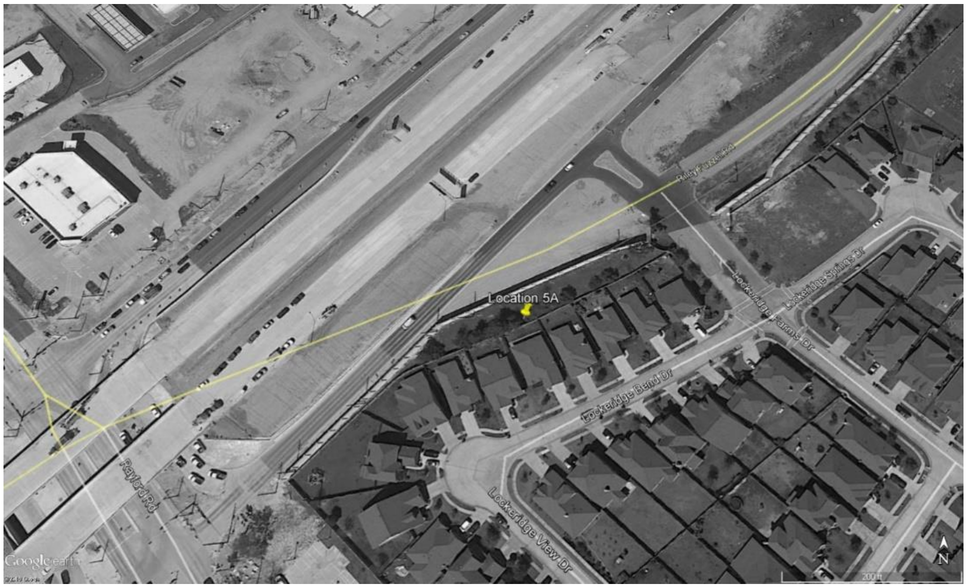
Source: (*1*).

Figure 66. Aerial View of Location 4, SH 99 Segment G.

Figure 67. Field Photo of Equipment Setup at Location 4, SH 99 Segment G.

Location 5A

The original location for the data collection was on private property (backyard of a house). A right-of-entry permit was requested, but the request was denied or not responded to. The study team used aerial images and field reconnaissance to choose an alternate site close to the original site for data collection. The study team walked behind the sound wall and set up study equipment close to the private property fence to collect noise and weather data. The study team was able to collect noise data and weather data successfully for all three time periods at this location.



Source: (*1*).

Figure 68. Aerial View of Location 5A, SH 99 Segment G.

Figure 69. Field Photo of Equipment Setup at Location 5A, SH 99 Segment G.

Location 6A

The original location for the data collection was on private property (backyard of a house). A right-of-entry permit was requested, but the request was denied or not responded to. The study team used aerial images and field reconnaissance to choose an alternate site close to the original site for data collection. The study team parked their vehicle on the public right-of-way and set up study equipment close to the private property fence but still on the SH 99 right-of-way to collect noise and weather data. The study team was able to collect noise data and weather data successfully for all three time periods at this location.

Source: (*1*).

Figure 70. Aerial View of Location 6A, SH 99 Segment G.

Figure 71. Field Photo of Equipment Setup at Location 6A, SH 99 Segment G.

Location 7

Location 7 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained prior to collecting data at this location. The study team was able to collect the noise data and weather data successfully for all three time periods at this location.

Source: (*1*).

Figure 72. Aerial View of Location 7, SH 99 Segment G.

Figure 73. Field Photo of Equipment Setup at Location 7, SH 99 Segment G.

Location 8

Location 8 was located on private property (backyard of a house). The study team requested and obtained a right-of-entry permit before collecting data at this location. When the study team arrived at this location for the AM period data collection, the resident was not available to unlock the front gate immediately. The study team had to wait approximately 10 minutes for the resident to allow the study team to enter the backyard. This resulted in a slight delay in collecting noise and weather data at this location in the AM period. The study team started collecting data at 8:50 AM and ended data collection at 9:05 AM (five minutes over the proposed data collection period of 7 AM to 9 AM). Data collection in the rest of the time periods occurred without any problems.

Source: (*1*).

Figure 74. Aerial View of Location 8, SH 99 Segment G.

Figure 75. Field Photo of Equipment Setup at Location 8, SH 99 Segment G.

Video Data Collection

As mentioned at the beginning of this appendix, the study team was not allowed onto the SH 99 right-of-way on Tuesday, July 12, so the study team was not able to collect any video data on Tuesday. A permit to enter the SH 99 right-of-way was obtained on Tuesday evening. The study team then mounted video cameras to the lighting pole and recorded data on Wednesday, July 13. The purpose of collecting video data was to obtain traffic classification data at the same time as noise and weather data.

Speed Data Collection

As mentioned at the beginning of this appendix, the study team was not allowed onto the SH 99 right-of-way on Tuesday, July 12, so the study team was not able to collect any video data on Tuesday. A permit to enter the SH 99 right-of-way was obtained on Tuesday evening. The study team used two radar guns to measure spot speeds for vehicles traveling on the tollway on Wednesday, July 13. The study team coordinated to start the speed measurement at the exact time of the noise and weather data collection at Locations 1A, 3A, 5A, and 6A. The speed data collection team made sure to collect spot speeds for different classes of vehicles and across various lanes.

Right-of-Entry Permits

Table 34 shows the locations for which right-of-entry (ROE) permits were requested and whether the permit was received.

Table 34. SH 99 Segment G Right-of-Entry Summary.

Property Address	Requested for Location #	ROE Received
611 Merrimac Ridge Ln, Spring, TX 77373	1	No
22814 Northridge Terrace Ct, Spring, TX 77373	2	Yes
22810 Northridge Terrace Ct, Spring, TX 77373		No
1915 Ryansbrook Ln, Spring, TX 77386	3	No
1907 Ryansbrook Ln, Spring, TX 77386		No
2534 Springstone Dr, Spring, TX 77386	4	No
2538 Springstone Dr, Spring, TX 77386		Yes
2811 Lockeridge Bend Dr, Spring, TX 77386	5	No
28702 Little River Ct, Spring, TX 77386	6	No
19291 Jenny Ln, Porter, TX 77365	7	No
19295 Jenny Ln, Porter, TX 77365		Yes
19330 Hallie Ln, Porter, TX 77365	8	Yes
19322 Hallie Ln, Porter, TX 77365		No

Weather Data

Table 35 shows the SH 99 Segment G weather data.

Table 35. SH 99 Segment G Summary of Weather Data.

Location	Time Period	Date	Avg Temp (°F)	Humidity (%)	Avg Wind Speed (mph)	Direction
1A	AM	7/13/2016	78.29	89.1	0.75	E-SE-ESE
	Midday	7/13/2016	99.48	42.1	3.25	E-SW-WSW
	PM	7/13/2016	96.84	51.4	5.313	SE-SW
2	AM	7/12/2016	80.3	85.3	0.938	SW-SSW
	Midday	7/12/2016	95.02	41.4	3.75	SW-SSW
	PM	7/12/2016	96.12	43.8	2.5	SW-WSW
3A	AM	7/13/2016	81.33	85.9	0	
	Midday	7/13/2016	97.61	45.3	1	SSW-SSE
	PM	7/13/2016	96.86	45	0.875	S-SSE
4	AM	7/12/2016	77.89	88.9	0	
	Midday	7/12/2016	96	45.8	0.313	NE-ENE
	PM	7/12/2016	97.09	40.4	0.438	E-W-WNW
5A	AM	7/13/2016	84.21	81.6	0.063	SE
	Midday	7/13/2016	99.01	42.4	0.688	ESE
	PM	7/13/2016	98.41	43.4	0.563	E-SE-ESE
6A	AM	7/13/2016	86.86	75.6	2.938	SSW
	Midday	7/13/2016	98.7	40.3	4.875	SW
	PM	7/13/2016	95.01	47	4.563	SW
7	AM	7/12/2016	82.96	80	0.75	E-ENE-ESE
	Midday	7/12/2016	93.29	50.8	1.438	SE-ESE
	PM	7/12/2016	92.78	50.9	1.688	E
8	AM	7/12/2016	84.64	76.7	0.5	E-SE-SW
	Midday	7/12/2016	95.17	46.7	0.625	E-SE-ESE
	PM	7/12/2016	90.72	56.3	0.813	SE-ESE

US 183A

Field data were collected at eight different locations along US 183A (Figure 76) between Tuesday, June 21, 2016, and Thursday, June 23, 2016. Except Location 2, every other location was on the public right-of-way. A right of entry was requested for Location 2 (9864 Ranch to Market Rd 2243, Leander, TX 78641—First Baptist Church Leander) and obtained prior to starting data collection.

Source: (*1*).

Figure 76. Aerial View of Field Locations at SH 183A in Austin.

Noise and Weather Data

Location 1

Location 1 was located within the boundaries of the public right-of-way, so no permission was needed to perform the data collection. The sound level measurements and weather data were collected successfully for all three time periods (AM, midday, and PM) at this location without any problems.

Calibration Problem

The study procedure required calibrating equipment before the research team began measurements for each time period (e.g., AM peak period measurements). When the study team got to Location 1 on Tuesday, June 21, 2016, the calibrator did not work, so a calibration was not performed for the AM peak period. However, the SLM was calibrated and certified by Brüel & Kjær in the lab prior to delivering the equipment to TTI, and this was the very first reading in the field, so the data collected are still valid.

Source: (*1*).

Figure 77. Aerial View of Location 1, US 183A.

Figure 78. Field Photo of Equipment Setup at Location 1, US 183A.

Location 2

Location 2 was in a church parking lot. A right-of-entry permit was requested and obtained before entering this property. The study team was able to successfully collect data for all three time periods at this location.

Source: (*1*).

Figure 79. Aerial View of Location 2, US 183A.

Figure 80. Field Photo of Equipment Setup at Location 2, US 183A.

Location 3

Location 3 was at the intersection of Cottonwood Creek Trail and New Hope Dr. The study team was able to park the vehicle on the shoulder of Cottonwood Creek Trail and successfully collect data for all three time periods without any problems.

Source: (*1*).

Figure 81. Aerial View of Location 3, US 183A.

Figure 82. Field Photo of Equipment Setup at Location 3, US 183A.

Location 4

Location 4 was at the intersection of Sunset Terrace and Moonlight Dr. It was the farthest location from the tollway. The study team was able to successfully collect the data for all three time periods without any problems.

Source: (*1*).

Figure 83. Aerial View of Location 4, US 183A.

Figure 84. Field Photo of Equipment Setup at Location 4, US 183A.

Location 5

Location 5 was at the intersection of Darkwoods Dr and Cashew Ln. One of the residents living in the house across the street from the measuring location came and talked to the study team and complained about noise levels due to traffic on the tollway.

Source: (*1*).

Figure 85. Aerial View of Location 5, US 183A.

Figure 86. Field Photo of Equipment Setup at Location 5, US 183A.

Location 6

Location 6 was at the intersection of Colt St and Buffalo Ave in the public right-of-way. The study team was able to successfully collect data in all time periods without any problems. A passing-by resident stopped and talked to the study team about the purpose of the study and mentioned the tollway noise was bothersome.

Source: (*1*).

Figure 87. Aerial View of Location 6, US 183A.

Figure 88. Field Photo of Equipment Setup at Location 6, US 183A.

Location 7

Location 7 was located on New Hope Dr near the toll road. The study team was able to park the vehicle safely on the side of the road and was successfully able to collect data for all three time periods without any problems.

Source: (*1*).

Figure 89. Aerial View of Location 7, US 183A.

Figure 90. Field Photo of Equipment Setup at Location 7, US 183A.

Location 8

Location 8 was across the toll road from Location 7, and the study team was able to use the old, abandoned roadway pavement, which is in a public right-of-way, to collect the data. The study team was able to collect the data successfully for all three time periods without any problems.

Source: (*1*).

Figure 91. Aerial View of Location 8, US 183A.

Figure 92. Field Photo of Equipment Setup at Location 8, US 183A.

Video Data Collection

The study team mounted video cameras to the lighting pole and started capturing data on the morning of Tuesday, June 21, and continued recording the data until the evening of Thursday, June 23. The purpose of collecting video data was to obtain traffic classification data at the same time as noise and weather data.

Video Data Problems

The video equipment stopped functioning on the evening of Tuesday, June 21, so no usable data were obtained from the video camera. However, the study team was able to contact the operating authority for the toll road (CTRMA) and obtain detailed classification data for the entire study period.

Speed Data Collection

The study team used two radar guns to measure spot speeds for vehicles traveling on the tollway. The study team coordinated to start the speed measurement at the exact time of the noise and weather data collection. The speed data collection team made sure to collect spot speeds for different classes of vehicles and across various lanes.

Weather Data

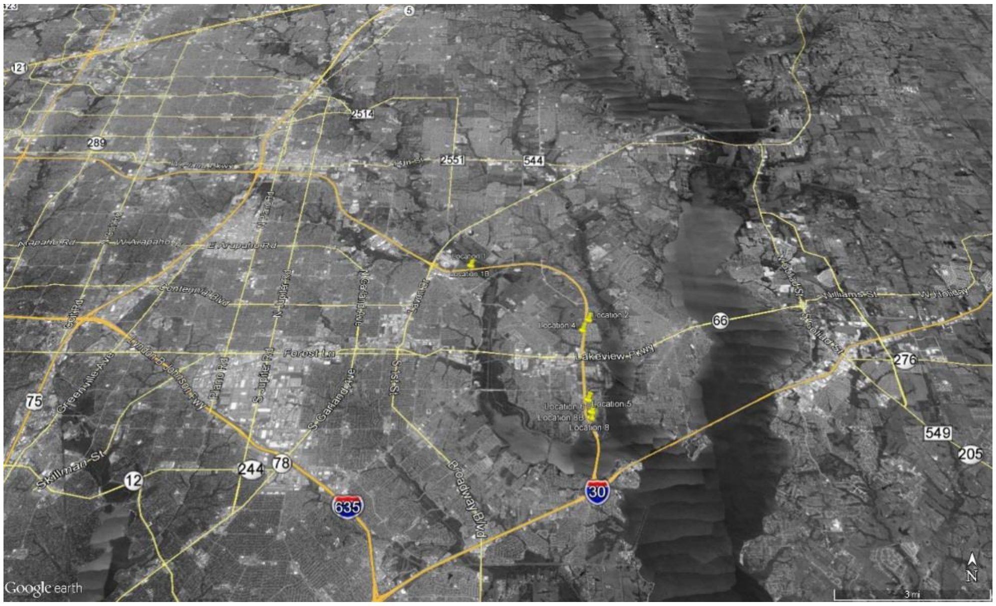
Table 36 shows weather data collected at each of the locations during each time period.

Table 36. US 183A Summary of Weather Data.

Location	Time Period	Date	Avg Temp (°F)	Humidity (%)	Avg Wind Speed (mph)	Direction
1	AM	6/21/2016	79.1	76.3	1.313	S-SSW
	Midday	6/22/2016	94.58	40.8	5.875	ESE-SE-SSE
	PM	6/22/2016	89.27	46.8	4.313	SE-SSE
2	AM	6/21/2016	79.58	74.6	3.25	WNW
	Midday	6/22/2016	93.04	43.1	6.438	SW-WSW-SSW
	PM	6/22/2016	89.61	48.1	6.063	SSE-SSW
3	AM	6/23/2016	75.71	83.2	0.375	W-WSW
	Midday	6/21/2016	96.03	40.3	3.188	S-SW-SSE
	PM	6/22/2016	95.32	40.3	5.125	SE-SSE
4	AM	6/22/2016	76.11	83.6	0.375	SSE-SW-E
	Midday	6/23/2016	93.27	45.8	3	E-SE
	PM	6/21/2016	94.54	39.9	2.438	S-SSE-ESE
5	AM	6/22/2016	75.15	87.9	2.813	SSW-SW-SE
	Midday	6/23/2016	90.86	45.7	4.938	SE-SSE-SW
	PM	6/21/2016	90.67	47	4.938	SE-ESE
6	AM	6/22/2016	77.48	81.3	3.938	SW-WSW-SSW
	Midday	6/23/2016	92.43	44.4	4.75	SSE-SW
	PM	6/21/2016	90.86	46	4.313	S-SSW-SSE
7	AM	6/23/2016	76.47	83.1	3.75	SW-SSW
	Midday	6/21/2016	94.72	40.6	2.313	SE-SSE-SW
	PM	6/22/2016	93.28	42.7	8.063	S-SW-SSW
8	AM	6/23/2016	77.94	79.1	6.75	S-SSW
	Midday	6/21/2016	94.06	39.1	3.313	SSW-E-SE
	PM	6/22/2016	92.66	43	7.313	S-SSW

President George Bush Turnpike Eastern Extension

Field data were collected at eight different locations along President George Bush Turnpike Eastern Extension (Figure 93). Field data were collected at four locations (Locations 1, 2, 4, and 8) on Thursday, June 30, and the other four locations (Locations 1B, 5, 6, and 8B) on Thursday, July 7.



Source: (*1*).

Figure 93. Aerial View of Field Locations on PGBT-EE in Dallas/Fort Worth.

Noise and Weather Data

Location 1

Location 1 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. The sound level measurements and weather data were collected successfully for the AM and midday periods without any problems. The sound level measurements were collected without any problems in the PM period, but the weather station data were overwritten by the instrument due to memory constraints; the study team was not able to recover the PM weather station data (please see problem description and solution portion of this section for a resolution).

Source: (*1*).

Figure 94. Aerial View of Location 1, PGBT-EE.

Figure 95. Field Photo of Equipment Setup at Location 1, PGBT-EE.

Location 1B

Location 1B was located on private property (backyard of a house). A right-of-entry permit was requested by visiting the resident personally on June 30 and explaining the purpose of the study. Location 1B was the neighboring house of Location 1. The study team was able to collect the noise data and weather data successfully for all three time periods (AM, midday, and PM) at this location.

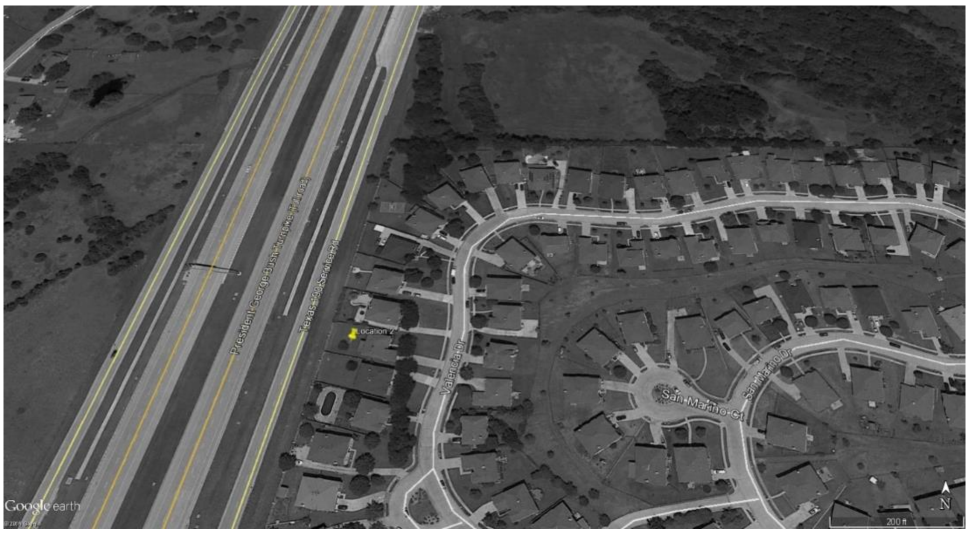
Source: (*1*).

Figure 96. Aerial View of Location 1B, PGBT-EE.

Figure 97. Field Photo of Equipment Setup at Location 1B, PGBT-EE.

Location 2

Location 2 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. The sound level measurements and weather data were collected successfully for the AM and midday periods without any problems. The sound level measurements were collected without any problems in the PM period, but the weather station data were overwritten by the instrument due to memory constraints; the study team was not able to recover the PM weather station data (please see problem description and solution portion of this section for a resolution).



Source: (*1*).

Figure 98. Aerial View of Location 2, PGBT-EE.

Figure 99. Field Photo of Equipment Setup at Location 2, PGBT-EE.

Location 4

Location 4 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. The sound level measurements and weather data were collected successfully for the AM and midday periods without any problems. The sound level measurements were collected without any problems in the PM period, but the weather station data were overwritten by the instrument due to memory constraints; the study team was not able to recover the PM weather station data (please see problem description and solution portion of this section for a resolution).

Source: (*1*).

Figure 100. Aerial View of Location 4, PGBT-EE.

Figure 101. Field Photo of Equipment Setup at Location 4, PGBT-EE.

Location 5

Location 5 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. The sound level measurements and weather data were collected successfully for the AM, midday, and PM periods without any problems at this location.

Source: (*1*).

Figure 102. Aerial View of Location 5, PGBT-EE.

Figure 103. Field Photo of Equipment Setup at Location 5, PGBT-EE.

Location 6

Location 6 was on a public ROW between two houses. The original location for this data collection was on private property, but the resident refused to provide a permit to enter the property. The study team was able to find a drainage passage on a public ROW between two houses to collect the data. The study team was able to successfully collect data in all time periods without any problems.

Source: (*1*).

Figure 104. Aerial View of Location 6, PGBT-EE.

Figure 105. Field Photo of Equipment Setup at Location 6, PGBT-EE.

Location 8

Location 8 was located on private property (backyard of a house). A right-of-entry permit was requested and obtained by the study team before performing the data collection at this location. The sound level measurements and weather data were collected successfully for the AM and midday periods without any problems. The sound level measurements were collected without any problems in the PM period, but the weather station data was overwritten by the instrument due to memory constraints; the study team was not able to recover the PM weather station data (please see problem description and solution portion of this section for a resolution).

Source: (*1*).

Figure 106. Aerial View of Location 8, PGBT-EE.

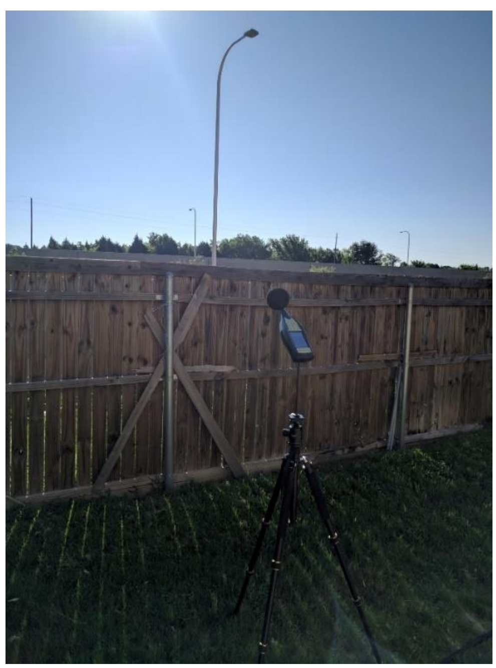


Figure 107. Field Photo of Equipment Setup at Location 8, PGBT-EE.

Location 8B

Location 8B was located on private property (backyard of a house). A right-of-entry permit was requested by visiting the resident personally on June 30 and explaining the purpose of the study. Location 8B was the neighboring house of Location 8. The study team was able to collect the noise data and weather data successfully for all three time periods at this location.

Source: (*1*).

Figure 108. Aerial View of Location 8B, PGBT-EE.

Figure 109. Field Photo of Equipment Setup at Location 8B, PGBT-EE.

Problem Description and Solution

The weather station was set to record at one-minute intervals, and by default, the instrument is set to overwrite data when it runs out of memory. Due to a miscommunication, the study team was not able to transfer the weather data immediately after finishing the collection of data, and the weather station overwrote the data collected during the PM peak period on June 30.

The study team was able to find several personal weather stations from publicly available weather archives at Weather Underground (http://www.wunderground.com) and download the data for the same day (June 30). The study team compared the downloaded data with the morning and midday period data collected from the weather station to make sure the downloaded data matched reasonably well with the weather station data collected at these sites.

Video Data Collection

The study team mounted video cameras to the lighting pole and recorded data on June 30 and July 7. The purpose of collecting video data was to obtain traffic classification data at the same time as noise and weather data.

Speed Data Collection

The study team used two radar guns to measure spot speeds for vehicles traveling on the tollway. The study team coordinated to start the speed measurement at the exact time of the noise and weather data collection. The speed data collection team made sure to collect spot speeds for different classes of vehicles and across various lanes.

Right-of-Entry Permits

Table 37 shows the locations for which ROE permits were requested and whether the permit was received.

Table 37. President George Bush Turnpike Eastern Extension Right-of-Entry Summary.

Property Address	Requested for TTI Location #	ROE Received
3306 Creek Meadow Ln, Garland, TX 75040	1	Yes
3302 Creek Meadow Ln, Garland, TX 75040	1A	Yes
5405 Valencia Dr, Rowlett, TX 75089	2	Yes
6401 Copano Bay Dr, Rowlett, TX 75089	3	No
6318 Ahnee Dr, Rowlett, TX 75089	4	Yes
4610 Bayonne Dr, Rowlett, TX 75088	5	Yes
5014 Southport Dr, Rowlett, TX 75088	6	No
2502 Brittany Dr, Rowlett, TX 75088	7	No
2018 Glenridge D, Rowlett, TX 75088	8	Yes
2014 Glenridge Dr, Rowlett, TX 75088	8A	Yes

Weather Data

Table 38 shows the weather summary for the President George Bush Turnpike Eastern Extension.

Table 38. President George Bush Turnpike Eastern Extension Weather Summary.

Location	Time Period	Date	Avg Temp (°F)	Humidity (%)	Avg Wind Speed (mph)	Direction
1	AM	6/30/2016	78.99	72.2	0	–
	Midday	6/30/2016	93.89	44.9	0.188	NNW-NE
	PM	6/30/2016	93.47	31.7	5.233	SE
1B	AM	7/7/2016	77.63	82	1.25	W-NW-WNW
	Midday	7/7/2016	95.59	47	2	WNW-WSW
	PM	7/7/2016	98.54	41.4	2.438	WSW-WNW
2	AM	6/30/2016	79.39	71.3	0	–
	Midday	6/30/2016	92.96	45	0.938	E-SW
	PM	6/30/2016	95.4	47	0	–
4	AM	6/30/2016	83.1	64.1	0.188	E-NE
	Midday	6/30/2016	94.89	41.9	0.813	WNW-ESE
	PM	6/30/2016	100.1	38	5	S
5	AM	7/7/2016	80.07	78	3	S-SSE
	Midday	7/7/2016	92.5	52.3	3	S-SSW
	PM	7/7/2016	95.83	48.8	2.625	S-SSE-SSW
6	AM	7/7/2016	80.84	76.4	3.438	W-WNW
	Midday	7/7/2016	95	47.5	3	W-WNW
	PM	7/7/2016	95.31	48.9	2.125	N-NNE-NNW
8	AM	6/30/2016	85.11	60	1.063	SE
	Midday	6/30/2016	93.14	43.8	1.875	S-SW-SSW
	PM	6/30/2016	100.2	39	1.7	E
8B	AM	7/7/2016	79.48	80.4	2.938	SE-SSE
	Midday	7/7/2016	91.47	54.4	4	SE-ESE
	PM	7/7/2016	93.69	51.9	3.563	SE-SSW

Reference

1. Google Earth™. http://google.com/earth. Accessed September 22, 2016.

Appendix L. Field Study Data Analysis

As part of the Implementation and Effectiveness of Sound Mitigation Measures on Texas Highways Study, TTI reviewed the TNM inputs for three corridors: PGBT-EE (Dallas), SH 99 (Houston), and US 183A (Austin). TTI compared noise model outputs to available published EA results. TTI also updated the traffic data inputs with 2016 data to estimate current noise levels.

In summer 2016, TTI requested and received TNM input files for the PGBT-EE, SH 99, and US 183A corridors from the operating agencies, North Texas Tollway Authority, Texas Department of Transportation, and Central Texas Regional Mobility Authority, respectively.

Traffic Noise Model Input File Cursory Review and Checks

TTI staff performed a cursory review and checks of the TNM input files received from the operating agencies. Specifically, four checks were performed:

1. Review the inputs through the TNM v2.5 and compare the "no barrier" output to the results published in the study location environmental documentation.
2. Review the roadway and noise mitigation measure in model cross-sections (skew view) and compare to field conditions in Google Earth Street View.
3. Rerun TNM v2.5 without changing original inputs to verify that the same sound level outputs are generated.
4. Compare the "with barrier" output to 2016 observed noise levels.

TNM input files were provided for all three corridors. Typically, two input files were provided per section of each corridor: objects.idx and objects.dat. However, a walls.dxf file was also provided for US 183A. PGBT-EE had several subfolders (input files) labeled as SECXX_PS&E or SECXX_ROW. As described later in the second check, these subfolders were examined, and the SEC31_PS&E subfolder was used instead of the main lane files. Multiple subfolders were also provided for US 183A (final, good, good2, goodm, kept, prop, and prop2). However, all of them covered only the southern portion of US 183A from FM 1431 to Brushy Creek Rd. Thus, only the input files in the "final" subfolder were used. Originally, eight SH 99 Seg G subfolders were provided. However, only four of them contained the subject receiver locations: I45toHardyonPowerline, Fox Run, LockerideonORF, and TimberlandRev. TTI noted that Receivers 38–40 were missing from the files. Thus, researchers contacted TxDOT to request the files from the Spring Trails subdivision.

Check 1. Comparison of EA Sound Levels to Traffic Noise Model Predictions and to Field Measurements

TTI made two comparisons from the TNM files provided. First, TTI compared each receiver's projected sound level published in the EA to its corresponding value under the "no barrier" case. Second, TTI compared the modeled "with barrier" value to the nearest observed noise level measured in the field. Note that the measured observed noise values represent a typical weekday, 15-minute interval, over three different time periods. Table 39 through Table 41 show the results of the comparisons by corridor.

Differences of 1 dB(A) or more between the EA projected noise and the "no barrier" TNM value are noted in red. All seven receivers for PGBT-EE had differences of less than 1 dB(A). Only two of the seven SH 99 receivers had modeled values greater than 1 dB(A) from the EA value, whereas both receivers for US 183A had differences of greater than 1 dB(A). Note that the previous version of the noise model, STAMINA, was used for the US 183A EA, which likely explains the large differences between the EA and the TNM values (see https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/). Also, the TNM input files provided for US 183A indicate that they are 2030 values (not 2020) and were based on TNM 2.1, as discussed later in the Traffic Data Assumptions section.

The values in red indicate when observed noise levels are higher than the TNM projected "with barrier" values. The three observed sites (out of 22) that did not have a noise barrier were not compared. The EAs did not indicate what time of day was modeled, but the FHWA guidelines (FHWA-DP-45-1R), *Sound Procedures for Measuring Highway Noise: Final Report* (*1*), indicate that the "worst hourly traffic noise impact" should have been modeled:

> *Highway traffic noise levels sensitive to traffic characteristics used to predict future traffic noise levels. The "worst hourly traffic noise impact" occurs at a time when truck volumes and vehicle speeds are the greatest, typically when traffic is free flowing and at or near level of service (LOS) C conditions. The numbers of medium and heavy trucks are very important. In large urban areas, this worst hourly traffic noise impact will usually not coincide with peak traffic periods, when LOS may drop to D or less.*

Consequently, the EA values were compared to all three time periods that were measured. Many of the receivers had current noise levels exceeding the projected values. For example, the midday value of 66 dB(A) for PGBT-EE at TTI Location 1 was higher than the 61 dB(A) for TNM Receiver 1 "with barrier."

Table 39. Sound Measurement Results and Comparisons for SH 99, Grand Parkway (Houston).

TTI Location	Wall?	TNM Name	2025 EA Value	TNM Results (Leq, dBA) No Barrier	With Barrier	Observed (Leq, dBA)	Time Period
1A	Yes	Receiver 9 NGXN	59	58	54	63	AM
						60	Midday
						62	PM
2	Yes	Receiver 19 NGXS	63	64*	57	56	AM
						54	Midday
						56	PM
3A	Yes	Receiver 38 SPRING TRAILS	67	58*	56	60	AM
						57	Midday
						60	PM
4	Yes	Receiver 49 Fox Run	66	66	59	60	AM
						58	Midday
						60	PM
5A	Yes	Receiver 65 Lockeridge	66	66	65	54	AM
						54	Midday
						55	PM
7	Yes	Receiver 145 Timberland S	66	66	58	52	AM
						53	Midday
						54	PM
8	Yes	Receiver 153	64	64	59	53	AM
						52	Midday
						56	PM

Note: Cell shading indicates that observed values exceeded TNM results with barrier.
* TNM results did not match published values in environmental document.

Table 40. Sound Measurement Results and Comparisons for US 183A (Austin).

TTI Location	Wall?	Name	2020 EA Value*	TNM Results (Leq, dBA) No Barrier	With Barrier	Observed (Leq, dBA)	Time Period
5	Yes	R2	75	72**	65	68	AM
						62	Midday
						64	PM
6	Yes	R3	76	72**	66	57	AM
						57	Midday
						63	PM

Note: Cell shading indicates that observed values exceeded TNM results with barrier.
* Based on STAMINA, Table 4-6 of Alt. 1 in 2001 US 183A FEIS.pdf (*2*).
** TNM results did not match published values in environmental document.

Table 41. Sound Measurement Results and Comparisons for PGBT-EE (Dallas).

TTI Location	Wall?	TNM Name	2030 EA Value	TNM Results (Leq, dBA) No Barrier	With Barrier	Observed (Leq, dBA)	Time Period
1	Yes	R1	65	65	61	59	AM
						66	Midday
						60	PM
1B	Yes	R1B	Not reported	65	63	59	AM
						57	Midday
						61	PM
2	Yes	Receiver 3	70	70	64	62	AM
						56	Midday
						58	PM
4	Yes	Receiver 5	70	70	65	57	AM
						56	Midday
						58	PM
5	Yes	Receiver 9	66	66	59	69	AM
						64	Midday
						64	PM
6	Yes	Receiver 10	62	62	59	66	AM
						63	Midday
						64	PM
8	Yes	Receiver 12A	71	71	63	68	AM
						67	Midday
						69	PM

Note: Cell shading indicates that observed values exceeded TNM results with barrier.

Check 2. Modeled Cross-Sections to Field Conditions Check

TTI compared modeled roadway cross-sections (skew view) to field conditions in Google Earth Street View. The skew views for each receptor location and a series of street views of main lanes followed by frontage road (if present) and by direction are shown later in this appendix. During this check, it was discovered that the main lane TNM files for PGBT-EE TTI 5 (TNM 9), TTI 6 and 8 (TNM 10 and 12A) did not match the field conditions. The skew views showed the noise walls to be between the main lanes and the frontage roads, but the street views showed them outside of the frontage roads (i.e., on the right-of-way). Consequently, all subfolders were examined and the “PS&E_rev040312” files were found to match the street views. Although the skew view for PGBT-EE TTI 4 (TNM 5) main lanes matched the street views, the PS&E files were also checked for consistency. The PS&E files were the same as the main lane files, but they contained the barrier design analysis, so they were used instead. The TNM outputs from Check 1 were updated to reflect the PS&E files, as needed.

Last, no Google Earth street views are currently available for SH 99. Thus, the skew views were compared to available site photos that were captured as part of TTI's video inventory at the time the field study was conducted. However, no frontage road photos were captured. The only discrepancy noted was at TTI 2 (TNM 19). A single-lane frontage road (both directions) appears to be modeled in TNM where no frontage roads are currently present.

Check 3. TNM Output Check

A quality check was done to see if there was a difference between opening the sound level results without running the TNM—"no run"—and running the model but not changing any inputs—"no change but rerun." The sound level results were calculated for all receivers in the "no change but rerun" tests, and all tables were exported as .csv files. All three sections of PGBT-EE and all four sections of SH 99 yielded the same results, as expected. However, US 183A yielded different results ranging from −0.4 dB(A) (for R24) to 3.5 dB(A) (for R35) but still below a discernible difference of 5 dB(A) for most people. The differences are shown later in this appendix. The differences were somewhat expected since the original files used TNM 2.1 but the rerun was done in TNM 2.5. FHWA (*3*) states that "TNM 2.5 has major improvements to the acoustics. Users should expect to see predicted sound levels that are different than sound levels predicted with previous versions of the FHWA TNM."

As a check, TTI contacted the supporting consultant for the Central Texas Regional Mobility Authority to inquire about these differences. CTRMA's investigation confirmed the finding.

Check 4. Updated TNM with 2016 Traffic

TTI used the TNM to estimate 2016 noise levels by inputting existing volumes, vehicle classification, and speeds collected in the field. TTI reran all test sections with the updated traffic inputs in the TNM. However, only the roadway inputs for the main lanes of the subject highway were updated. No other inputs were modified, even for frontage roads and/or cross streets.

Traffic Data Assumptions

As discussed previously, projected noise levels are modeled for the loudest hour, and since the main source for noise is traffic, the DHV is used in the TNM. The DHV is typically the 30th highest hour of the ADT data. Table 42 through Table 45 show the forecasted ADTs for each corridor.

Table 42. SH 99 Segment G Forecasted Future Traffic Volumes.

Year	Forecasted Average Daily Traffic (*4*)	ADT Roadway (*5*)
2015	25,800	43,400
2025	53,700	64,500

Table 43. Projected 2025 Traffic Volume Data for SH 99 Segment G Noise Analysis.

Location	Design Year ADT	Peak-Hour Volume
IH 45 to Hardy Toll Road	43,888	4,564
Hardy Toll Road to Riley Fuzzel	64,173	6.673
Riley Fuzzel to Rayford Sawdust	64,511	6.709
Rayford Sawdust to Benders Landing Blvd	61,112	6.355
Benders Landing Blvd to FM 1314	61,564	6.402
FM 1314 to US 59	45,657	4.748

Source: (*5*).

Table 44. US 183A Forecasted Year 2020 Traffic Volumes.

Segment		Forecasted 24-hour, Two-Way Traffic Volume
Begin	**End**	
RM 620	Davis Springs Rd	126,500
Davis Springs Rd	Brushy Creek Rd	116,200
Brushy Creek Rd	Park St	109,200
Park St	FM 1431	106,300
FM 1431	New Hope Rd	105,200
New Hope Rd	CR 272	87,200
CR 272	FM 2243	67,000
FM 2243	Existing US 183	46.900

Source: (*2*).

Table 45. 2025 Average Daily Traffic Volumes on PGBT-EE.

Location along PGBT-EE	Average Daily Traffic
West of SH 78	125,000
Between SH 78 and Northeast Pkwy	69,000
Between Northeast Pkwy and Miles Rd	75,000
Miles Rd to Liberty Grove Rd	67,000
Between Liberty Grove Rd and SH 66	72,000

Source: (*6*).

A K-factor and a directional split (DS) are applied to the ADT to derive at the DHV. For example, a K-factor of 8.5 percent was used for PGBT-EE. However, the DS varied for PGBT-EE, as shown in Table 46.

Table 46. Assumed Directional Splits for PGBT-EE DHV.

Section	WB/NB	EB/SB
28	0.6	1.0
30	0.4	0.6
31	0.4	0.6

For consistency, TTI assumed the same K-factor of 8.5 percent for all sections. However, a directional split of 1.0 was assumed for all sections because the field ADT data were collected by direction, so a directional split was not applicable or needed. The 2016 traffic volumes and the corresponding speeds used in the TNM are shown later in this appendix. Note that the same volumes/speeds were used for all main lane sections within a corridor. For example, the same volumes/speeds were used in Section 28, 30, and 31 of PGBT-EE.

The traffic input for US 183A differed from the other corridors in three ways: (a) it classified volumes into auto or heavy trucks; (b) it modeled all volumes in one lane instead of dividing the volumes equally among the three lanes present per FHWA and TxDOT recommended practice; and (c) toll plazas were modeled but were never constructed since it is a modern, all-electronic toll road, meaning drivers do not have to stop—or even slow down—to pay their tolls. For consistency and to be conservative, TTI combined the medium and heavy trucks into one truck classification and modeled all volumes as one lane.

Table 47 compares the derived 2016 DHVs to the projected DHVs found in the original TNM input files. Note that because the DHV varied by section, even within the same corridor, the minimum and maximum values of each section are shown. The difference and percent difference are also shown in the table.

Table 47. TNM Design Hour Volume Inputs.

SH 99 (Houston) 2016 Observed Traffic			2025 Design Year—EA Document				Difference				Percent Difference			
			WB/NB		EB/SB		WB/NB		EB/SB		WB/NB		EB/SB	
WB/NB	EB/SB	Section	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
619	580	I45toHardyonPowerline	1770	2278	1400	3336	1151	1659	820	2756	186%	268%	141%	475%
		FoxRunBarORF	2962	3162	3150	3354	2343	2543	2570	2774	379%	411%	443%	478%
		LockeridgeonORF	2808	3162	2808	3194	2189	2543	2228	2614	354%	411%	384%	451%
		TimberlandRev	2288	2350	2392	2392	1669	1731	1812	1812	270%	280%	313%	313%
		SpringTrailBar	2212	3162	2230	3354	1593	2543	1650	2774	257%	411%	285%	478%
										Average	289%	356%	313%	439%

US 183A (Austin) 2016 Observed Traffic			2020 Design Year—EA Document				Difference				Percent Difference			
			WB/NB		EB/SB		WB/NB		EB/SB		WB/NB		EB/SB	
WB/NB	EB/SB		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
2205	1940		476	4288	2162	2656	−1729	2083	222	716	−78%	94%	11%	37%

PGBT-EE (Dallas) 2016 Observed Traffic			2030 Design Year—EA Document				Difference				Percent Difference			
			WB/NB		EB/SB		WB/NB		EB/SB		WB/NB		EB/SB	
WB/NB	EB/SB	Section	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
2963	3047	SEC_28	1126	1274	1960	2154	−1837	−1689	−1087	−893	−62%	−57%	−36%	−29%
		SEC_30	987	1389	1506	2112	−1976	−1574	−1541	−935	−67%	−53%	−51%	−31%
		SEC_31	987	1266	1506	1923	−1976	−1697	−1541	−1124	−67%	−57%	−51%	−37%
										Average	−65%	−56%	−46%	−32%

In general, there are large differences between the projected and the 2016 traffic inputs. The projected DHV for PGBT-EE was −32 percent to −65 percent lower than the 2016 DHV. This difference is likely a combination of the apparent error in applying a 60/40 DS to one-way ADT (Table 47) and the likely accelerated development of the PGBT-EE corridor over what was originally forecasted. However, the projected DHV for SH 99 was 289 percent to 439 percent higher than the 2016 DHV. The projected DHV for US 183A ranged from −78 percent lower than the 2016 DHV to 94 percent higher than the 2016 DHV.

Another important aspect of traffic noise is the traffic mix, particularly for heavy trucks or all cargo vehicles with three or more axles—generally with gross vehicle weight more than 12,000 kg (26,400 lb). Table 48 shows that PGBT-EE and SH 99 generally had a higher percentage of heavy trucks in 2016 than the projected year. In fact, the number is about twice as high if the medium and heavy trucks are combined. Interestingly, although TTI combined the 2016 medium trucks with the heavy truck classification for US 183A, as discussed earlier, the percentage was still lower than the projected heavy truck percentage.

Table 48. Design Hour Volume Vehicle Mix.

SH 99 (Houston)				
	2016		2025	
	WB/NB	EB/SB	WB/NB	EB/SB
Auto	87.7%	91.4%	95.0%	95.0%
Med Truck	6.9%	4.9%	2.0%	2.0%
Heavy Truck	5.1%	3.2%	3.0%	3.0%
Buses	0.0%	0.0%	0.0%	0.0%
Motorcycle	0.3%	0.4%	0.0%	0.0%

US 183A (Austin)				
	2016		2020	
	WB/NB	EB/SB	WB/NB	EB/SB
Auto	97.0%	97.0%	95.0%	95.0%
Med Truck	0.0%	0.0%	0.0%	0.0%
Heavy Truck	3.0%	3.0%	5.0%	5.0%

PGBT-EE (Dallas)				
	2016		2030	
	WB/NB	EB/SB	WB/NB	EB/SB
Auto	91.1%	88.0%	96.7%	96.7%
Med Truck	5.8%	9.7%	2.7%	2.6%
Heavy Truck	2.7%	2.0%	0.7%	0.7%
Buses	0.1%	0.1%	0.0%	0.0%
Motorcycle	0.3%	0.3%	0.0%	0.0%

Table 49 through Table 51 compare the 2016 TNM estimate to the projected values and to the observed noise levels. The 2016 TNM values are generally the same as the projected TNM values for PGBT-EE and SH 99 (< 1 dB[A] difference). However, Receiver 65 Lockeridge of SH 99 and both receivers on US 183A (Table 49 and Table 50) generally showed differences ≥ 1.0 dB(A). The larger differences on US 183A are likely due to the combination of TNM 2.1 vs. TNM 2.5 and the modeling techniques employed, as discussed previously. These issues put the US 183A results into question. Further examination and sensitivity testing of the TNM inputs and outputs are recommended before accepting the US 183A results.

Table 49. Sound Level Measurements and Comparisons to 2016 Estimates for SH 99, Grand Parkway 2016 (Houston).

TTI Location	Wall?	Name	2025 TNM Results (Leq, dBA) No Barrier	2025 TNM Results (Leq, dBA) With Barrier	2016 TNM Results (Leq, dBA) No Barrier	2016 TNM Results (Leq, dBA) With Barrier	2016 Observed (Leq, dBA)	Time Period
1A	Yes	Receiver 9 NGXN	58	54	58	53	63	AM
							60	Midday
							62	PM
2	Yes	Receiver 19 NGXS	64	57	64	57	56	AM
							54	Midday
							56	PM
3A	Yes	Receiver 38 SPRING TRAILS	58	56	57	56	60	AM
							57	Midday
							60	PM
4	Yes	Receiver 49 Fox Run	66	59	66	58	60	AM
							58	Midday
							60	PM
5A	Yes	Receiver 65 Lockeridge	66	65	65	64	54	AM
							54	Midday
							55	PM
7	Yes	Receiver 145 Timberland S	66	58	66	58	52	AM
							53	Midday
							54	PM
8	Yes	Receiver 153	64	59	64	59	53	AM
							52	Midday
							56	PM

Note: Cell shading indicates that observed values exceeded 2025 TNM results with barrier.

Table 50. Sound Level Measurements and Comparisons to 2016 Estimates for US 183A 2016 (Austin).

TTI Location	Wall?	Name	2020 TNM Results (Leq, dBA) No Barrier	2020 TNM Results (Leq, dBA) With Barrier	2016 TNM Results (Leq, dBA) No Barrier	2016 TNM Results (Leq, dBA) With Barrier	2016 Observed (Leq, dBA)	Time Period
5	Yes	R2	72	65	70	61	68	AM
							62	Midday
							64	PM
6	Yes	R3	72	66	70	65	57	AM
							57	Midday
							63	PM

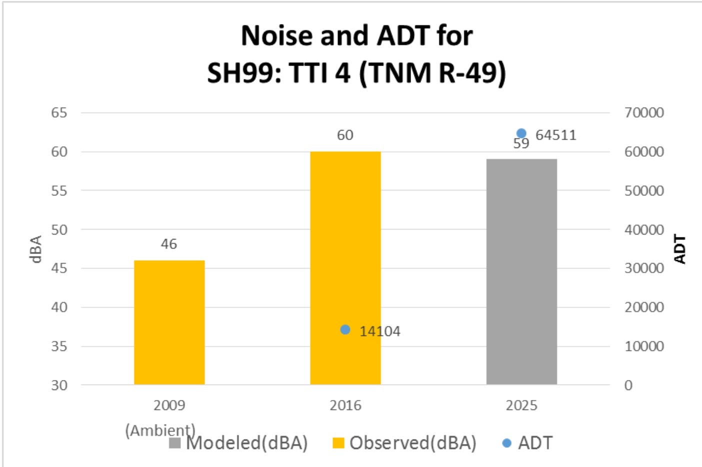
Note: Cell shading indicates that observed values exceeded 2030 TNM results with barrier.

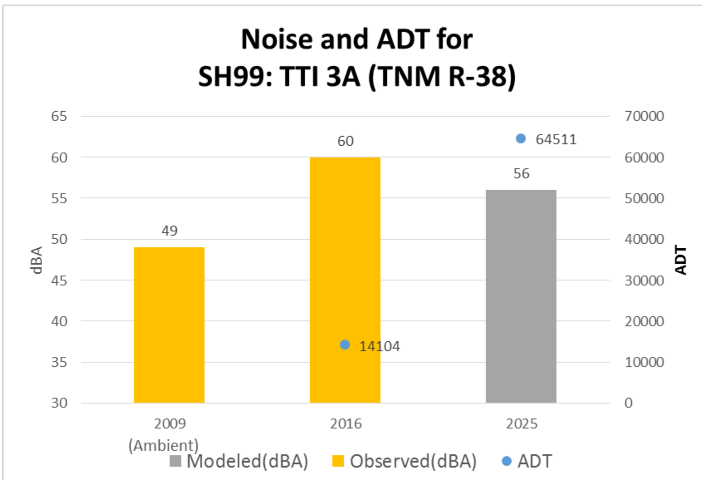
Table 51. Sound Level Measurements and Comparisons to 2016 Estimates for PGBT-EE 2016 (Dallas).

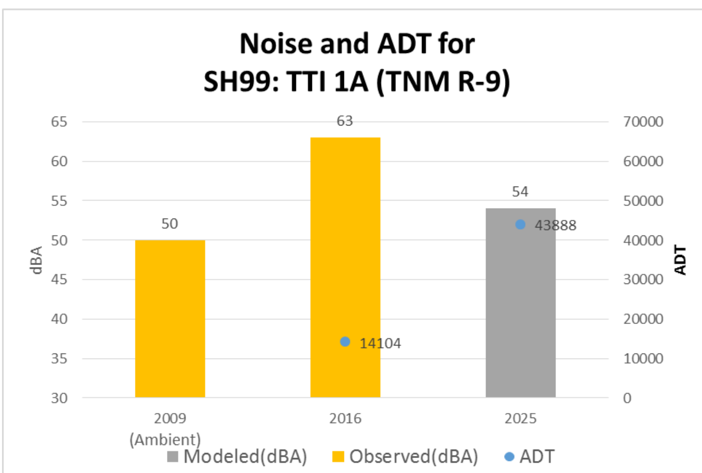
TTI ID	Wall?	Name	2030 TNM Results (Leq, dBA) No Barrier	2030 TNM Results (Leq, dBA) With Barrier	2016 TNM Results (Leq, dBA) No Barrier	2016 TNM Results (Leq, dBA) With Barrier	2016 Observed (Leq, dBA)	Time Period
1	Yes	R1	65	61	65	62	59	AM
							66	Midday
							60	PM
1B	Yes	R1B	65	63	65	63	59	AM
							57	Midday
							61	PM
2	Yes	Receiver 3	70	64	70	64	62	AM
							56	Midday
							58	PM
4	Yes	Receiver 5	70	65	70	65	57	AM
							56	Midday
							58	PM
5	Yes	Receiver 9	66	59	66	59	69	AM
							64	Midday
							64	PM
6	Yes	Receiver 10	62	59	62	59	66	AM
							63	Midday
							64	PM
8	Yes	Receiver 12A	71	63	71	63	68	AM
							67	Midday
							69	PM

Note: Cell shading indicates that observed values exceeded 2030 TNM results with barrier.

Since several sites had existing noise levels higher than what was projected, the ambient noise conditions documented in the FEIS for each corridor were also compared to existing and projected noise and available ADTs. Note that little to no development existed on these corridors when the baseline (ambient) noise levels were measured. Figure 110 and Figure 111 show a less dramatic jump in noise level but a bigger difference between 2016 and 2025 ADTs. In contrast, Figure 112 shows that three out of the four PGBT-EE sites showed a spike in the noise level from 2009 to 2016 (TTI 5 [TNM R-9] was the exception). Generally, they all show that noise has increased significantly since ambient noise was measured, with most sites already exceeding the projected noise level. In fact, PGBT-EE's ADT is already at 95–98 percent of projected ADT, but this is likely due to the misapplication of the directional split, as discussed previously







Source: (*5*).

Figure 110. Noise Levels and ADTs for SH 99.

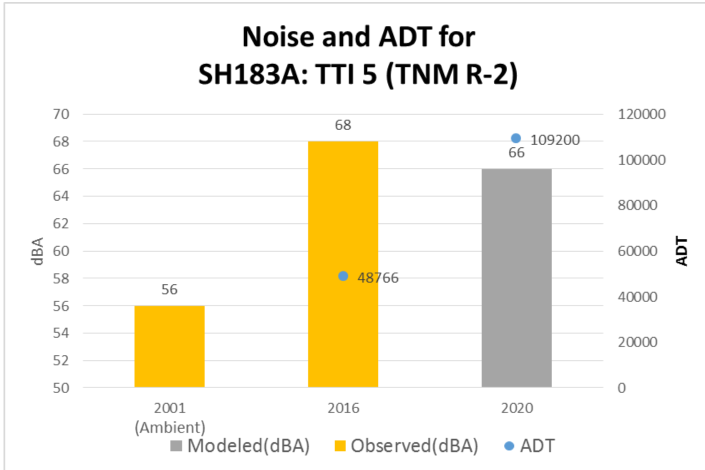
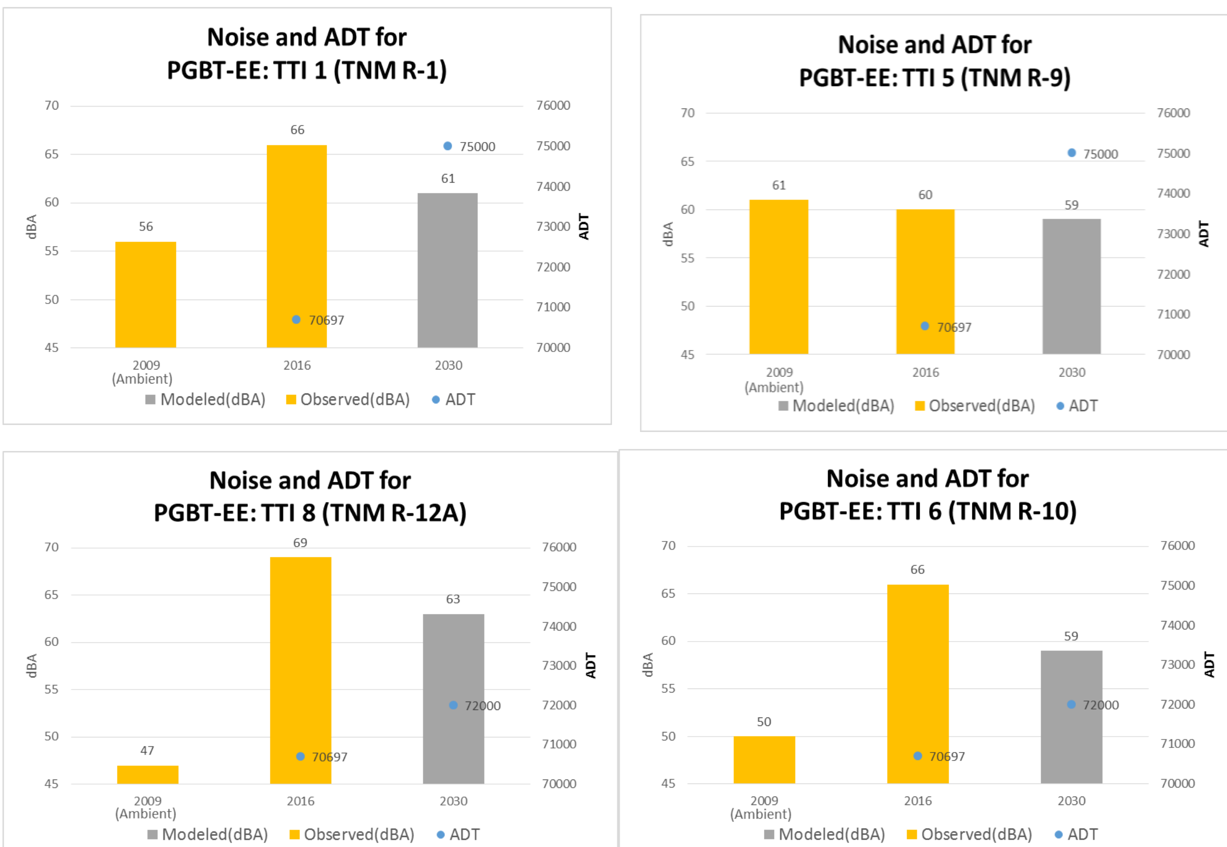


Figure 111. Noise Levels and ADTs for US 183A.



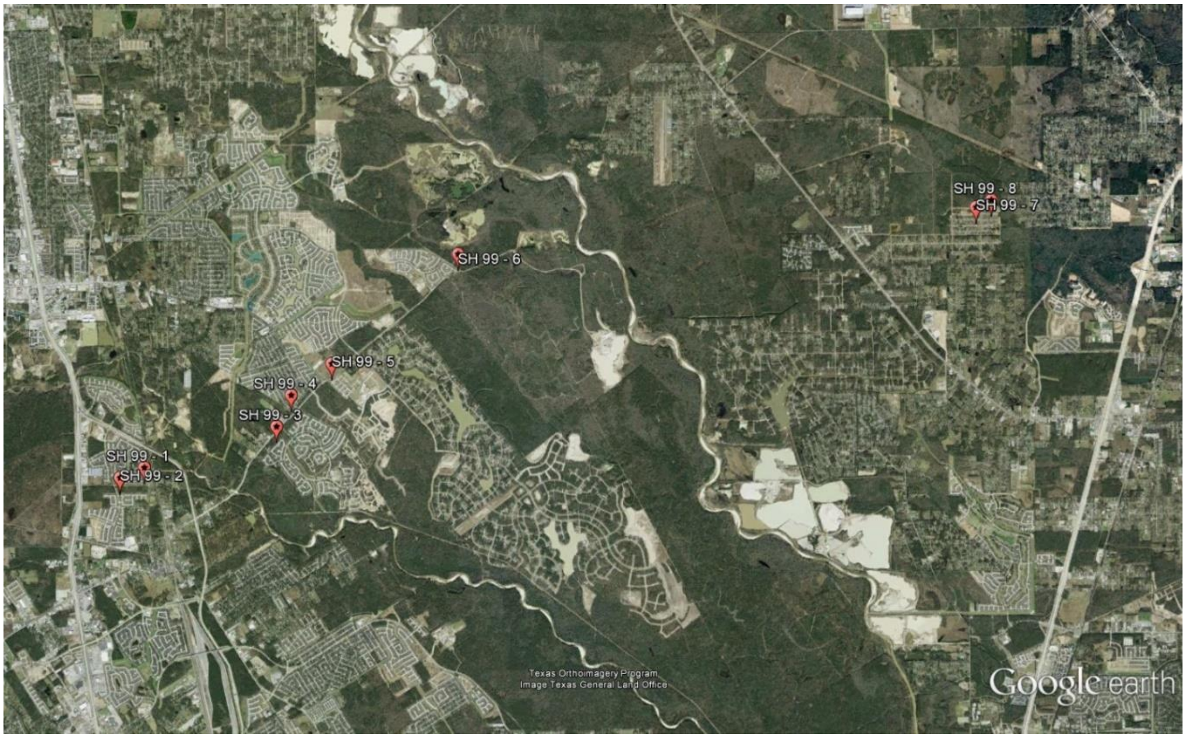
Source: (*6*).

Figure 112. Noise Levels and ADTs for PGBT-EE.

Land Use Changes

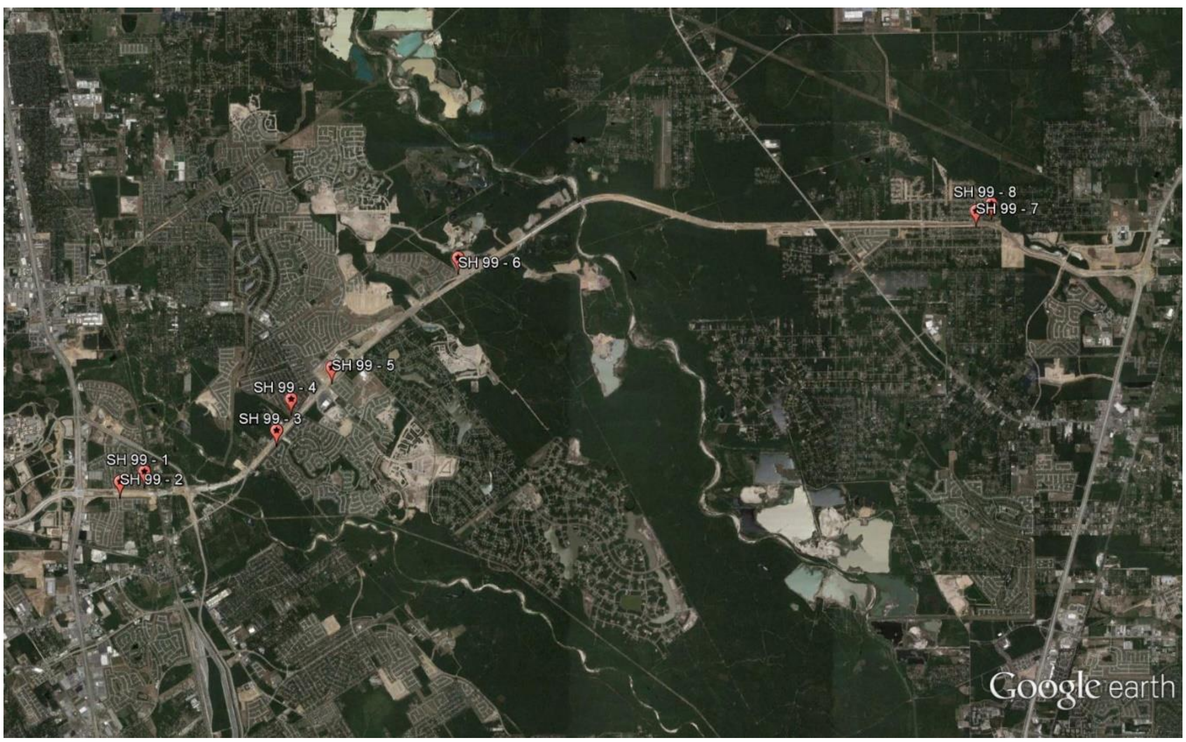
Development around the study sites between the environmental assessment and present time can contribute to an increase in the ambient noise level. Figure 113 and Figure 114 show satellite images of the SH 99 Segment G study site corridor between 2009 and 2016. A visual comparison of these images shows little change in land use near the field measurement sites.

Figure 115 and Figure 116 show satellite images of the US 183A study site corridor between 2002 and 2016. A visual comparison of these images shows some moderate resident and commercial development. Figure 117 and Figure 118 show satellite images of the President George Bush Turnpike Eastern Extension study site corridor between 2004 and 2016. A visual comparison of these images shows some moderate resident and commercial development.



Source: (*7*).

Figure 113. SH 99 Segment G circa January 2009.

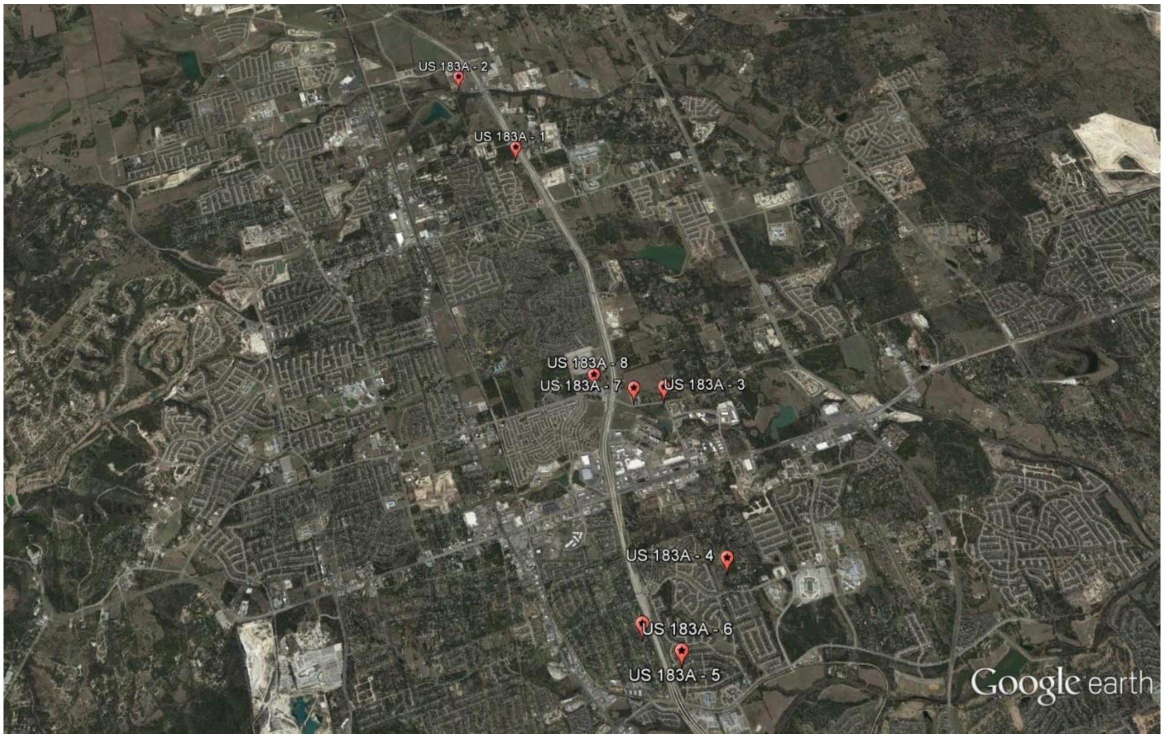


Source: (*7*).

Figure 114. SH 99 Segment G circa February 2016.

Source: (*7*).

Figure 115. Satellite View of US 183A Area circa April 2002.

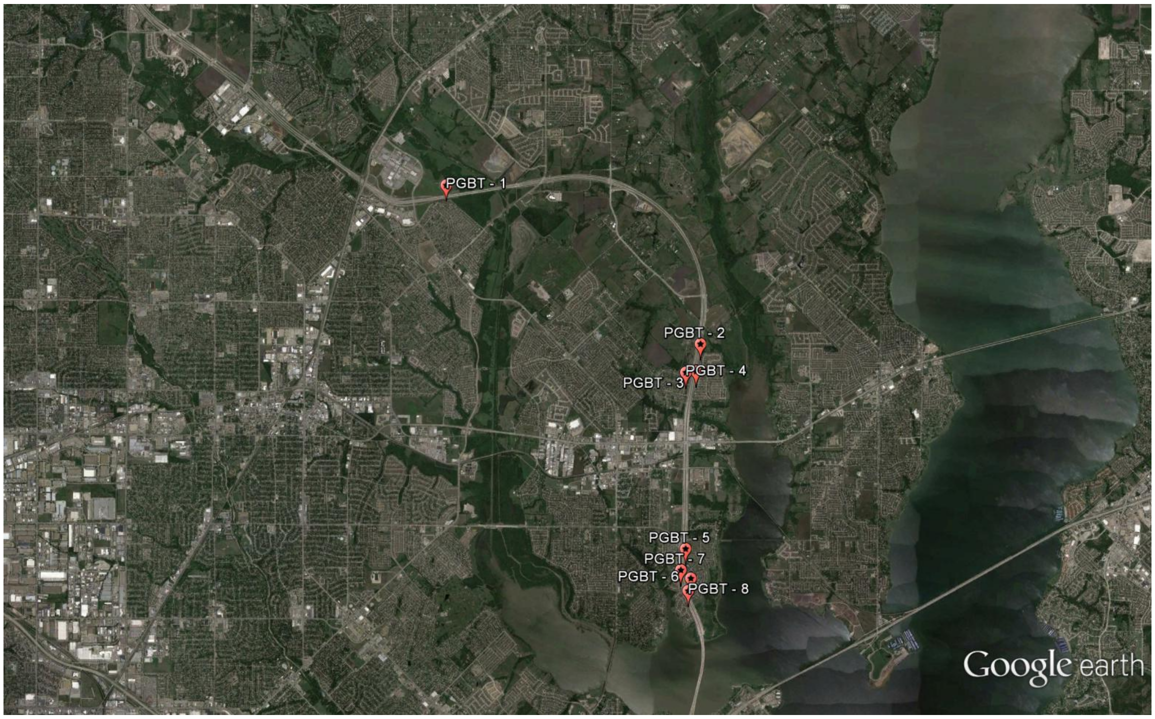


Source: (*7*).

Figure 116. Satellite View of US 183A Area circa February 2016.

Source: (*7*).

Figure 117. President George Bush Turnpike Eastern Extension Area circa March 2004.



Source: (*7*).

Figure 118. President George Bush Turnpike Eastern Extension Area circa March 2016.

TNM 2.5 Skew View vs. Google Earth Street View Images

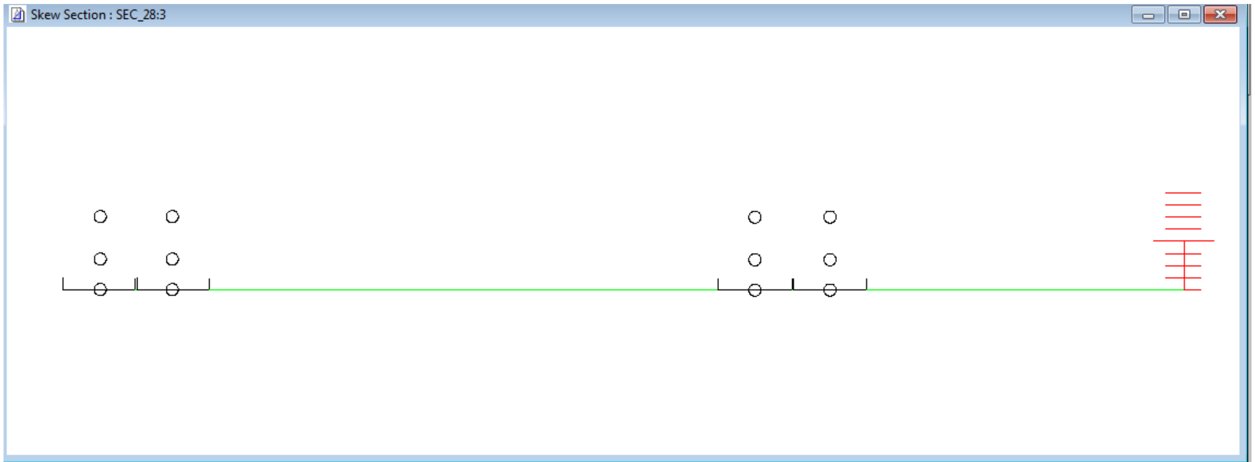


Figure 119. Traffic Noise Model Skew View for TTI Location 1 and 1B at TNM R-1 and R-1B, PGBT-EE.

Source: (*7*).

Figure 120. Google Street View of Eastbound Main Lanes at TTI Location 1 and 1B, PGBT-EE.

Source: (*7*).

Figure 121. Google Street View of Westbound Main Lanes at TTI Location 1 and 1B, PGBT-EE.

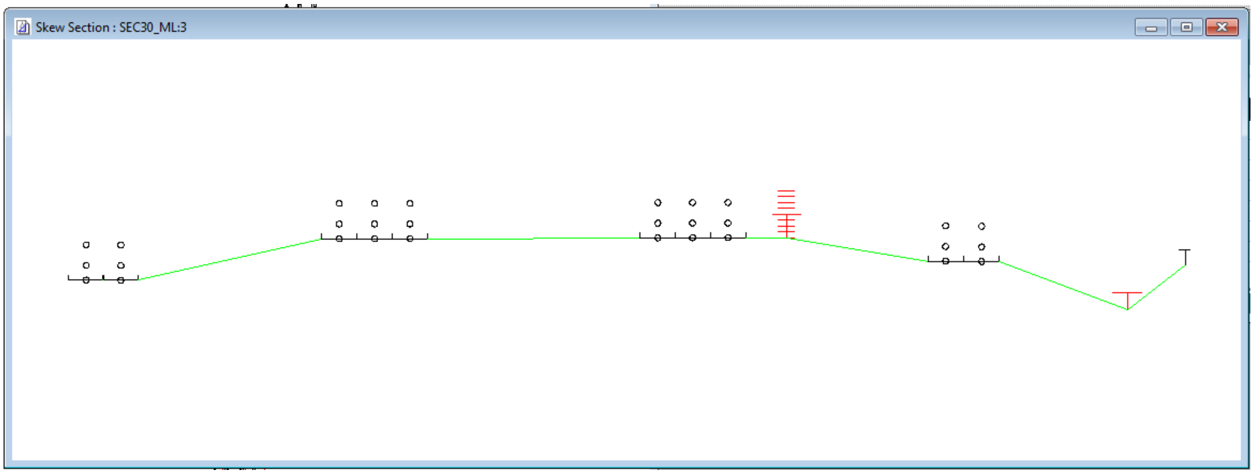


Figure 122. Traffic Noise Model Skew View for TTI Location 2 at TNM R-3, PGBT-EE.

Source: (*7*).

Figure 123. Google Street View of Southbound Main Lanes at TTI Location 2, PGBT-EE.

Source: (*7*).

Figure 124. Google Street View of Southbound Frontage Road at TTI Location 2, PGBT-EE.

Source: (*7*).

Figure 125. Google Street View of Northbound Main Lanes at TTI Location 2, PGBT-EE.

Source: (*7*).

Figure 126. Google Street View of Northbound Frontage Road at TTI Location 2, PGBT-EE.

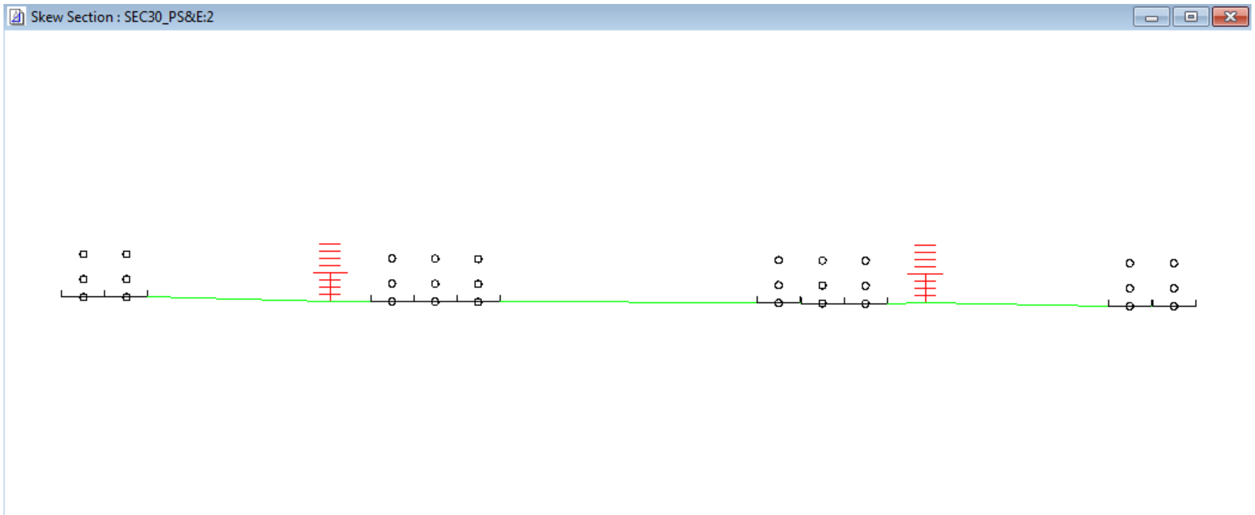


Figure 127. Traffic Noise Model Skew View for TTI Location 4 at TNM R-5, PGBT-EE.

Source: (*7*).

Figure 128. Google Street View of Southbound Main Lanes at TTI Location 4, PGBT-EE.

Source: (*7*).

Figure 129. Google Street View of Southbound Frontage Road at TTI Location 4, PGBT-EE.

Source: (*7*).

Figure 130. Google Street View of Northbound Main Lanes at TTI Location 4, PGBT-EE.

Source: (*7*).

Figure 131. Google Street View of Northbound Frontage Road at TTI Location 4, PGBT-EE.

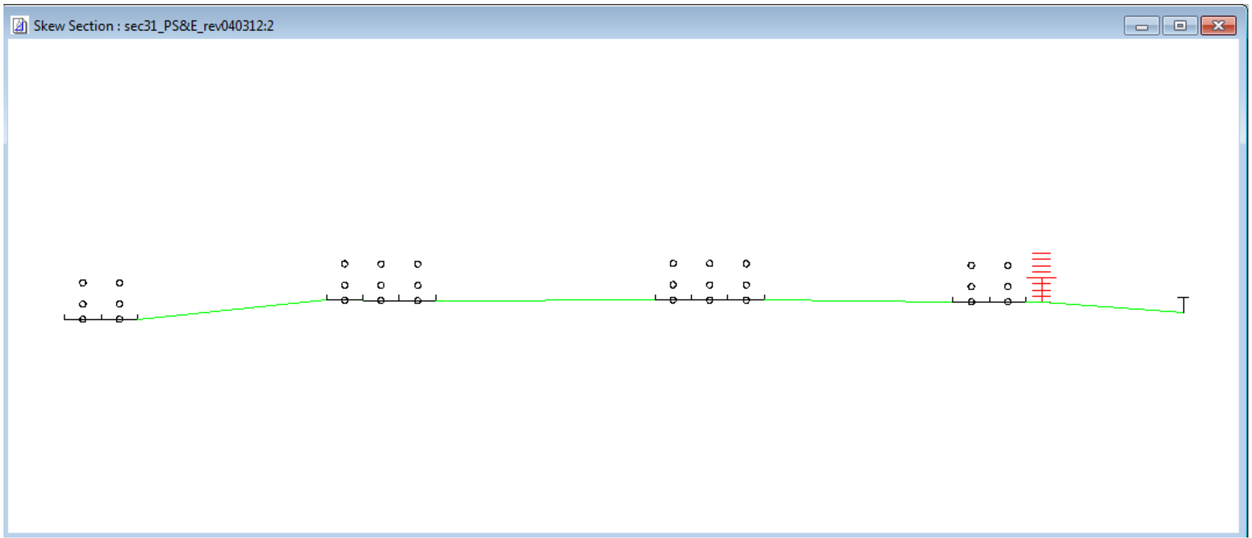


Figure 132. Traffic Noise Model Skew View for TTI Location 5 at TNM R-9, PGBT-EE.

Source: (*7*).

Figure 133. Google Street View of Southbound Main Lanes at TTI Location 5, PGBT-EE.

Source: (*7*).

Figure 134. Google Street View of Southbound Frontage Road at TTI Location 5, PGBT-EE.

Source: (*7*).

Figure 135. Google Street View of Northbound Main Lanes at TTI Location 5, PGBT-EE.

Source: (*7*).

Figure 136. Google Street View of Northbound Frontage Road at TTI Location 5, PGBT-EE.

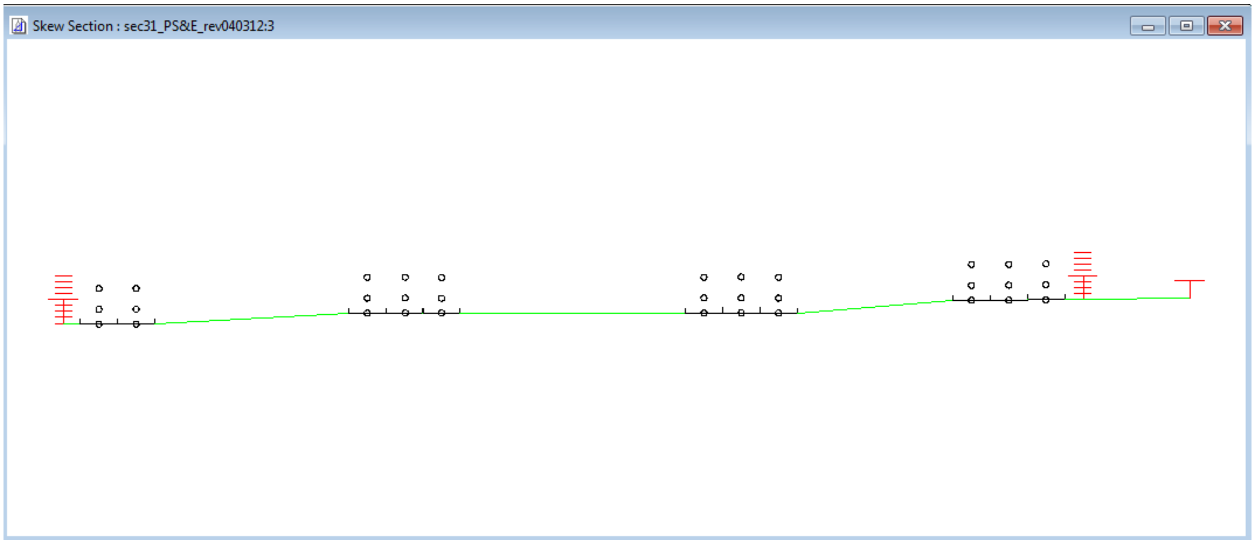


Figure 137. Traffic Noise Model Skew View for TTI Location 6 and 8 at TNM R-10 and R-12A, PGBT-EE.

Source: (*7*).

Figure 138. Google Street View of Southbound Main Lanes at TTI Location 6 and 8, PGBT-EE.

Source: (*7*).

Figure 139. Google Street View of Southbound Frontage Road at TTI Location 6 and 8, PGBT-EE.

Source: (*7*).

Figure 140. Google Street View of Northbound Main Lanes at TTI Location 6 and 8, PGBT-EE.

Source: (*7*).

Figure 141. Google Street View of Northbound Frontage Road at TTI Location 6 and 8, PGBT-EE.

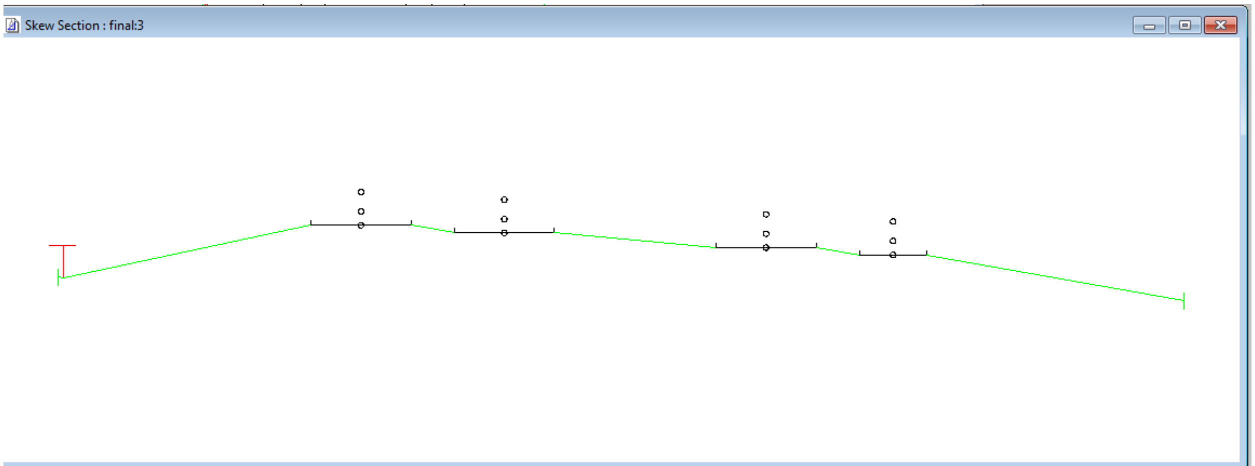
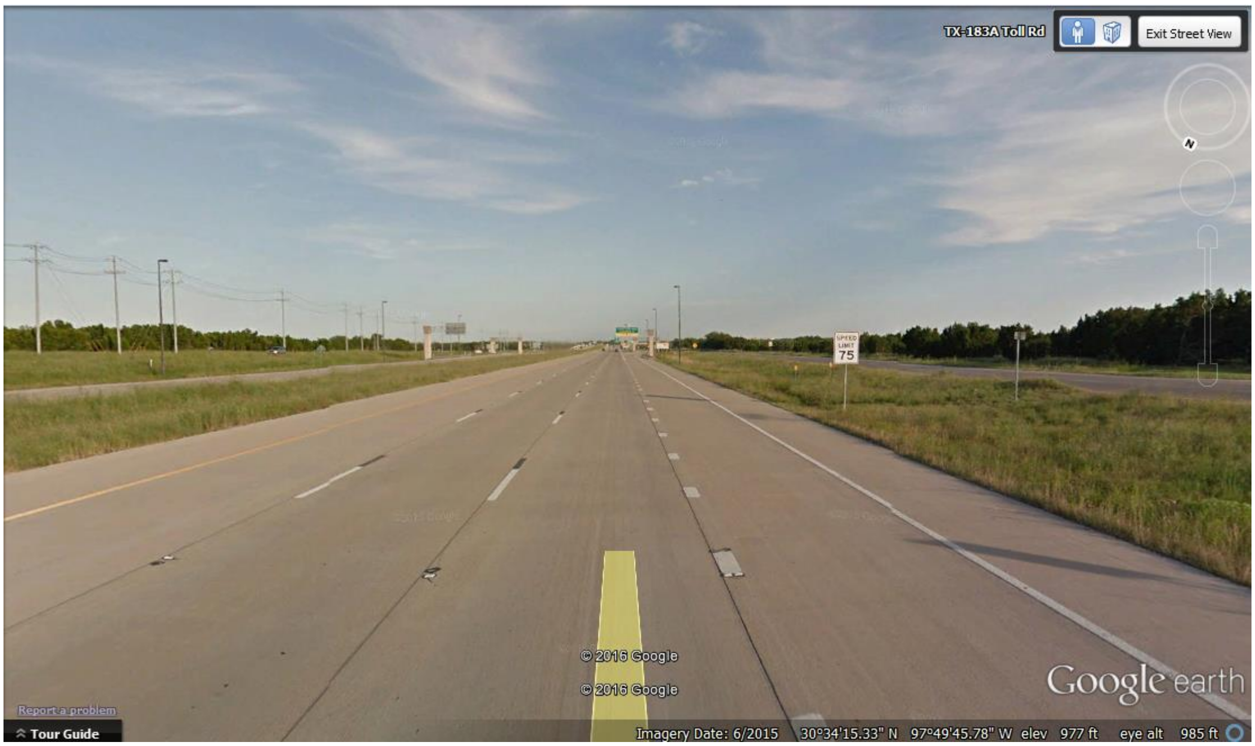


Figure 142. Traffic Noise Model Skew View for TTI Location 1 at TNM R-12, US 183A.



Source: (*7*).

Figure 143. Google Street View of Southbound Main Lanes at TTI Location 1, US 183A.

Source: (*7*).

Figure 144. Google Street View of Southbound Frontage Road at TTI Location 1, US 183A.

Source: (*7*).

Figure 145. Google Street View of Northbound Main Lanes at TTI Location 1, US 183A.

Source: (*7*).

Figure 146. Google Street View of Northbound Frontage Road at TTI Location 1, US 183A.

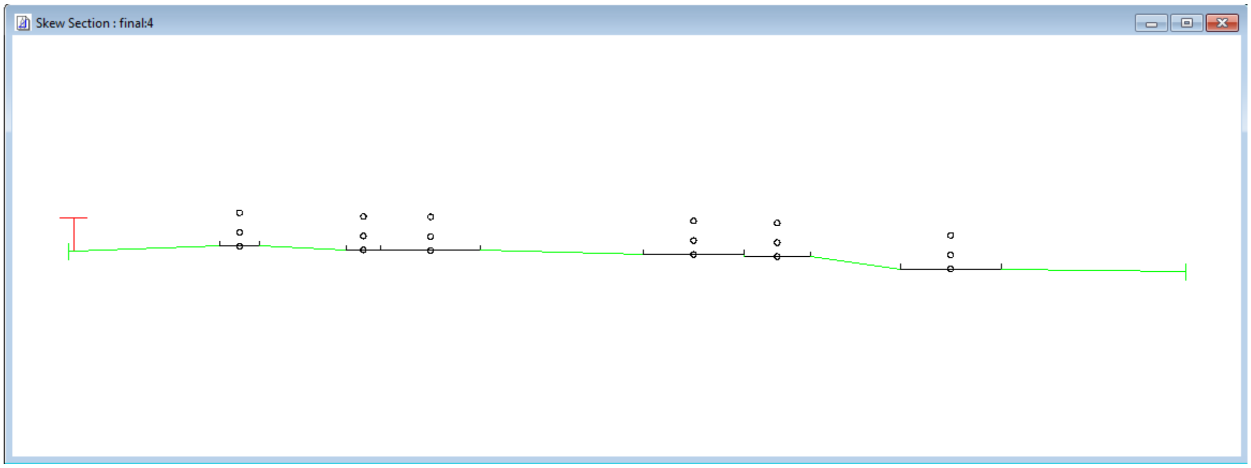


Figure 147. Traffic Noise Model Skew View for TTI Location 5 and 6 at TNM R-2 and R-3, US 183A.

Source: (*7*).

Figure 148. Google Street View of Southbound Main Lanes at TTI Location 5 and 6, US 183A.

Source: (*7*).

Figure 149. Google Street View of Northbound Main Lanes at TTI Location 5 and 6, US 183A.

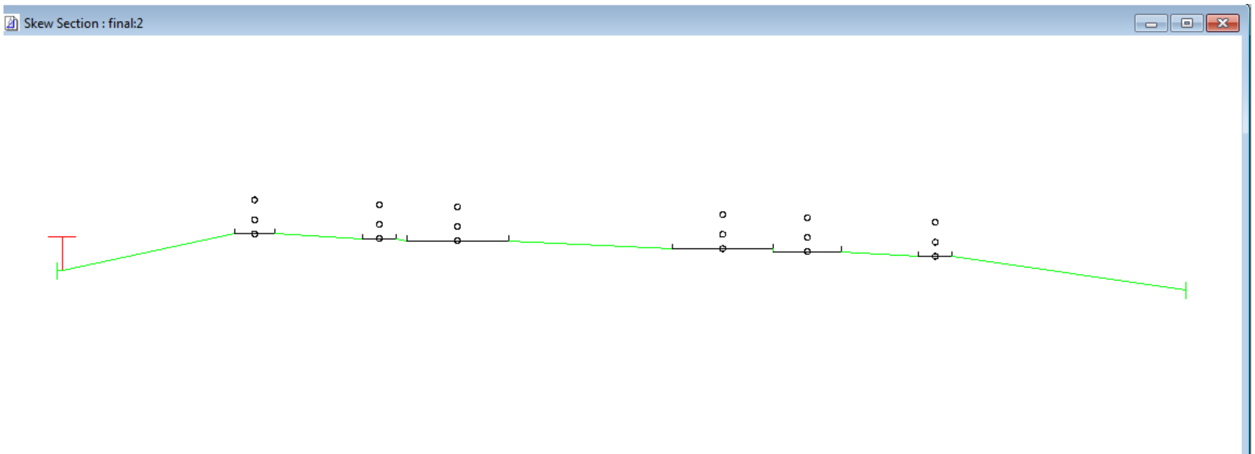


Figure 150. Traffic Noise Model Skew View for TTI Location 7 and 8 at TNM R-6 and R-7, US 183A.

Source: (*7*).

Figure 151. Google Street View of Southbound Main Lanes at TTI Location 7 and 8, US 183A.

Source: (*7*).

Figure 152. Google Street View of Southbound Frontage Road at TTI Location 7 and 8, US 183A.

Source: (*7*).

Figure 153. Google Street View of Northbound Main Lanes at TTI Location 7 and 8, US 183A.

Source: (*7*).

Figure 154. Google Street View of Northbound Frontage Road at TTI Location 7 and 8, US 183A.

Note: No Google Street Views were available for SH 99 Segment G. Only TTI site photos were available for main lanes.

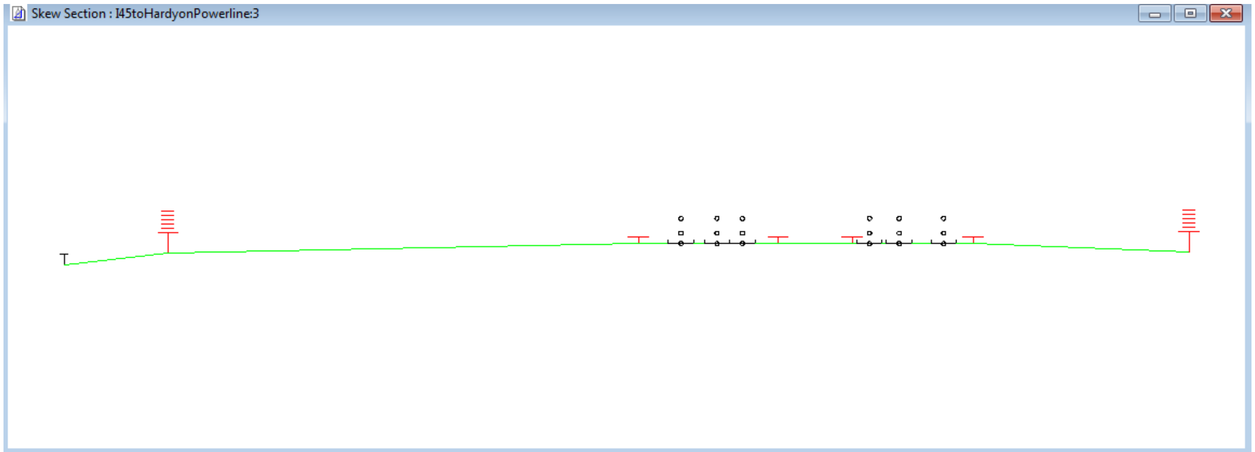


Figure 155. Traffic Noise Model Skew View for TTI Location 1A at TNM R-9, SH 99 Segment G.

Note: Noise barrier on north side is discontinuous (gap). Model shows frontage roads, but none were noted in field notes.

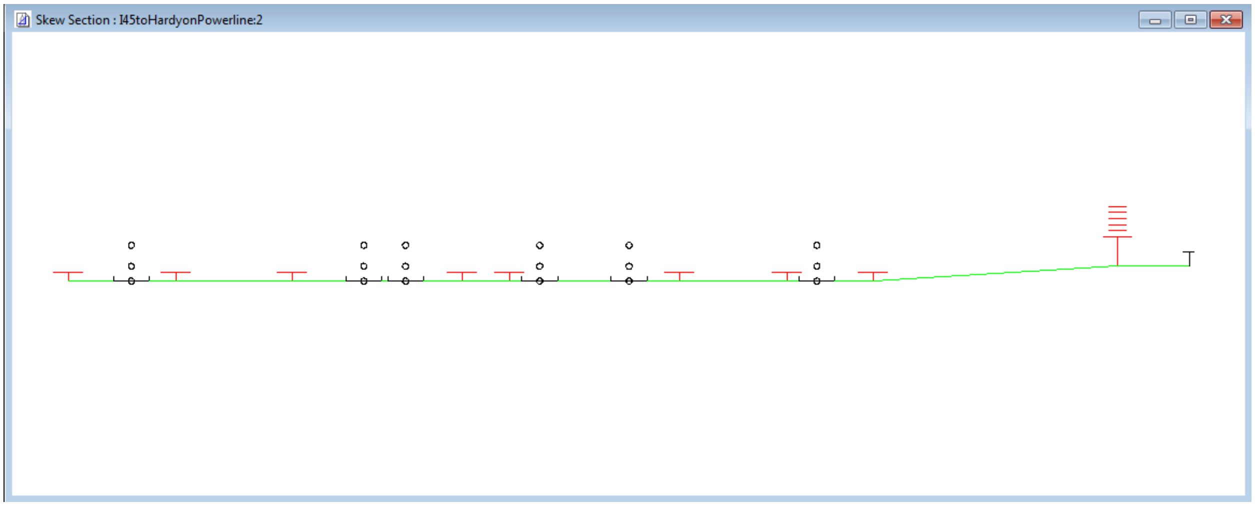


Figure 156. Traffic Noise Model Skew View for TTI Location 2 at TNM R-19, SH 99 Segment G.

Figure 157. TTI Field Photo of Eastbound Main Lanes of Northgate Crossing Blvd Underpass at TTI Location 1 and 2, SH 99 Segment G.

Figure 158. TTI Field Photo of Westbound Main Lanes of Northgate Crossing Blvd Underpass at TTI Location 1 and 2, SH 99 Segment G.

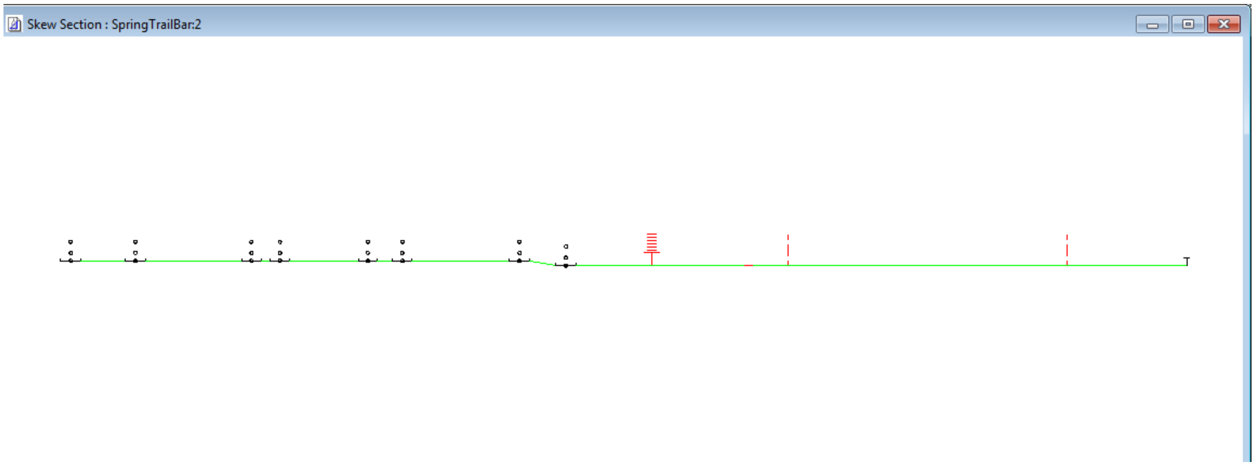


Figure 159. Traffic Noise Model Skew View for TTI Location 3A at TNM R-38, SH 99 Segment G.

Figure 160. TTI Field Photo of Eastbound Main Lanes West of Spring Trails Ridge at TTI Location 3A, SH 99 Segment G.

Figure 161. TTI Field Photo of Westbound Main Lanes West of Spring Trails Ridge at TTI Location 3A, SH 99 Segment G.

Note: Missing noise barrier on south side.

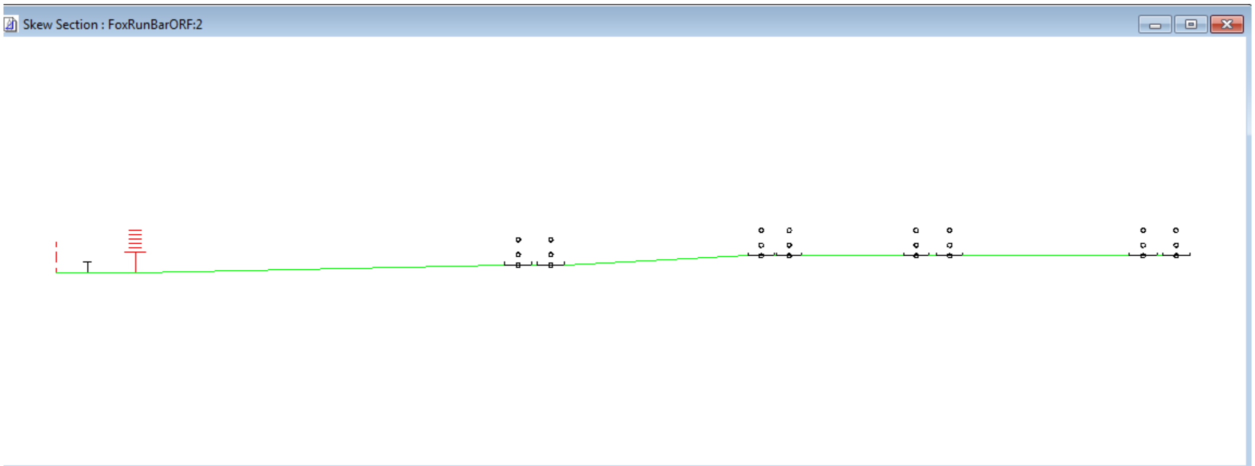


Figure 162. Traffic Noise Model Skew View for TTI Location 4 at TNM R-49, SH 99 Segment G.

Figure 163. TTI Field Photo of Eastbound Main Lanes at Discovery Creek Underpass at TTI Location 4, SH 99 Segment G.

Figure 164. TTI Field Photo of Westbound Main Lanes at Discovery Creek Underpass at TTI Location 4, SH 99 Segment G.

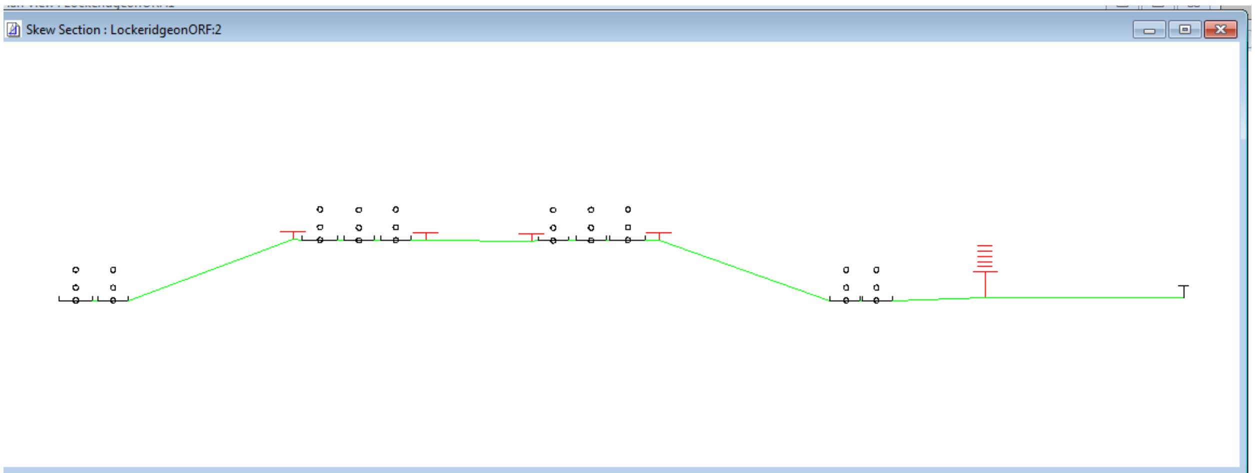


Figure 165. Traffic Noise Model Skew View for TTI Location 5 at TNM R-65, SH 99 Segment G.

Figure 166. TTI Field Photo of Eastbound Main Lanes East of Rayford Rd Underpass at TTI Location 5, SH 99 Segment G.

Figure 167. TTI Field Photo of Westbound Main Lanes East of Rayford Rd Underpass at TTI Location 5, SH 99 Segment G.

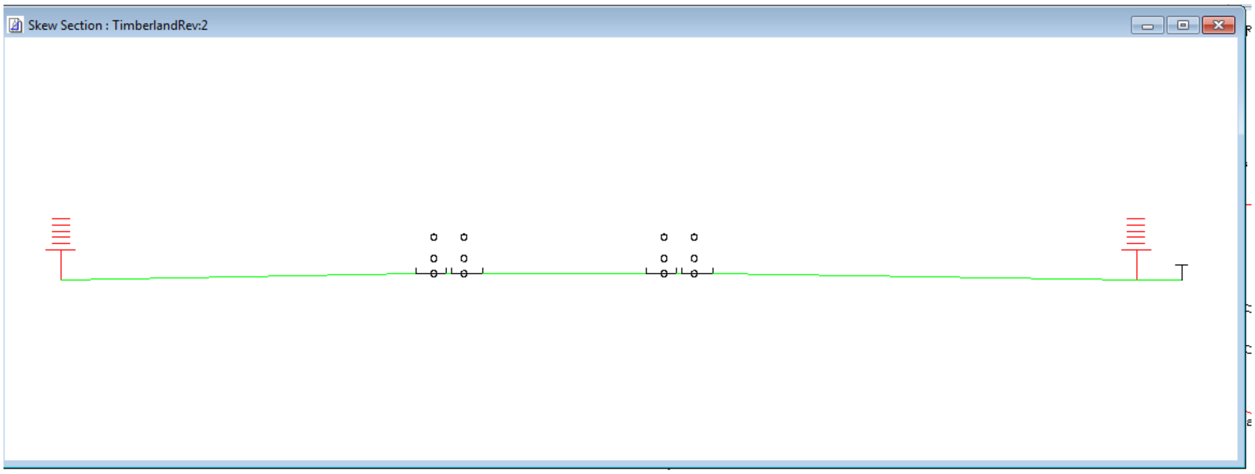


Figure 168. Traffic Noise Model Skew View for TTI Location 7 at TNM R-145, SH 99 Segment G.

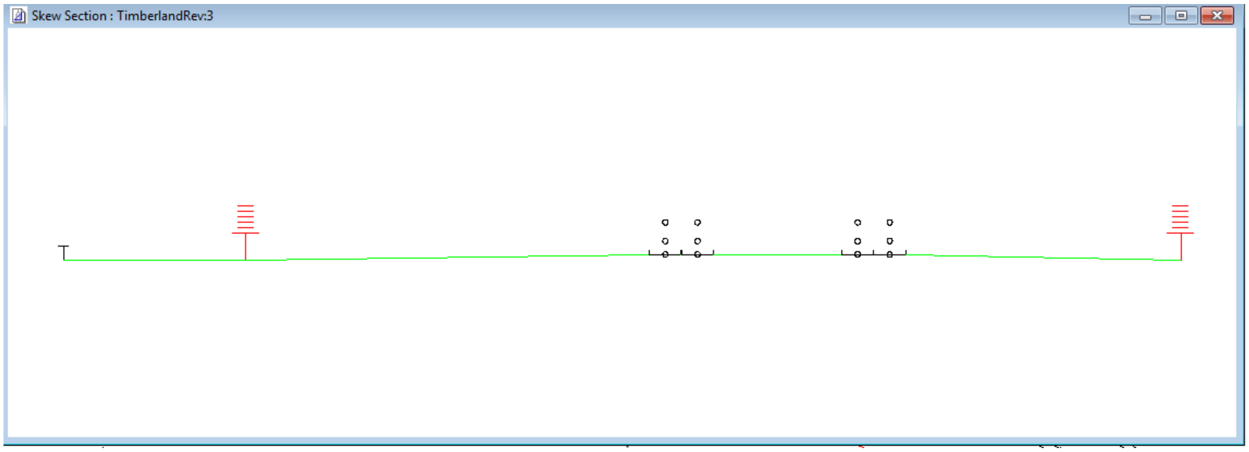


Figure 169. Traffic Noise Model Skew View for TTI Location 8 at TNM R-153, SH 99 Segment G.

Figure 170. TTI Field Photo of Eastbound Main Lanes East of Timber Ln at TTI Location 8, SH 99 Segment G.

Figure 171. TTI Field Photo of Eastbound Main Lanes East of Timber Ln at TTI Location 8, SH 99 Segment G.

US 183A Output Check

No Run	No Barrier	With Barrier			
Receiver	Laeq 1h		Noise Reduction		
Name	Calculated	Calculated Laeq 1h	Calculated	Goal	Calculated-Goal
R2	75.4	66.2	9.2	5	4.2
R4"	72.5	64.9	7.6	5	2.6
R7"	69.8	64.9	4.9	5	-0.1
R8"	69.3	64.3	5	5	0
R11"	70.7	63.4	7.3	5	2.3
R14"	72.5	71.5	1	5	-4
R17"	72.2	70	2.2	5	-2.8
R18"	72	71.3	0.7	5	-4.3
R21"	74.4	73.2	1.2	5	-3.8
R20"	70	69.9	0.1	5	-4.9
R23"	69.8	69.6	0.2	5	-4.8
R22"	65.3	65.2	0.1	5	-4.9
R24"	72.3	72.3	0	5	-5
R25"	71.7	71.6	0.1	5	-4.9
R27"	69.2	67.4	1.8	5	-3.2
R26"	74	73.2	0.8	5	-4.2
R29"	72.7	65.6	7.1	5	2.1
R28"	74.4	72.3	2.1	5	-2.9
R30"	74	70.2	3.8	5	-1.2
R31"	72.9	66.1	6.8	5	1.8
R32"	74.1	66.4	7.7	5	2.7
R34"	73.8	69.9	3.9	5	-1.1
R33"	76.6	71.4	5.2	5	0.2
R35"	72.6	65.4	7.2	5	2.2
R41"	69.2	64.4	4.8	5	-0.2
R38"	74.3	73	1.3	5	-3.7
R43"	68.1	62.9	5.2	5	0.2
R42"	74.1	72.9	1.2	5	-3.8
R5"	70.5	65.3	5.2	8	-2.8
R6"	70.2	64.8	5.4	8	-2.6
R9"	69.2	63.9	5.3	8	-2.7
R10"	69.8	63.5	6.3	8	-1.7
R12"	69.8	66.5	3.3	8	-4.7
R13"	69.3	66.4	2.9	8	-5.1
R15"	66.5	61.2	5.3	8	-2.7
R16"	66.8	61.5	5.3	8	-2.7
R19"	67.2	62.8	4.4	8	-3.6
R36"	70.5	65.7	4.8	8	-3.2
R37"	70.3	65.9	4.4	8	-3.6
R39"	70.1	65.5	4.6	8	-3.4
R40"	73.6	73.6	0	8	-8
R3"	69	68.9	0.1	8	-7.9
R1"	70.6	70.6	0	8	-8

No change but ReRun	No Barrier	With Barrier			
Receiver	Laeq 1h		Noise Reduction		
Name	Calculated	Calculated Laeq 1h	Calculated	Goal	Calculated-Goal
R2	74.2	65.4	8.8	5	3.8
R4"	71.5	63	8.5	5	3.5
R7"	67.9	63	4.9	5	-0.1
R8"	67.6	62.2	5.4	5	0.4
R11"	69.1	61.6	7.5	5	2.5
R14"	71	70.2	0.8	5	-4.2
R17"	72.5	69.7	2.8	5	-2.2
R18"	72.4	70.9	1.5	5	-3.5
R21"	71.3	70	1.3	5	-3.7
R20"	70.1	70	0.1	5	-4.9
R23"	68.6	68.5	0.1	5	-4.9
R22"	64.3	64.3	0	5	-5
R24"	72.7	72.7	0	5	-5
R25"	71.3	71.3	0	5	-5
R27"	66.6	65.8	0.8	5	-4.2
R26"	73.5	73	0.5	5	-4.5
R29"	70.2	65.7	4.5	5	-0.5
R28"	74.6	72.2	2.4	5	-2.6
R30"	74.1	69.4	4.7	5	-0.3
R31"	70.7	65.6	5.1	5	0.1
R32"	72.2	65.1	7.1	5	2.1
R34"	73	70.1	2.9	5	-2.1
R33"	75.8	71.6	4.2	5	-0.8
R35"	70.4	61.9	8.5	5	3.5
R41"	67.7	63.4	4.3	5	-0.7
R38"	72	71.5	0.5	5	-4.5
R43"	66.5	61.5	5	5	0
R42"	71.5	71.2	0.3	5	-4.7
R5"	68.5	62	6.5	8	-1.5
R6"	68.2	61.5	6.7	8	-1.3
R9"	67.4	61.2	6.2	8	-1.8
R10"	68	60.8	7.2	8	-0.8
R12"	68	66.4	1.6	8	-6.4
R13"	66.9	64.7	2.2	8	-5.8
R15"	64.2	59.3	4.9	8	-3.1
R16"	64.6	59.5	5.1	8	-2.9
R19"	64.2	60.6	3.6	8	-4.4
R36"	68.4	65.2	3.2	8	-4.8
R37"	68.4	64.9	3.5	8	-4.5
R39"	68.4	64.4	4	8	-4
R40"	71.6	71.5	0.1	8	-7.9
R3"	66.4	66.4	0	8	-8
R1"	69.6	69.6	0	8	-8

DIFF.	No Barrier	With Barrier			
Receiver	Laeq 1h		Noise Reduction		
Name	Calculated	Calculated Laeq 1h	Calculated	Goal	Calculated-Goal
R2	1.2	0.8	0.4	0	0.4
R4"	1	1.9	-0.9	0	-0.9
R7"	1.9	1.9	0	0	0
R8"	1.7	2.1	-0.4	0	-0.4
R11"	1.6	1.8	-0.2	0	-0.2
R14"	1.5	1.3	0.2	0	0.2
R17"	-0.3	0.3	-0.6	0	-0.6
R18"	-0.4	0.4	-0.8	0	-0.8
R21"	3.1	3.2	-0.1	0	-0.1
R20"	-0.1	-0.1	0	0	0
R23"	1.2	1.1	0.1	0	0.1
R22"	1	0.9	0.1	0	0.1
R24"	-0.4	***-0.4***	***0***	***0***	***0***
R25"	0.4	0.3	0.1	0	0.1
R27"	2.6	1.6	1	0	1
R26"	0.5	0.2	0.3	0	0.3
R29"	2.5	-0.1	2.6	0	2.6
R28"	-0.2	0.1	-0.3	0	-0.3
R30"	-0.1	0.8	-0.9	0	-0.9
R31"	2.2	0.5	1.7	0	1.7
R32"	1.9	1.3	0.6	0	0.6
R34"	0.8	-0.2	1	0	1
R33"	0.8	-0.2	1	0	1
R35"	2.2	***3.5***	***-1.3***	***0***	***-1.3***
R41"	1.5	1	0.5	0	0.5
R38"	2.3	1.5	0.8	0	0.8
R43"	1.6	1.4	0.2	0	0.2
R42"	2.6	1.7	0.9	0	0.9
R5"	2	3.3	-1.3	0	-1.3
R6"	2	3.3	-1.3	0	-1.3
R9"	1.8	2.7	-0.9	0	-0.9
R10"	1.8	2.7	-0.9	0	-0.9
R12"	1.8	0.1	1.7	0	1.7
R13"	2.4	1.7	0.7	0	0.7
R15"	2.3	1.9	0.4	0	0.4
R16"	2.2	2	0.2	0	0.2
R19"	3	2.2	0.8	0	0.8
R36"	2.1	0.5	1.6	0	1.6
R37"	1.9	1	0.9	0	0.9
R39"	1.7	1.1	0.6	0	0.6
R40"	2	2.1	-0.1	0	-0.1
R3"	2.6	2.5	0.1	0	0.1
R1"	1	1	0	0	0

2016 Traffic Inputs for TNM 2.5

SH 99 (Houston)

MAIN LANES SH99 near Brinham Woods July 2016									
WB					EB				
%Cars=	87.74		Kfactor =	0.085	%Cars=		91.4		
%Medium Trucks=	6.85				%Medium T		4.94		
%Heavy Trucks=	5.08				%Heavy Tru		3.24		
%Buses	0.01				%Buses		0.01		
%Motorcycles	0.32				%Motorcyc		0.41		
TNM WB 1_28			# LANES	SPEED	TNM EB ML 1_28			# LANES	SPEED
ADT=		7,283			ADT=		6,821		
Multiply		1.0			Multiply		1.0		
Kfactor =		0.085			Kfactor =		0.085		
east bound dir. split=		1.00			west bound dir. split=		1.00		
DHV=		619.06	2		DHV=		580	2	
Cars		543	272	70	Cars		530	265	71
Medium Trucks		42	21	70	Medium Trucks		29	14	71
Heavy Trucks		31	16	70	Heavy Trucks		19	9	71
Buses		0	0	70	Buses		0	0	71
Motorcycle		2	1	70	Motorcycle		2	1	71

US 183A (Austin)

MAIN LANES SH183A at Lakeline June 2016									
DHV Mixture (From TPP sheets)									
%Cars=	97		Kfactor =	0.085					
%Medium Trucks=	2								
%Heavy Trucks=	1								
TNM NB ML 1_28			# LANES	SPEED	TNM SB ML 1_28				
ADT=		25,938			ADT=		22,828		
Multiply		1.0			Multiply		1.0		
Kfactor =		0.085			Kfactor =		0.085		
east bound dir. split=		1.00			west bound dir. split=		1.00		
DHV=		2204.73	3	72.1	DHV=		1940	3	73.7
Cars		2139	713	72	Cars		1882	627	74
Medium Trucks		44	15	72	Medium Trucks		39	13	74
Heavy trucks		22	7	72	Heavy trucks		19	6	74
Cars		2139	72		Cars		1882	74	
Heavy trucks		66	72		Heavy trucks		58	74	

PGBT-EE (Dallas)

MAIN LANES PGBT Eastern Extension (From FM 78 to IH 30)									
DHV Mixture (From TPP sheets)									
%Cars=	88		Kfactor = Nc	0.085	%Cars=	91.1			
%Medium Trucks=	9.7				%Medium Trucks=	5.8			
%Heavy Trucks=	2				%Heavy Trucks=	2.7			
%Buses=	0.1				%Buses=	0.1			
%Motorcycles=	0.3				%Motorcycles=	0.3			
TNM EB ML 1_28			**# LANES**	**SPEED**	**TNM WB ML 2_28**				
ADT=		35,844			**ADT=**		34,853		
Multiply		1.0			Multiply		1.0		
Kfactor =		0.085			Kfactor =		0.085		
east bound dir. split=		1.00			west bound dir. split=		1.00		
DHV=		**3046.74**	**2**		**DHV=**		**2963**	**2**	
Cars		2681	1341	70	Cars		2699	1349	72
Medium Trucks		296	148	70	Medium Trucks		172	86	72
Heavy Trucks		61	30	70	Heavy Trucks		80	40	72
Buses		3	2	70	Buses		3	1	72
Motorcycles		9	5	70	Motorcycles		9	4	72
DHV=		**3046.74**	**3**		**DHV=**		**2963**	**3**	
Cars		2681	894	70	Cars		2699	900	72
Medium Trucks		296	99	70	Medium Trucks		172	57	72
Heavy Trucks		61	20	70	Heavy Trucks		80	27	72
Buses		3	1	70	Buses		3	1	72
Motorcycles		9	3	70	Motorcycles		9	3	72

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