Recommended Best Practices for the Use of the FHWA Traffic Noise Model (TNM)

TNM Object Input, Noise Barrier Optimization, and Quality Assurance

Final Report — December 8, 2015

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16. Abstract

Federal-aid highway projects that require a traffic noise analysis must use the latest version of the Federal Highway Administration Traffic Noise Model (FHWA TNM), according to 23 CFR 772.9(a). While the FHWA TNM provides for the accurate prediction of traffic noise levels along the wayside of a highway, accurate results are not necessarily guaranteed. Accurate results depend upon the quality of the input data and the care with which the user replicates objects in the physical world with objects in the virtual world of the FHWA TNM. This study provides TNM users with the best sources for information and input data that are critical to the development of an accurate model of highway traffic noise. This report provides best practices and guidance related to:

- Sources of quality geospatial and elevation data, including advice for conducting an online search for such data,
- Traffic distributions across a multiple-lane highway,
- Noise barrier optimization, and
- Quality assurance of TNM models and noise study reports.

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Executive Summary

Federal-aid highway projects that require a traffic noise analysis must use the latest version of the Federal Highway Administration Traffic Noise Model (FHWA TNM), according to 23 CFR 772.9(a). While the FHWA TNM provides for the accurate prediction of traffic noise levels along the wayside of a highway, accurate results are not necessarily guaranteed. Accurate results depend upon the quality of the input data and the care with which the user replicates objects in the physical world with objects in the virtual world of the FHWA TNM. This study provides TNM users with the best sources for information and input data that are critical to the development of an accurate model of highway traffic noise. This report provides best practices and guidance related to:

- Sources of quality geospatial and elevation data, including advice for conducting an online search for such data,
- Traffic distributions across a multiple-lane highway,
- Noise barrier optimization, and
- Quality assurance of TNM models and noise study reports.

Sources of Quality Geospatial and Elevation Data

There is a wide range of geospatial data available to TNM users in a variety of clearinghouses, catalogs, and portals, and hosted by a broad range of partners/stakeholders, including various Federal, state, local, and tribal governments through their agencies, as well as academia and the private sector. While this study does not include a catalog of all sources for geospatial and elevation data, the study team identified *The National Map* as a good source for orthographic images, elevation, geographic names, hydrography, boundaries, transportation, structures, and land cover. *The National Map* is a collaborative effort among the United States Geological Survey and other Federal, state, and local partners to improve and deliver topographic information for the nation. Research conducted in support of this study shows that a number of state highway agencies (SHAs) and their consultants rely on *The National Map* for geospatial and elevation data for highway noise studies.

Traffic Distributions across a Multiple-lane Highway

The effects of a non-uniform traffic distribution across a multiple-lane highway are generally less than 1 dBA at typical distances from the near lane of travel. Because other factors affecting sound propagation (e.g., rows of buildings, noise barriers, tree zones, etc.) have larger effects on calculated sound levels, traffic distributions across the lanes of multiple-lane highways may be ignored for environmental noise studies prepared in support of the permitting process under the National Environmental Protection Act (NEPA). Although the effect of a non-uniform traffic distribution is small, the study team believes the effect should be considered for certain roadway geometries and receiver locations, especially during the final design stage of a highway project, when final decisions about noise barriers are made.

The recommended Best Practices for modeling non-uniform traffic distributions on a multiple-lane highway are summarized as follows:

- For NEPA noise studies, it is not necessary to model non-uniform traffic distributions for multiple-lane highways. This recommendation applies to freeway sections that are up to 12 lanes wide. While similar results likely occur for freeway sections with more than 12 lanes, such facilities were not included in the sensitivity testing.
- For final noise abatement design studies, consider modeling non-uniform traffic distributions for multiple-lane highways if all of the following conditions are met:
    - The facility is 8 general-purpose lanes or more;
    - Sound propagation occurs over soft ground;
    - There is a high percentage of heavy trucks in the vehicle mix (20% or more); and
    - The freeway is either elevated or depressed, such that intervening terrain blocks the line of sight between any number of lanes and receivers of interest.
- If traffic distributions are not available for the project, use the typical distributions that were developed for this study.
- There is no need to develop a non-uniform speed distribution for multiple-lane highways.

Noise Barrier Optimization

While every state highway agency has established a policy to identify what constitutes a feasible and reasonable noise barrier design, few have established the methods and procedures to identify the optimum noise barrier design. Consequently, the noise barrier design optimization process is one of the primary challenges for SHAs. TNM users and analysts recognize that the acoustical benefits provided by a noise barrier generally increase with increased barrier height, but only up to a point. A point of diminishing returns is met when further increases in barrier height yield little or no increase in acoustical benefit. The optimum noise barrier design is that design that provides the best balance between barrier cost and acoustical benefit. The process used to identify the optimum design is called *noise barrier optimization.*

This report reviews the current practices in use by SHAs for noise barrier optimization and presents a spreadsheet-based tool that helps TNM users determine the appropriate balance between a low-cost noise barrier design that meets the minimum acoustical requirements and a barrier design that provides the most benefits within the state's cost-effectiveness limit.

Quality Assurance

Quality assurance / quality control (QA/QC) of a product or service, such as an environmental noise assessment or a noise abatement design report, depends upon the processes and procedures that the responsible organization (SHA, engineering firm, acoustical consulting firm, etc.) has set in place. That is, quality assurance depends upon the organization's Quality Management System. This report provides guidance to those organizations looking to incorporate QA practices into highway noise studies or to enhance policies already in place, and provides examples of simple processes and/or tools that may be used for QA. The recommended processes and tools include the use of spreadsheets and special views within the FHWA TNM to verify the accuracy of vertical geometry, as well as the use of checklists to document not only the development and review of TNM object input, but also the development and review of noise study reports and noise abatement design reports.

Report Structure

This report provides Best Practices and guidance related to a range of subjects of interest to TNM users. Chapter I provides sources of quality elevation data and includes advice for TNM users when faced with conducting a search for geospatial and elevation data. In addition, it identifies best practices for distributing traffic volumes across the lanes of multiple-lane roadways and provides guidance related to the use of design hourly speeds, level-of-service speeds, and posted speed limits. Chapter II reviews the current practices for noise barrier design optimization and provides an overview of a Noise Barrier Optimization Tool to help users identify the optimum noise barrier design for a given scenario. The final chapter – Chapter III – provides best practices for quality assurance as it pertains to the development of TNM models and noise study reports.

The appendices provide supporting details including, but not limited to, a small sample of additional sources for geospatial data, compiled traffic data for the development of non-uniform traffic distributions for multiple-lane highways, tabulated sound-level results for the sensitivity analyses that were performed in support of the best practices identified in Chapter I, a sample quality assurance plan, and sample checklists for the development of noise study reports.

I. Best Practices for TNM Object Input

Introduction

The Federal Highway Administration (FHWA) released Traffic Noise Model (TNM) 1.0 in 1998 as the new generation of highway noise modeling software for use on Federal-aid projects. The FHWA has updated the software on several occasions since the initial release, with the last major update in 2004 to the current version 2.5 (version 3.0 is expected to be released in 2016). The FHWA TNM has been shown to be quite accurate for the prediction of highway traffic noise, as demonstrated by FHWA's multiple-phased model validation study that began in July 1999 and continues to this day.[1] With the release of FHWA TNM version 2.5 in 2004, the tendency of earlier versions of the FHWA TNM to over-predict noise levels at moderate to large distances over hard ground was addressed.[2] While the FHWA TNM provides for the accurate prediction of traffic noise levels along the wayside of a highway, accurate results are not necessarily guaranteed. Accurate results depend upon the quality of the input data and the care with which the user replicates objects in the physical world with objects in the virtual world of the FHWA TNM.

The FHWA provides guidance and advice on the use of the model through its webpage[3] and supporting documents, such as the FHWA TNM User's Manual, and through training courses offered by the National Highway Institute.[4] These resources provide users with basic knowledge and guidance for the routine application of the FHWA TNM for the prediction of highway traffic noise. In recognition that user practices for the input of TNM objects vary, the FHWA has undertaken additional studies to provide additional guidance and recommended best practices for special scenarios that run somewhat outside the routine application of the model. The recently released National Cooperative Highway Research Program (NCHRP) Report 791 provides recommended best practices and analysis techniques for modeling scenarios that range from structure-reflected noise to tunnel-radiated noise.[5] Although that document provides much needed guidance, it does not identify the best sources for input data or how to find the additional information that is critical to the development of an accurate model of highway traffic noise. As a result, the FHWA has undertaken the current study that builds upon the work in the prior projects, so that collectively the entire body of work will provide a comprehensive set of Best Practices for the use of the FHWA TNM.

[1] Available at: http://www.fhwa.dot.gov/environment/noise/traffic_noise_Model/model_validation

[2] Rochart, Judith L. and Gregg G. Fleming, "TNM Version 2.5 Addendum to Validation of FHWA's TNM® (TNM) Phase 1, Final Report," U.S. Department of Transportation, Federal Highway Administration, FHWA-EP-02-031 Addendum and DOT-VNTSC-FHWA-02-01 Addendum, July 2004.

[3] Available at: http://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_faqs/

[4] Available at: http://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=142051&course_no=142051&res=1#more_information

[5] Available at: http://www.trb.org/NCHRP/Blurbs/171433.aspx

Geospatial and Elevation Data Used to Develop TNM Objects

The TNM objects that describe the project geometry are familiar to TNM users and include roadways, receivers, noise barriers, rows of buildings, terrain lines, ground zones, and tree zones. An accurate model of highway traffic noise depends upon the accuracy with which users code the horizontal and vertical geometry of the project.

More often than not, project geometry within the right-of-way is developed with a high level of accuracy and is often based on survey data. Horizontal and vertical geometry are provided in the form of roadway plans, profiles, and cross-sections. While survey data always are available for highway design studies, survey data may not be available for planning studies. As a result, TNM users must find their own sources for geospatial and elevation data in these cases.

In addition, the high-quality elevation data that are developed for highway projects and based on surveys usually have limited coverage for the purposes of highway noise analysis. That is, the survey data often are limited to areas that are within the highway's existing and/or proposed right-of-way. However, highway noise analysts require geospatial and elevation data to predict traffic noise levels in the communities adjacent to highway corridors, often at distances of 500 to 1,000 feet from the project roadways. For this reason, TNM users may need to supplement the project's survey data with geospatial and elevation data from third-party sources.

The use of high-quality geospatial and elevation data is just one requirement for producing accurate results from the FHWA TNM. Before identifying sources of high-quality geospatial and elevation data, the next section provides an overview of the industry's current best practices and guidance related to topography.

Current Best Practices and Guidance Related to Topography

Tip: Do not use the lines that comprise a triangular irregular network (TIN) to digitize or create terrain lines in the FHWA TNM. The TIN is the framework used to connect elevation points. A TIN is a derivative product that can be used to create topographic contours. Users should use topographic contours to guide the creation of terrain lines in the FHWA TNM.

NCHRP Report 791 Chapter 8 provides guidance on the use of geographic features within the FHWA TNM, including best practices associated with locating the outside edge of pavement (or "equivalent" terrain line) in the horizontal plane, placing terrain lines along elevated roadways, minimum spacing for terrain lines, vertical precision for terrain lines and barrier tops, and modeling of flat-top earthen berms. It is worthwhile to highlight some of the key findings of NCHRP Report 791 that pertain to these topographic objects in the FHWA TNM.

- Terrain lines should always be placed along elevated roadways that are either on fill or on structure.
- Never place terrain lines less than 4 feet apart, especially on an intervening hill or intervening flat ground.
- Terrain lines should not be placed in an attempt to duplicate the triangular topography regions that are produced by digital terrain models.
- For noise barrier design projects, the vertical precision of terrain lines should be ±1 foot to yield noise-level results that are in the range of ±1 to ±2 dB.
- Depending upon the geometry of the intervening terrain, the vertical precision of the intervening terrain lines should be no worse than ±2 feet.
- Computed noise levels at receivers located behind barriers are extremely sensitive to the vertical precision of barrier tops – especially for sound paths that are "near grazing." As a result, the vertical precision of a barrier top should be within 1 foot.

TNM users should review NCHRP Report 791 Chapter 8 and the supporting details in Appendix G of that report to increase their understanding of the FHWA TNM's sensitivity to the vertical precision of the modeled geometry. Based on the recommendations of NCHRP Report 791, it is clear that TNM users require high-quality topographic data to ensure the accurate prediction of highway traffic noise levels and design of noise barriers. The next sections provide an overview of the National Spatial Data Infrastructure and the different types of elevation data that are available.

National Spatial Data Infrastructure (NSDI)

The Federal Geographic Data Committee (FGDC) is a 32-member interagency committee with representatives from the Executive Office of the President, along with Cabinet-level and independent Federal agencies. It was established in 1990 to promote "the coordinated development, use, sharing, and dissemination of geospatial data on a national basis." This nationwide effort is known as the National Spatial Data Infrastructure (NSDI) and is hosted by the U.S. Geological Survey (USGS).[6]

The NSDI is made up of a number of connected elements ranging from clearinghouses, catalogs, and portals, to metadata, framework data, and standards. Other elements of the NSDI include collaborative partnerships between diverse sets of stakeholders and public policies that promote a number of goals including public access to and sharing of data. One of the core elements of the NSDI

[6] See https://www.fgdc.gov/

is the development of standards for geospatial data and technology. FGDC-endorsed standards are required for use by Federal agencies.[7] At least one state highway agency (SHA) has adopted FGDC standards as recommended practice.[8] The NSDI Framework is comprised of seven themes of data designated as:

1. Cadastral data theme – refers to property interests; the custodians are the Department of the Interior (DOI) Bureau of Land Management (BLM) for land-based interests and the Bureau of Ocean Energy Management (BOEM) for offshore interests.
2. Elevation data theme – provides information about terrain and vertical positions above or below a vertical datum; the custodians are DOI USGS for terrestrial datasets and the Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA) for hydrographic datasets.
3. Geodetic data theme – provides a common reference system for establishing the coordinate positions of all geographic data; the custodian is the DOC NOAA.
4. Governmental units data theme – provides boundary information for various governmental units; the custodian is the DOC Census Bureau.
5. Hydrography data theme – includes surface water features; the custodian is the DOI USGS.
6. Orthoimagery data theme – provides georeferenced images prepared from aerial photographs; the custodian is the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA).
7. Transportation data theme – provides major common features of transportation networks; the custodian is the U.S. Department of Transportation (USDOT) Bureau of Transportation Statistics (BTS).

Types of Topographic Data

In 2014, the USGS published Circular 1399 "The 3D Elevation Program Initiative – A Call for Action"[9] as a means to achieve an overarching goal, which is to accelerate the collection of three-dimensional (3D) elevation data, in an attempt to completely refresh the National Elevation Dataset with new elevation data products and services on a nationwide basis, in a period of 8 years. This report summarizes some of Circular 1399's findings in a later section, focusing on the findings related to the existing coverage of elevation data for a given quality level. Circular 1399, Appendix 1 provides detailed definitions for different types of source data, elevation models, and derivative products.

[7] Bossler, Dr. John D., Dr. David J. Cowen, James E. Geringer, Susan Carson Lambert, John J. Moeller, Thomas D. Rust, Robert T. Welch. "Report Card on the U.S. National Spatial Data Infrastructure – Compiled for the Coalition of Geospatial Organizations." February 6, 2015.

[8] See an overview of the North Carolina Department of Transportation (NCDOT) geospatial standards and practices at https://connect.ncdot.gov/resources/gis/Pages/GIS-Standards.aspx.

[9] Sugarbaker, L.J., Constance, E.W., Heidemann, H.K., Jason, A.L., Lukas, Vicki, Saghy, D.L., and Stoker, J.M., 2014, "The 3D Elevation Program initiative—A call for action: U.S. Geological Survey Circular 1399," 35 p., http://dx.doi.org/10.3133/cir1399.

"Source data" are the raw data for elevation models and other derivative products (e.g., contours, cross-sections, profiles, etc.). Examples of source data include:

- LiDAR (light detection and ranging) is a technology that uses a pulsing laser to produce a dataset comprised of millions of points and their x-, y-, and z-coordinates from the pulse's reflection off features on the earth's surface.
- Ifsar (interferometric synthetic aperture radar) is a technology based on pulsed radio waves that analyzes differences between emitted and reflected waveforms.

"Elevation models" depict the Earth's surface and its features. Elevation models may represent a bare-earth surface, which is a surface that excludes vegetation and structures, or a surface that includes such features. Examples of elevation models include:

- Digital Elevation Model (DEM), in its most basic form, is a raster dataset of bare-earth elevations without hydrologic features. Variations on a DEM include "hydro-flattened," "hydro-enforced," and "hydro-conditioned."
- Digital Terrain Model (DTM) is a bare-earth model that includes breaklines, which are vector lines, and polygons used to define abrupt changes in topography or surface features.
- Digital Surface Model (DSM) is a raster grid of surface elevations, but includes the top of surfaces such as buildings and tree canopies.

The most familiar derivative product of the models list above is a set of topographic contours, or lines of equal elevation on the Earth's surface. Another type of derivative product is a triangulated irregular network (TIN). A TIN is a vector-based representation of a land surface, made up of irregularly distributed nodes and lines with 3D coordinates creating a network of triangles.[10]

TNM users should be aware that there are many different types of elevation datasets; some much older than others. The datasets and types of data listed above represent some of the more recent/common types of elevation data in use today. TNM users can find standard definitions and more details about the types of elevation datasets available to the public by searching the internet for the type of dataset.[11]

Having introduced some terminology and concepts related to geospatial data, the next section identifies sources of high-quality data for use in highway noise studies.

Where Can a User Find Quality Geospatial and Elevation Data?

A wide range of geospatial data exists in a variety of clearinghouses, catalogs, and portals, hosted by a broad range of partners/stakeholders, including various Federal, state, local, and tribal governments through their agencies, as well as academia and the private sector. This study does not include a catalog of all sources for geospatial and elevation data; however, the study team identified a source of high quality data elevation data available to the public and provided examples of other reliable sources of data from state governmental agencies. See the end of this chapter for tips for conducting a search for other geospatial and elevation data.

[10] "Triangulated irregular network" on https://en.wikipedia.org/wiki/Triangulated_irregular_network.

[11] Some useful sites that provide more detailed information about elevation datasets include:
http://en.wikipedia.org/wiki/GIS_file_formats
https://www.e-education.psu.edu/geog480/node/513
http://www.gislounge.com/overview-of-elevation-data/

The National Map

The National Map is a collaborative effort among the USGS and other Federal, state, and local partners to improve and deliver topographic information for the nation. *The National Map* contains a broad range of geospatial data and information including: orthographic images, elevation, geographic names, hydrography, boundaries, transportation, structures, and land cover.[12] Research conducted in support of this study indicates that a number of SHAs and their consultants rely on *The National Map* for geospatial and elevation data for highway noise studies.[13]

For more than 15 years, the USGS has offered a variety of elevation data products and services through the National Elevation Dataset (NED), which was the elevation layer for *The National Map*. The USGS derived the NED from diverse source datasets processed to a specification with consistent resolutions, coordinate system, elevation units, and horizontal and vertical datums (refer to Table I-1). Elevation data contained within the NED were typically represented as topographic contour lines and bare earth DEMs. In 2015, the USGS incorporated new sources of elevation data (LiDAR and Ifsar) into *The National Map* through the 3D Elevation Program (3DEP) initiative. As a result of the transition to 3DEP, the USGS now provides source LiDAR point clouds, Ifsar DSMs, and orthorectified radar intensity images (ORIs) over certain areas of the country.[14] The data holdings of the NED have been incorporated into the 3DEP, and as a dataset and system, the NED has been retired.[15]

Table I-1. Specification for the National Elevation Dataset

Coordinate System	Geographic (decimal degrees of latitude and longitude)
Horizontal Datum	North American Datum of 1983 (NAD 83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD 88) over the conterminous United States and varies in other areas
Elevation Units	Decimal meter

Source: Gesch, D., Evans, G., Mauck, J., Hutchinson, J., Carswell Jr., W.J., 2009, The National Map—Elevation: U.S. Geological Survey Fact Sheet 2009-3053, 4 p.

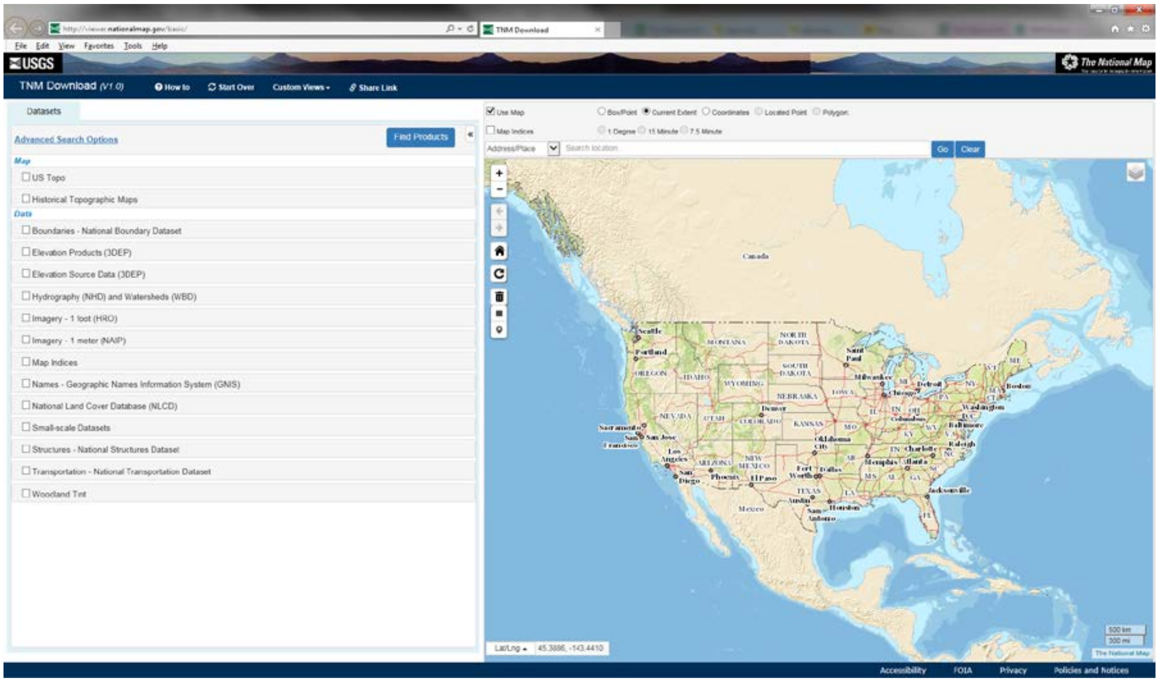
[12] See http://nationalmap.gov/about.html

[13] Users of the FHWA TNM in Massachusetts, Montana, and Tennessee identified *The National Map* as a source of geospatial data for highway projects.

[14] See http://nationalmap.gov/elevation.html

[15] See http://nationalmap.gov/3DEP/3dep_transition.html

Figure I-1 shows a screen-shot of *The National Map* Viewer and Download Platform,[16] which allows visualization and download of the most current topographic base map and products free of charge. Various data themes of geospatial data are available for download, including: boundaries (National Boundary Dataset), elevation products (3DEP), elevation source data (3DEP), hydrography and watersheds, imagery (1-foot), imagery (1-meter), map indices, geographic names (Geographic Names Information System), structures (National Structures Dataset), transportation (National Transportation Dataset), and woodland tint.



Source: http://viewer.nationalmap.gov/basic/.

Figure I-1. *The National Map* Download Client (v1.0)

The next section provides background on the 3DEP initiative and insight into the ongoing development of the elevation dataset layer in *The National Map*.

The 3D Elevation Program (3DEP)

As discussed in USGS Circular 1399, the 3DEP initiative serves to accelerate the collection of 3D elevation data and update the NED with new elevation data products and services within an 8-year timeframe. The initiative strives to replace elevation data older than 30 years old, on average, with newly created elevation data derived from LiDAR and Ifsar technologies. The success of the initiative depends upon a number of factors, not the least of which is the participation of cooperating agencies from Federal, state, and tribal governments.

[16] The National Map Viewer may be found at http://viewer.nationalmap.gov/basic.

Figure I-2 (taken from USGS Circular 1399) serves to illustrate the current task. It shows a map of the U.S. with the status of the NED as of May 2014. It shows that elevation data (DEMs) based on LiDAR technology is available for only 26 percent of the conterminous United States (CONUS), Hawaii, and U.S. territories, while Alaska has DEMs based on Ifsar technologies covering 37 percent of the state. The aforementioned rates of coverage are for DEMs obtained from LiDAR and Ifsar datasets covering the full range of Quality Levels.[17] The goal of the 3DEP initiative is to obtain full coverage for the CONUS at a Quality Level of 2 or better by 2022. As of the publication of USGS Circular 1399, only 4 percent of the CONUS, Hawaii, and U.S. territories had LiDAR data that met the desired Quality Level.

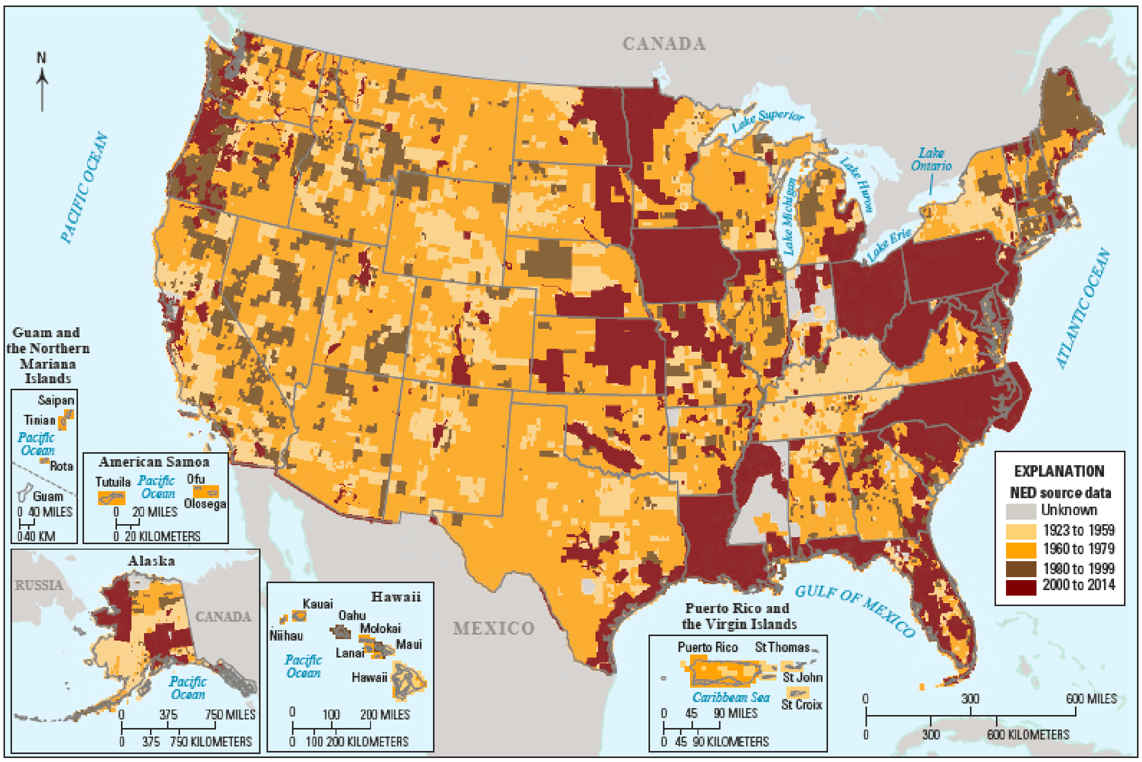


Figure 2. Map of the United States showing the status of the National Elevation Dataset (NED) as of May 2014. The NED is maintained by the U.S. Geological Survey (USGS) at multiple resolutions for the United States. Generally, digital elevation models (DEMs) are derived from light detection and ranging (lidar) data acquired after 2000, which are available for 26 percent of the conterminous United States, Hawaii, and the U.S. territories. Alaska has DEMs derived from interferometric synthetic aperture radar (ifsar) data for about 37 percent of the State. The remaining areas have coarser resolution DEMs created prior to 2000 from contours on scanned USGS topographic maps.

Source: USGS Circular 1399

Figure I-2. Status of the National Elevation Dataset (NED) as of May 2014

[17] Elevation data Quality Levels (QL) for the 3DEP initiative range from QL1 to QL5, with a QL1 designation representing the highest level of accuracy for elevation data. These data Quality Levels are in terms of four parameters. One parameter is the vertical error in elevation datasets, defined in terms of the root mean square error in the z- dimension ($RMSE_z$), which ranges from 10 centimeters for QL1 to 185 centimeters for QL5. Another parameter is the DEM cell size, which ranges from 0.5 meters for QL1 to 5 meters for QL5. The goal of the 3DEP initiative is to achieve a data quality level of QL2 nationally by 2022. The specifications for QL2 include an $RMSE_z$ of 10 centimeters and a DEM cell size of 1 meter.

Clearly there is still work to be done if the USGS and its cooperating agencies are to meet the goals of the 3DEP initiative. Nevertheless, based on the progress made to date, the study team believes that *The National Map* and the 3DEP dataset are a reliable source for high-quality geospatial and elevation data. If the goals of the 3DEP initiative are met, *The National Map* will very likely represent the largest collection of high-quality elevation data for the CONUS, Hawaii, U.S. territories, and Alaska.

State Agencies

A broad range of partners and stakeholders including various Federal, state, local, and tribal governments through their agencies, as well as academia and the private sector, provide geospatial and elevation data through a variety of clearinghouses, catalogs, and portals. *The National Map* Viewer and Download Platform is one example of a clearinghouse for geospatial and elevation data. The study team conducted research to identify what other sources of geospatial and elevation data may be available from agencies at other levels of government. Additionally, the study team obtained information from the Transportation Research Board (TRB) Committee ADC-40 on Transportation-Related Noise and Vibration and the American Association of State Highway Transportation Officials (AASHTO) Noise Work Group about sources of geospatial and elevation data used by participating SHAs.

Table B-1 in Appendix B contains a list of sources for geospatial and elevation data used by various SHAs across the country provided by TRB ADC-40 and the AASHTO Noise Work Group. Table B-1 shows information provided by SHAs from Florida, Kansas, Massachusetts, Montana, New Hampshire, Ohio, Tennessee, Virginia, and Washington.

Many states, such as Massachusetts, have independent departments or offices that coordinate activities within the state. MassGIS is the Commonwealth's Office of Geographic Information, within the Massachusetts Office of Information Technology of the Administration and Finance Secretariat. The Massachusetts Legislature established MassGIS as the official state agency assigned to the collection, storage, and dissemination of geospatial data.

Table B-2 in Appendix B contains additional sources of geospatial and elevation data obtained by the study team through a series of systematic searches on the internet, using official state websites as a starting point in each case. The online searches indicated that in a few cases, SHAs are sources of geospatial and elevation data within a state. In other cases, a state's Department of Natural Resources is a source of geospatial and elevation data.

Table I-2 provides a brief listing of additional sources for geospatial data.

Table I-2. Additional Sources for Geospatial Data

Environmental Systems Research Institute (ESRI)	http://www.esri.com/data/find-data (ESRI is an international supplier of GIS software and applications. ESRI products are available at different levels of licensing. Access to GIS content on the ESRI website requires an online subscription.)
Open Topography	OpenTopography is supported by the National Science Foundation under Award Numbers 1226353 & 1225810 http://www.opentopography.org/index.php
USDA Geospatial Data Gateway (GDG)	http://datagateway.nrcs.usda.gov/
US Census Bureau TIGER/Line® Shapefiles and TIGER/Line Files	https://www.census.gov/geo/maps-data/data/tiger-line.html
USGS Earth Resources Observation and Science (EROS) Center	https://eros.usgs.gov/find-data

Tips for TNM Users When Conducting a Search for Geospatial Data

TNM users may be faced with the possibility of having to conduct an online search for geospatial data – especially if they are working on a highway project in a region unfamiliar to them. Below are tips for conducting such searches.

- Check with your project's technical lead at the SHA.
- Search for local agencies that provide geospatial data – start with agencies at the Town, District, and County level. Then, look for agencies at the State level. Some states, like Massachusetts, require towns to submit data to a central geographic data holding, which the state makes available to the public (e.g., through MassGIS).[18]
- Search for information on websites hosted by state agencies that routinely use geospatial data, such as: SHAs, Conservation Commissions, Planning Commissions, Departments of Natural Resources, Redevelopment Authorities, etc.
- Search University Geographic Libraries – some universities provide geospatial data to the public – at times free of charge.
- Use GIS-specific key words and acronyms when searching.
- Know the coordinates for the geographic extent of your highway project, as well as the named geographic location.
- Know the coordinate system, as well as the horizontal and vertical datums for your project.

Geospatial data are available in a range of formats. If data are not available in the preferred format, be prepared to convert the data to other formats, as needed. Most GIS- and CAD-based applications can handle a range of data formats and can convert data from one format to another.

[18] See: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/about-massgis/whatis.html

Traffic Distribution across the Travel Lanes of a Multiple-lane Highway

This section identifies best practices for dividing traffic volumes and vehicle mixes across roadways with multiple lanes. In developing the best practices, the study team modeled a variety of scenarios to test for changes in calculated TNM sound-level results attributable to changes in traffic distributions across multiple lanes. The study team used the FHWA TNM to model 4-, 8-, and 12-lane limited access highway facilities and tested the sensitivity of TNM-calculated sound levels to a non-uniform distribution of vehicle volumes / mixes across multiple lanes. As detailed in a later section, the study team derived a typical non-uniform traffic distribution from traffic counts obtained by the Volpe Center during the Phase 1 TNM Validation Study. This research compared TNM sound-level results for the non-uniform traffic distribution to a reference case with even distribution of vehicle volumes and mixes across all lanes of travel. Additional scenarios tested the sensitivity of the FHWA TNM to traffic data input (volume, mix, and speed), focusing on Level of Service (LOS) based approaches compared to approaches using design hourly volumes.

Before describing the process used to develop the recommended best practices, the following section reviews the status of the current best practices related to modeling multiple-lane highways in the FHWA TNM.

An Overview of Current Best Practices and Guidance Related to Multiple-lane Highways

NCHRP Report 791 Chapter 6 provides guidance and recommendations related to modeling techniques for multiple-lane highways using the FHWA TNM. The evaluation of the candidate modeling techniques included comparisons of modeled sound-level results to measurement data obtained by the Volpe Center as part of the Phase 1 TNM Validation Study. The study evaluated three modeling techniques to account for the effects of the roadway shoulder and the “outer” diffracting edge created by the edge of pavement and/or the edge of the shoulder and considered the effects of grouping the lanes on a multiple-lane highway as an alternative to modeling individual lanes. It is worthwhile to highlight some of the key findings of NCHRP Report 791 Chapter 6:

- Other factors affecting sound propagation from a highway (pavement type, noise barriers, ground type, terrain features, rows of buildings, etc.) affect predicted noise levels more than the method used to model the lanes of a multiple-lane highway.
- Analysis of 4-lane lane facilities resulted in insignificant differences between the modeling techniques using “grouped” lanes and the modeling technique using individual lanes.
- When using the group-lane technique on 8-lane lane facilities, the grouped-lane technique under-predicted computed noise levels, compared to the individual lane technique, for receivers located close to and lower than the highway elevation.

The recommended best practices for modeling multiple-lane highways cited in NCHRP Report 791 are to:

- Model each travel lane separately when receptors are located below the elevation of the highway.
- Model individual lanes when there are any intervening objects in the sound propagation path that block the line of sight between the roadway and receiver.

- Consider the super-elevation of the highway and model individual lanes with their proper elevation.
- Use "pavement" as default ground type in the FHWA TNM to avoid inadvertently locating strips of soft ground between travel lanes, or between travel lanes and the shoulder.
- Provide an overlap of 0.1 to 1.0 feet between travel lanes and between travel lanes and the shoulder.
- Use a "dummy lane"[19] for modeling the shoulder of a roadway and for locating the diffracting edge of the roadway.
- If available, use separate profiles to determine the elevation of each travel lane (and the shoulders) for roadway sections that are super-elevated.

The above best practices were based upon the calculated TNM sound-level results for a "generic" project, consisting of a 4,000-foot long divided highway with a level grade, a paved median and shoulders, with directional volumes of 2,000 automobiles, 200 medium trucks, and 200 heavy trucks, all traveling at a speed of 60 miles per hour (mph). The individual-lane scenarios considered an even distribution of traffic volumes across multiple lanes of travel.[20]

This study built upon the best practices described in NCHRP Report 791 and examined the effects of a non-uniform traffic distribution across a multiple-lane highway. The next section describes the steps taken to develop a "typical" non-uniform traffic distribution for use in the evaluation.

Development of a Typical Traffic Distribution

This analysis required traffic distribution across lanes for 4-, 8-, and 12-lane highways for all traffic and by vehicle class. Traffic distribution has significant local variability, and traditional sources such as the "Highway Capacity Manual (HCM)" do not discuss this issue in sufficient detail.[21] The study team used the volume counts collected by the Volpe Center for the Phase 1 TNM Validation Study to derive the needed traffic distributions. These data consist of actual 5-minute volume counts collected at eight 4-lane highway locations, nine 8-lane highway locations, and two 12-lane highway locations that include six, one, and zero rural locations, respectively, with the balance being conducted in urban areas. These volume counts classify vehicles as auto, medium truck, heavy truck, bus, or motorcycle. The study team judged these data as the best available set of data for the objectives of this study.

Conducting the analysis required determination of traffic distributions for each 5-minute time interval. The first step in this process required determining the distribution of several grouped vehicle classes by lane for each time interval. These groups included: auto and motorcycle; medium truck and bus; heavy truck only; medium truck, heavy truck, and bus; and all vehicle classes. The next step involved averaging these distributions for each highway across all time intervals to develop representative traffic distributions of each vehicle class group for 4- and 8-lane highways (urban, rural, and overall) and 12-lane highways (urban only). For example, for a rural 4-lane highway, the representative traffic distribution indicates that 59 percent of autos and motorcycles are in the outside lane and 41 percent

[19] A "dummy lane" is a TNM roadway without traffic. The width of the dummy lane is modeled such that the outer edge of the lane defines the diffracting edge of the roadway.

[20] See Appendix E of Report 791.

[21] Transportation Research Board, "Highway Capacity Manual," National Research Council, Washington, D.C., 2000.

are in the inside lane, with similar values available for the other highway types and vehicle class groups mentioned.

The study team also examined traffic distributions for 4- and 8-lane highways for facilities with lower and higher truck volumes and used truck percentages on the 4-lane highways (7-34%) and 8-lane highways (6-19%) to identify the facilities as having lower or higher truck volumes. Next, the team determined representative traffic distributions for the same vehicle class groups listed above for 4- and 8-lane highways with lower truck volumes (average of 10% and 8% trucks, respectively) and higher truck volumes (average of 29% and 16%, respectively). As a point of reference, the "2013 FHWA Freight Facts and Figures"[22] references 4.3 percent and 25 percent as a typical and a high truck percentage, respectively.

Finally, the study team determined traffic distributions needed to simulate rural and urban 4- and 8-lane highways with zero trucks in the vehicle mix. To do this, the team applied the HCM passenger car equivalent (PCE) conversion factor of 1.5 to the truck vehicle classifications in the Volpe dataset and summed these new volumes by lane for each time interval, and for each time interval the proportion of traffic for each lane was calculated and averaged across all time intervals to derive a representative traffic distribution for 4- and 8-lane highways without trucks.

The two 12-lane highways in the Volpe dataset each have managed high-occupancy vehicle lanes. However, it was desirable to derive a representative traffic distribution for a 12-lane facility that was all general-purpose lanes. Because the innermost lane will generally have lower traffic volumes, data from the fifth lane was used to derive an estimate. Rather than simply duplicate the values from the fifth lane, new values were derived for the fifth and six lanes by multiplying the original volumes for the fifth lane by 1.1 and 0.9, respectively.

Appendix C summarizes the traffic distributions derived from the Volpe data in tabular format. The traffic distributions in the appendix provide the basis for the test cases described in the next section.

Finally, the HCM and AASHTO's Green Book[23] provided representative LOS and speed values for rural and urban 8-lane highways, as shown in Table I-3. The speeds in the table are those used to conduct additional TNM sensitivity analyses for the 8-lane scenario.

[22] See: http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/13factsfigures/pdfs/fff2013_highres.pdf

[23] American Association of State Highway and Transportation Officials. (2011). A Policy on Geometric Design of Highways and Streets. Washington, D.C.

Table I-3. Representative Vehicle Speeds for an 8-Lane Highway

8-lane Freeway	Rural	Urban	Notes
Design Hour Factor (K-factor)	15%	9%	K-factor assumed for rural and urban; the Design Hourly Volume (DHV) is given by: DHV = K x ADT
Design Speed in mph	70 or 75	65	Select corresponding rural value for design speed as typical posted speed
LOS (C/D) Volume (pc/h/direction)	6,800	6,200	Passenger car equivalent is 1.5 trucks per 1 car
LOS (C/D) Speed in mph	68	60	Assumed 12' lanes, 6' shoulders, and 1 rural/2 urban interchanges per mile
Typical Posted Speeds in mph	65 or 70	55	

Source: Based on the Highway Capacity Manual, 2000

Notes: ADT = average daily traffic.

Scenarios to Quantify the Effects of a Non-uniform Traffic Distribution

In developing the scenarios to test the FHWA TNM's sensitivity to a non-uniform traffic distribution, the study team followed the NCHRP Report 791 best practices for multiple-lane highways as a starting point. In particular, the scenarios made use of dummy lanes to model the outer and inner shoulders of each multiple-lane highway. Each scenario also provided 0.1-foot overlaps between adjacent travel lanes and between travel lanes and shoulders, along with a 10-foot median. Each "test" scenario for a non-uniform traffic distribution was compared to the reference scenario, which simply consisted of a uniform vehicle distribution across the lanes of travel.

In developing the modeling scenarios, the study team focused on the distribution of traffic across general-purpose lanes and did not include high occupancy vehicle (HOV) lanes, collector-distributor roads, or ramps. Traffic volumes and vehicle mixes for these other types of travel lanes typically originate from the traffic study for a highway project. TNM users do not routinely develop traffic data for such types of travel lanes.

Figure I-3 shows the cross-sectional geometry for the 4-lane at-grade highway configuration along with the lane designations used in this study. Following the convention shown in the figure, Lane 1 is the outermost lane or the rightmost lane in the direction of travel. Lanes 2 to 4 are additional travel lanes located to the left of Lane 1, when in the direction of travel. Figure I-3 also shows the locations of the shoulders ("s") and median ("m"), as well as the 5-foot receiver at a distance of 50 feet from the near lane of travel.

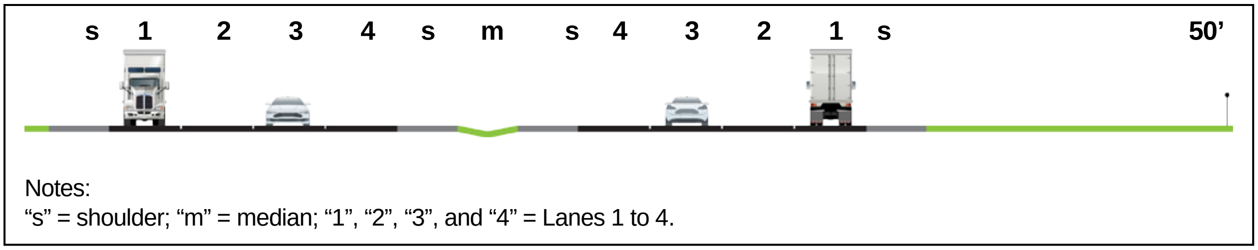


Figure I-3. Cross-sectional Geometry and Lane Designations for the 8-lane at-grade Divided Highway with Shoulders, Median, and the 5-foot Receiver at a Distance of 50 Feet from the Centerline of the Near Travel Lane

The modeled scenarios are described as follows:

- Three lane configurations, including 4-, 8-, and 12-lane limited-access highway facilities:
  - 4,000-foot long roadway segment with zero-percent grade and average pavement,
  - 12-foot lanes, 10-foot shoulders, and a 10-foot median,
  - “Dummy lanes” for shoulders,
  - Uniform speeds across all travel lanes, and
  - Directional split of 50%/50%.
- Three cross-sectional geometries: (i.) roadway at-grade; (ii.) depressed roadway (20 feet below grade); and (iii.) elevated roadway (20 feet above grade)
- One 11 x 2 matrix of receivers for each cross-section geometry:
  - At 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 feet from centerline of near lane of travel,
  - Two different heights: 5 and 15 feet above ground level (AGL).
- Two different ground types:
  - Default ground type “pavement” with a “lawn” ground zone located beyond the outside edge of the shoulder (i.e., at the receiver locations),
  - “Hard” ground everywhere.
- Different percentages of heavy trucks in the vehicle mix: 0% trucks, a “typical” percent of trucks (4.3%), and a “high” percent of trucks (25%).

Figure I-4 shows TNM cross-section views of the modeled geometry for each of the three scenarios developed for a 4-lane highway facility: (i.) highway at-grade; (ii.) depressed highway; and (iii.) elevated highway. [24] Note that the 4-lane highway is configured from left to right in the figure, as follows:

- The near direction of travel consists of one (1) outer shoulder, two (2) general-purpose lanes, and one (1) inner shoulder.
- The far direction of travel consists of one (1) inner shoulder and two (2) general-purpose lanes.

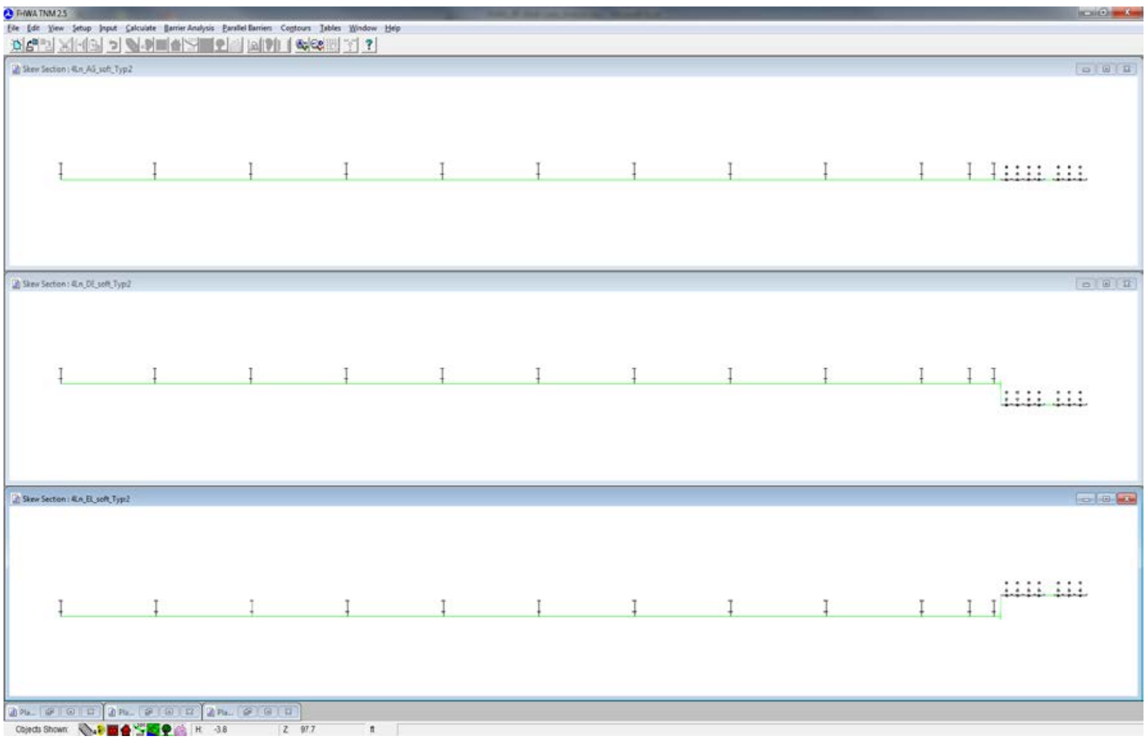


Figure I-4. TNM Cross-section Views showing the Modeled Geometry for the 4-lane Facility

[24] The TNM 2.5 runs also included a receiver at a distance of 25 feet from the centerline of the near lane of travel. The TNM results for that receiver location are not presented in this report, because the study team felt that, in the end, the 25-foot receiver location was not representative of a "real world" scenario.

Table I-4 shows the non-uniform traffic distributions used in the scenarios for the 4- and 8-lane highways, while

Table I-5 shows the traffic distributions for the 12-lane highway. These distributions were based on an analysis of the traffic data that were collected by the Volpe Center for the Phase 1 TNM Validation Study.

Table I-4. Non-uniform Traffic Distributions for 4- and 8-lane Facilities

With a Typical Truck Percentage in the Traffic Flow						
Facility:	**4-lane**		**8-lane**			
Lane:	**1**	**2**	**1**	**2**	**3**	**4**
Lane % MT+Bus	81.8	18.2	38.1	40.5	17.3	4.1
Lane % HT	76.9	23.1	49.4	35.8	11.8	3.1
Lane % Trucks	77.7	22.3	44.2	38.5	13.7	3.6
Lane % Car	53.0	47.0	30.4	26.5	29.1	14.0
% Total Traffic	55.3	44.7	31.5	27.6	27.8	13.1
With a High Truck Percentage in the Traffic Flow						
Facility:	**4-lane**		**8-lane**			
Lane:	**1**	**2**	**1**	**2**	**3**	**4**
Lane % MT+Bus	82.8	17.2	49.0	32.3	14.9	3.8
Lane % HT	74.7	25.3	38.1	52.7	9.0	0.2
Lane % Trucks	76.0	24.0	41.6	45.8	11.2	1.4
Lane % Car	55.3	44.7	32.4	26.5	27.4	13.7
% Total Traffic	60.6	39.4	33.7	29.6	25.0	11.7

Table I-5. Non-uniform Traffic Distributions for 12-lane Facilities

With a Typical Truck Percentage in the Traffic Flow						
Lane:	**1**	**2**	**3**	**4**	**5**	**6**
Lane % MT+Bus	17.8	18.1	34.9	25.7	1.9	1.7
Lane % HT	8.3	17.1	37.1	34.1	1.9	1.6
Lane % Trucks	10.8	17.5	36.8	31.3	1.9	1.7
Lane % Car	12.1	16.0	22.4	21.6	15.1	12.9
% Total Traffic	12.0	16.1	23.7	22.3	13.9	11.9

Results: Effect of a Non-uniform Traffic Distribution using FHWA TNM 2.5

Figure I-5 through Figure I-8 present the effects of a non-uniform traffic distribution on TNM-calculated sound levels. The graphs summarize the sound-level differences between the uniform and non-uniform traffic distributions for 4-, 8-, and 12-lane highway facilities with cross-sectional geometries that are at-grade ("AG"), depressed ("DE"), and elevated ("EL"). FHWA TNM version 2.5 calculated all results depicted in Figure I-5 through Figure I-8. The following observations are made about the effects of a non-uniform traffic distribution for a multiple-lane highway:

- In general, the effect is negligible at most distances from the roadway.
- For all of the scenarios considered, the effect of a non-uniform traffic distribution ranges from 0.8 to +1.2 dBA.
- For most scenarios, the greatest effect occurs at 50 feet from the centerline of the near lane of travel.
- In general, the effect of a non-uniform traffic distribution is greatest with a high percentage of trucks in the vehicle mix and over soft ground.
- For 8-lane highways, the greatest effect occurs over intermediate distances with soft ground and a high truck percentage.
- For 12-lane highways, the TNM-calculated noise levels for a non-uniform distribution are consistently, albeit fractionally, greater than the noise levels for a uniform distribution at distances of 100 feet, or more, from the near lane of travel.

Appendix D includes tabulated sound-level results for all of the scenarios depicted in Figure I-5 through Figure I-8.

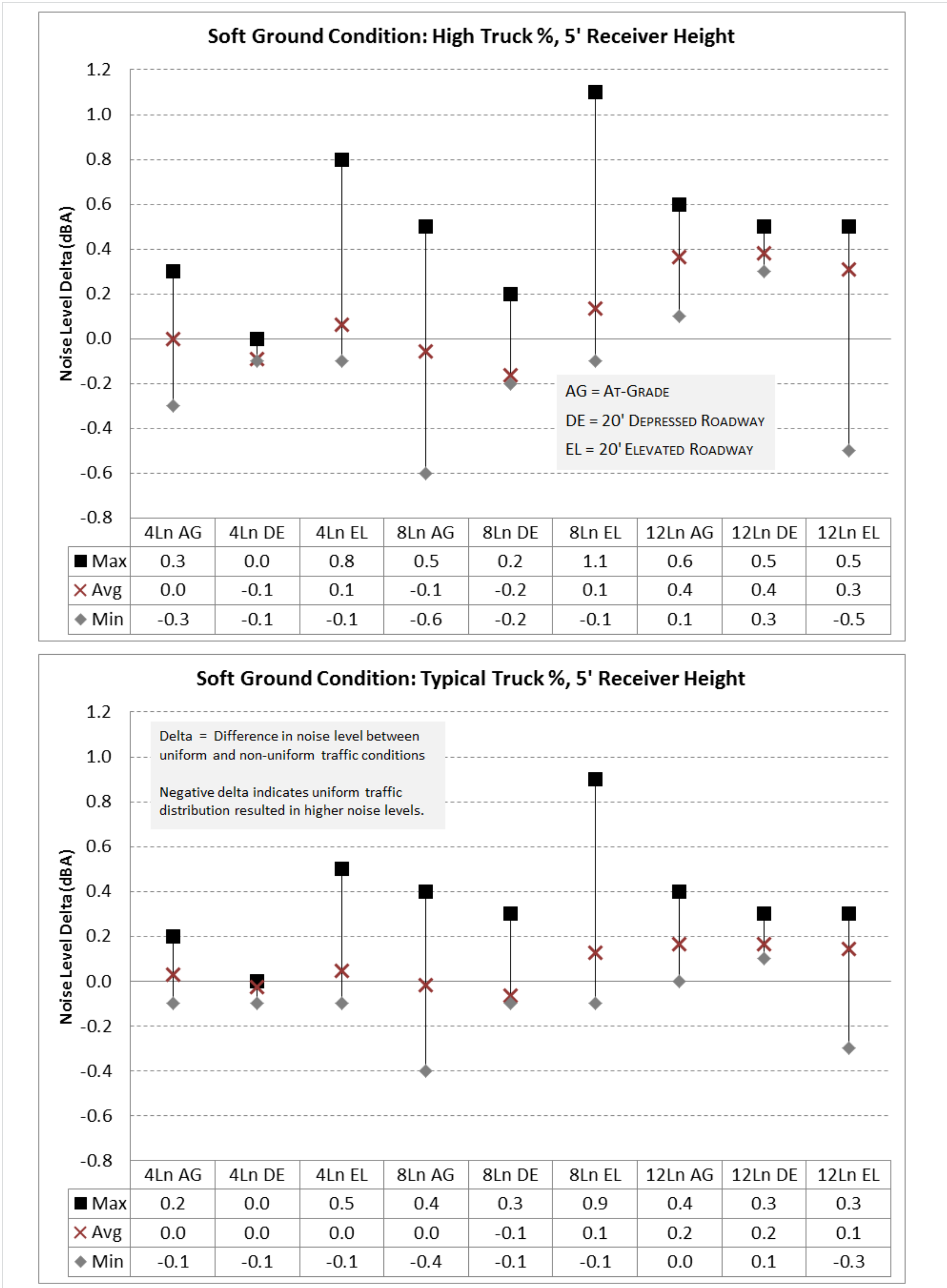
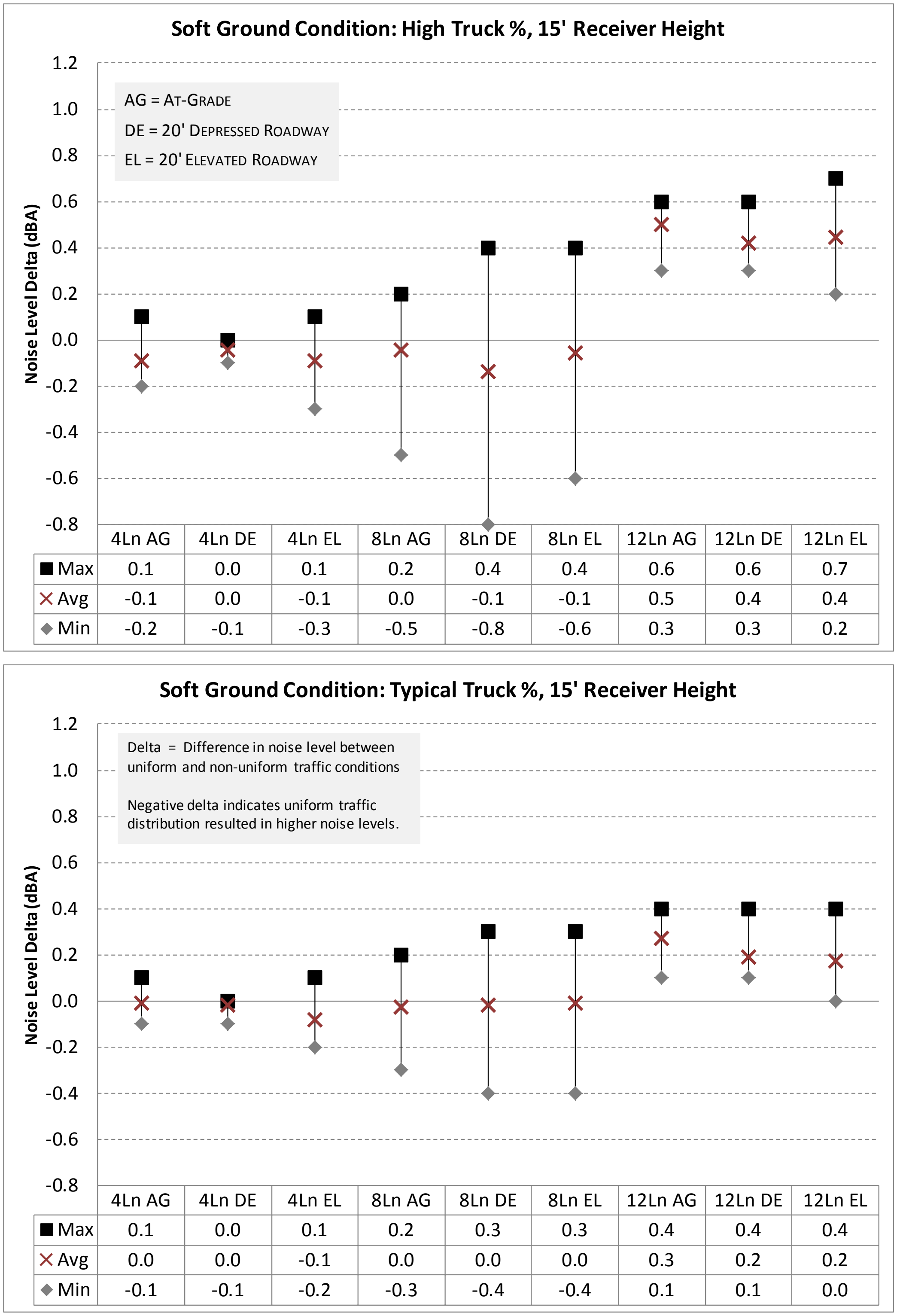


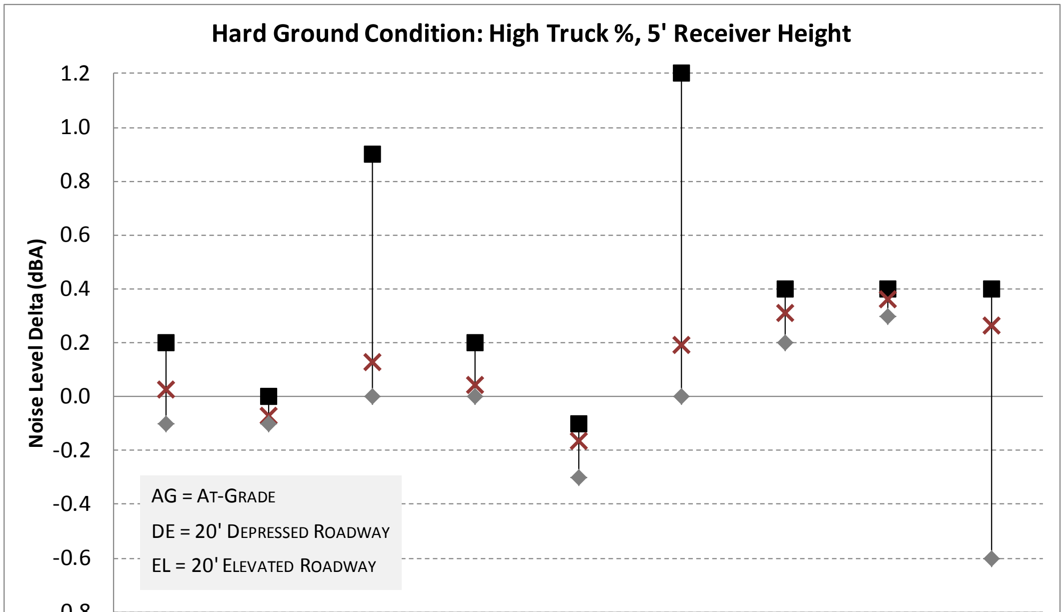
Figure I-5. Effects of a Non-uniform Traffic Distribution for Soft Ground and 5-foot Receiver Height



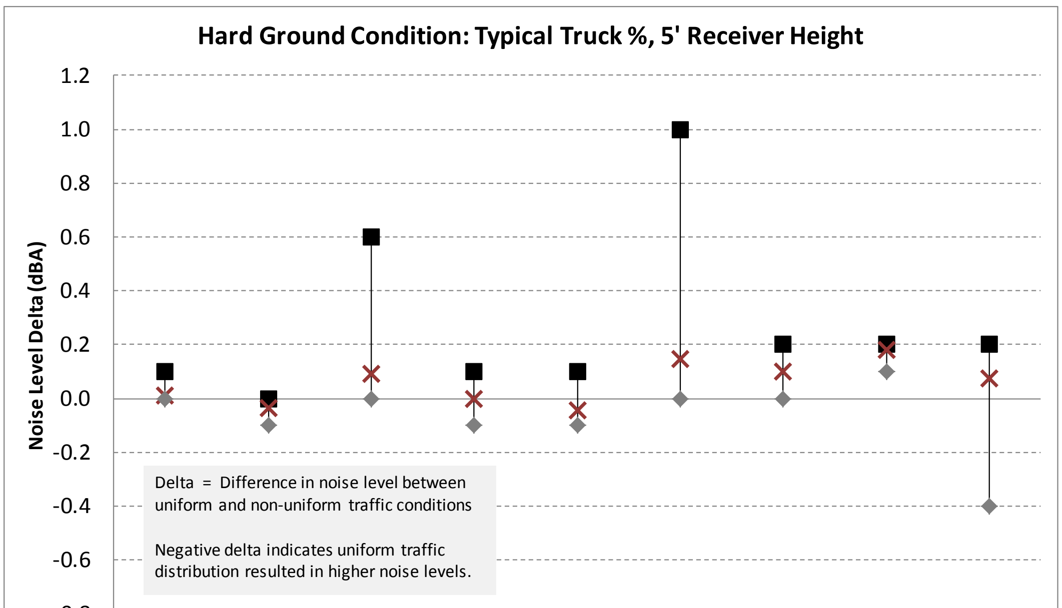
	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
Max	0.1	0.0	0.1	0.2	0.4	0.4	0.6	0.6	0.7
Avg	-0.1	0.0	-0.1	0.0	-0.1	-0.1	0.5	0.4	0.4
Min	-0.2	-0.1	-0.3	-0.5	-0.8	-0.6	0.3	0.3	0.2

	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
Max	0.1	0.0	0.1	0.2	0.3	0.3	0.4	0.4	0.4
Avg	0.0	0.0	-0.1	0.0	0.0	0.0	0.3	0.2	0.2
Min	-0.1	-0.1	-0.2	-0.3	-0.4	-0.4	0.1	0.1	0.0

Figure I-6. Effects of a Non-uniform Traffic Distribution for Soft Ground and 15-foot Receiver Height

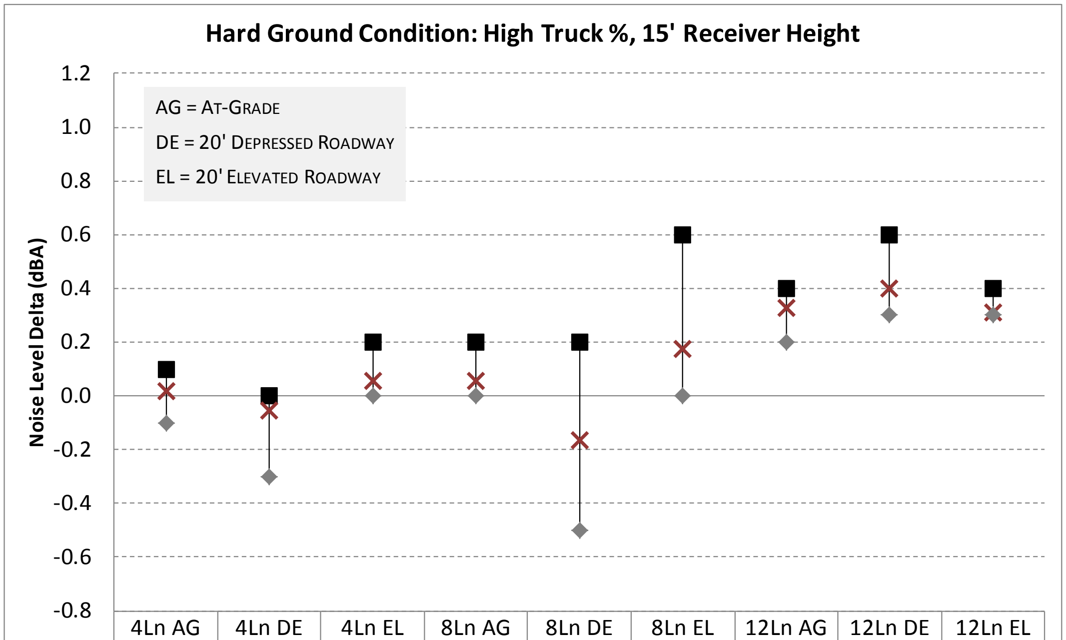


	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
■ Max	0.2	0.0	0.9	0.2	-0.1	1.2	0.4	0.4	0.4
× Avg	0.0	-0.1	0.1	0.0	-0.2	0.2	0.3	0.4	0.3
◆ Min	-0.1	-0.1	0.0	0.0	-0.3	0.0	0.2	0.3	-0.6

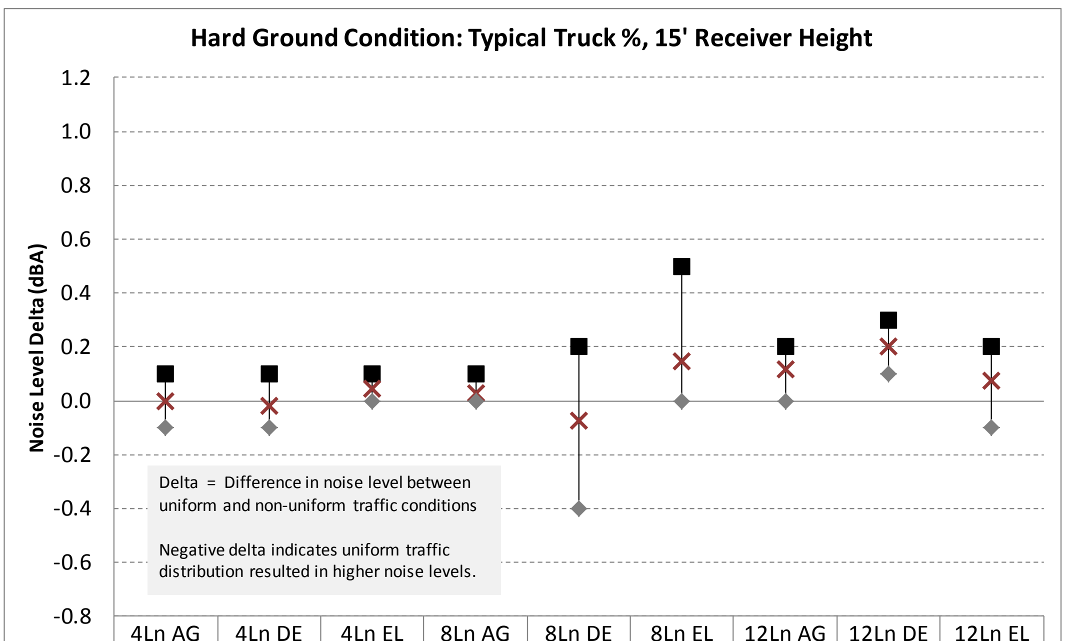


	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
■ Max	0.1	0.0	0.6	0.1	0.1	1.0	0.2	0.2	0.2
× Avg	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.1
◆ Min	0.0	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.1	-0.4

Figure I-7. Effects of a Non-uniform Traffic Distribution for Hard Ground and 5-foot Receiver Height



	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
■ Max	0.1	0.0	0.2	0.2	0.2	0.6	0.4	0.6	0.4
× Avg	0.0	-0.1	0.1	0.1	-0.2	0.2	0.3	0.4	0.3
◆ Min	-0.1	-0.3	0.0	0.0	-0.5	0.0	0.2	0.3	0.3



	4Ln AG	4Ln DE	4Ln EL	8Ln AG	8Ln DE	8Ln EL	12Ln AG	12Ln DE	12Ln EL
■ Max	0.1	0.1	0.1	0.1	0.2	0.5	0.2	0.3	0.2
× Avg	0.0	0.0	0.0	0.0	-0.1	0.1	0.1	0.2	0.1
◆ Min	-0.1	-0.1	0.0	0.0	-0.4	0.0	0.0	0.1	-0.1

Figure I-8. Effects of a Non-uniform Traffic Distribution for Hard Ground and 15-foot Receiver Height

Results: Effect of a Non-uniform Traffic Distribution using FHWA TNM 3.0

The calculated sound-level results summarized in the previous section came from scenarios modeled in FHWA TNM version 2.5. The study team also used a beta version of FHWA TNM 3.0 to check the consistency of its sound-level results with version 2.5 and found that the effect of a non-uniform traffic distribution using FHWA TNM 3.0 resulted in a close match with the effect using FHWA TNM 2.5, as demonstrated by the graphs of Figure I-9 and Figure I-10 for a 12-lane facility. While the figures show very good agreement between version 2.5 and 3.0, note that the “effects of non-uniform traffic distributions” show the difference between TNM-calculated sound levels for a non-uniform case and a uniform traffic distribution. The study team noted poor agreement when comparing the absolute sound levels calculated by each model for sound propagation over soft ground. In general, FHWA TNM 3.0-calculated sound levels lower than FHWA TNM 2.5-calculated sound levels by up to 8 dB, or approximately 2.6 dB, on average. Absolute sound levels calculated with FHWA TNM 3.0 showed better agreement with FHWA TNM 2.5 for sound propagation over hard ground. FHWA TNM 3.0 sound levels ranged from 0.4 to +0.3 dB relative to FHWA TNM 2.5 sound levels.

Testing with FHWA TNM 3.0 evaluated only the 12-lane scenarios. The study team expects similar results would be obtained for the 4- and 8-lane scenarios.

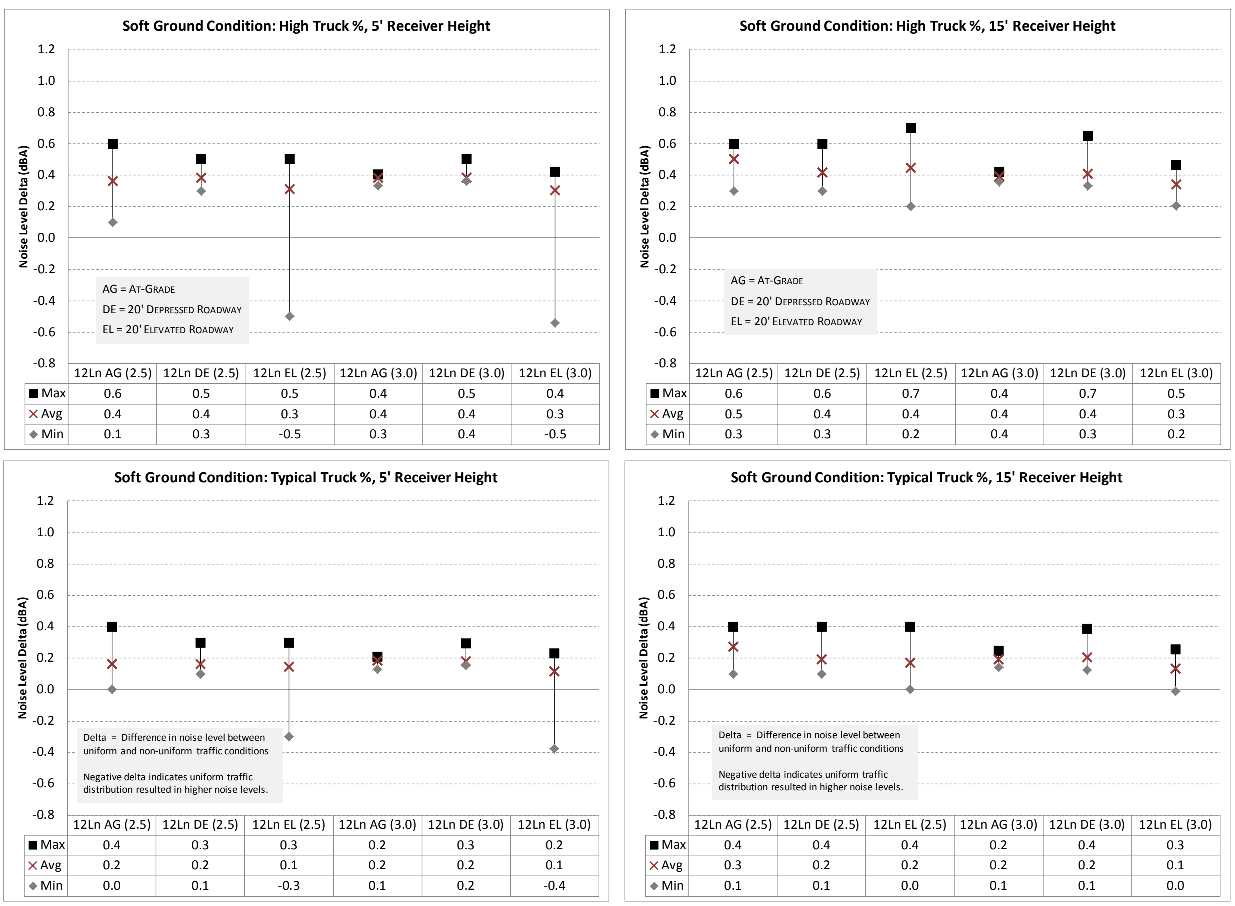


Figure I-9. Comparison of TNM 3.0 and TNM 2.5 Results for a 12-lane Highway over Soft Ground

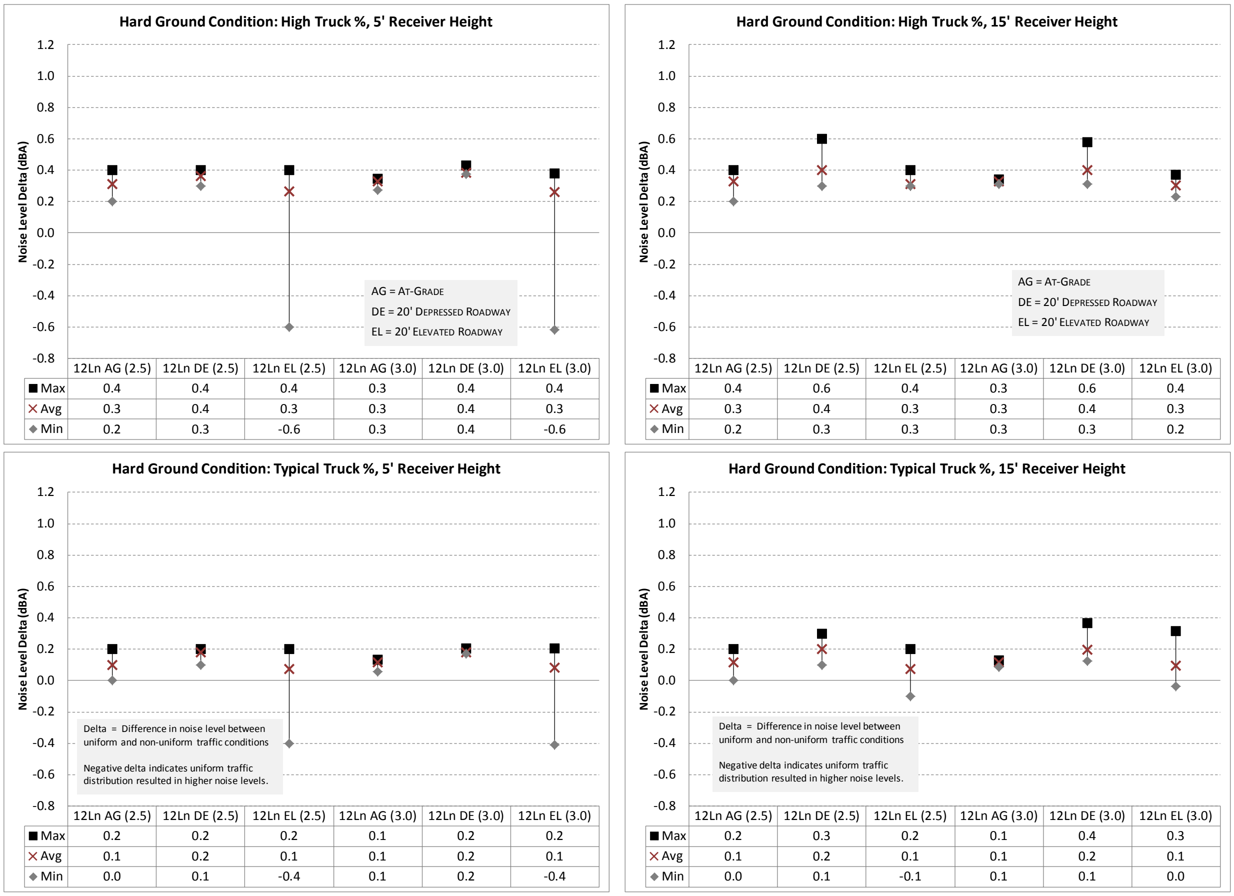


Figure I-10. Comparison of TNM 3.0 and TNM 2.5 Results for a 12-lane Highway over Hard Ground

The Use of Design Speeds, Level-of-Service Speeds, and Posted Speed Limits

TNM users often face the task of identifying sources of traffic data, or even developing traffic data for use as input to the model, most often during the planning stage of a highway project. Typical forms of traffic data used to approximate traffic conditions for the loudest hour of the day include design hourly volumes (DHV) and speeds, level-of-service (LOS) volumes and speeds, and posted speed limits. The study team conducted sensitivity testing using FHWA TNM version 2.5 to compare approaches based on LOS traffic data to approaches using DHV data, and to evaluate the effects of using LOS speeds, DHV speeds, and posted speeds limits as input to the model.

The study team developed a modeling scenario based on an 8-lane limited access highway in an urban environment, with rolling terrain and an assumed average daily traffic (ADT) of 140,000 vehicles per day. To test the FHWA TNM's sensitivity to traffic data input, the team used the following combinations of volumes and speeds to calculate noise levels for a typical 8-lane freeway: DHV with design speed; DHV with posted speed; and LOS volumes with uninterrupted free flow speed. The representative ADT, truck mix, LOS volume, and free flow speed (FFS) used in the third scenario originated from traffic data developed for a highway improvement project in the Commonwealth of Virginia. Table I-6 lists the relevant traffic parameters used in the modeling. FHWA TNM 2.5 was used for the computations.

Figure I-11, which shows TNM-calculated noise levels as a function of distance from the near lane of travel at two receiver heights, depicts the results of the sensitivity analysis for propagation over soft ground and a traffic flow with a relatively high percentage of heavy trucks in the vehicle mix.

Based on the relationship between design speed and posted speed, as expected, the use of DHV and design speed produced noise levels that were consistently higher than the other two approaches. Noise levels using DHV and design speed were on average 1.4 dB higher than noise levels based on the LOS volume and FFS. The DHV with posted speed produced noise levels that averaged 0.5 dB lower than the noise levels based on LOS volume and FFS.

Table I-6. Traffic Parameters for an 8-lane Freeway

Typical 8-lane Freeway	
ADT	140,000
K-factor	9%
Design Hourly Volume (vph)	12,780
Volume based on LOS (vph)	12,430
Directional Split	50% / 50%
Posted Speed (mph)	60
Uninterrupted Free Flow Speed (mph)	66
Design Speed (mph)	70
Percent Medium Trucks (EB / WB)	2.8% / 3.7%
Percent Heavy Trucks (EB / WB)	4.2% / 4.5%

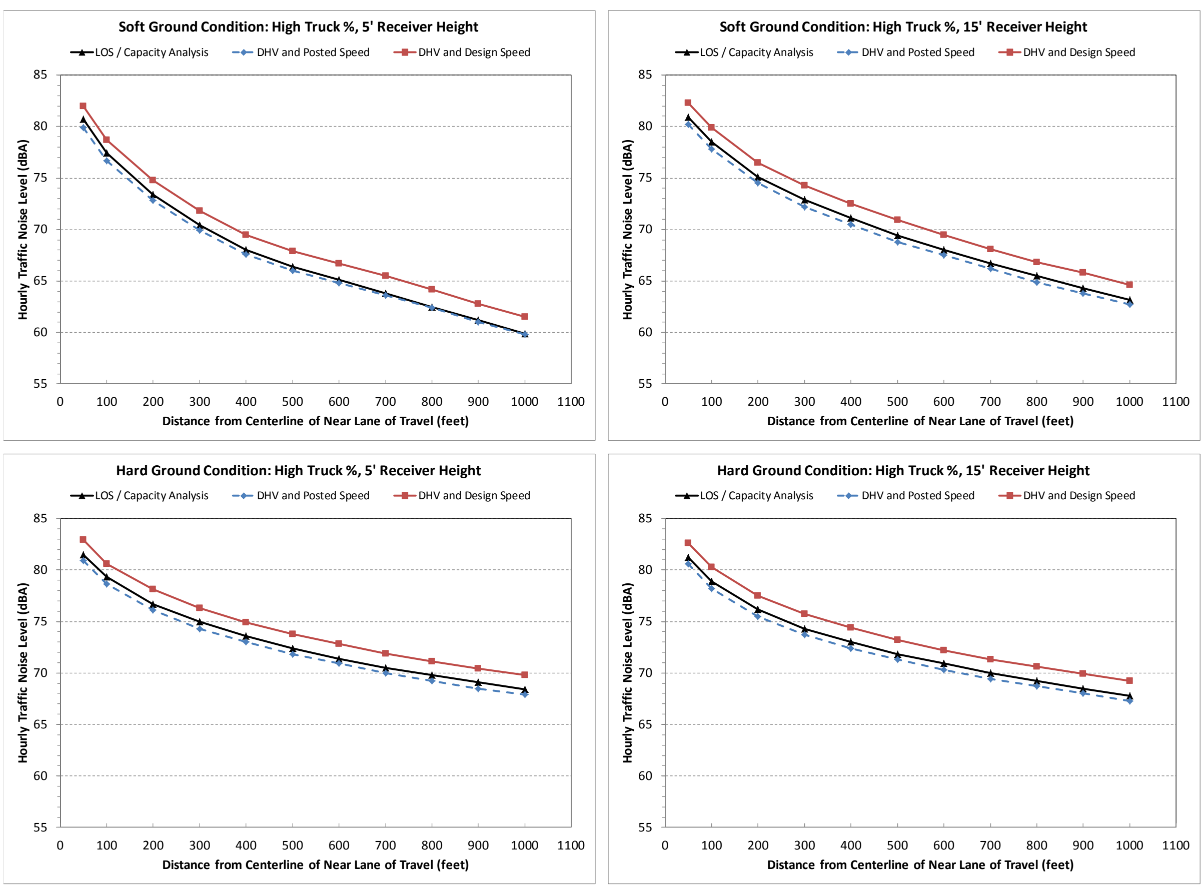


Figure I-11. TNM-calculated Noise Levels for an 8-lane Freeway using Combinations of Traffic Volumes and DHV, LOS, and Posted Speeds

Effect of Non-uniform Speeds Combined with Non-uniform Volumes

One of the objectives of this study was to test the FHWA TNM's sensitivity to a non-uniform traffic distribution for a multiple-lane highway. Up to this point, the scenarios assumed a non-uniform distribution of vehicle volumes and types across multiple lanes, while maintaining a uniform speed across multiple lanes. Realizing that a uniform-speed assumption does not accurately represent real-world traffic flow on a multiple-lane highway, the study team analyzed the data collected by the Volpe Center for the Phase 1 TNM Validation Study for representative 8-lane freeways and developed the curves shown in the graph of Figure I-12.

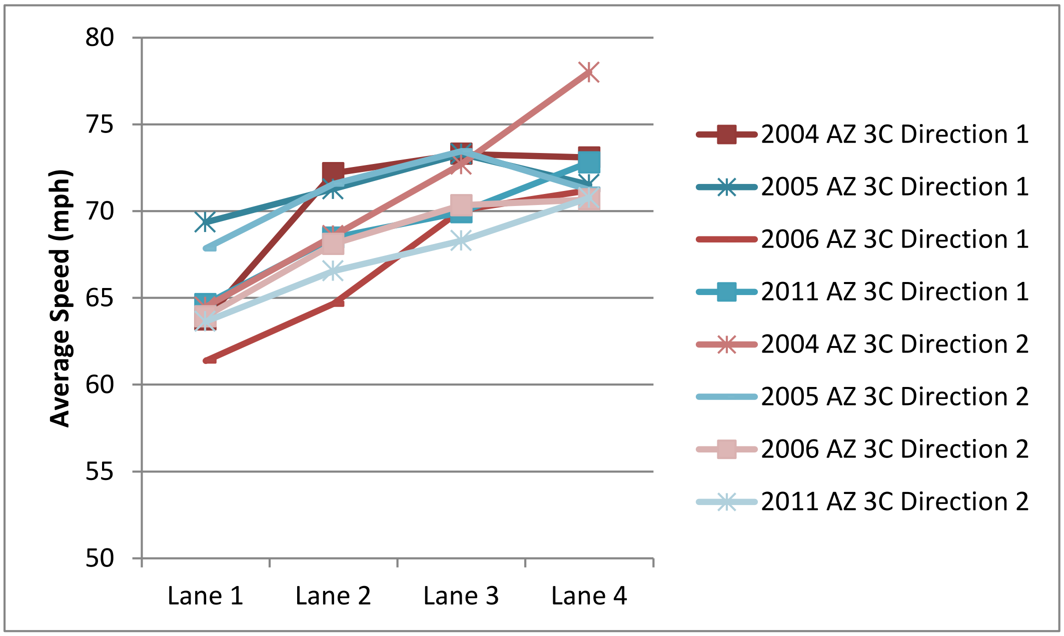


Figure I-12. Average Vehicle Speeds by Lane on Selected 8-lane Highway Facilities (based on data collected by the Volpe Center)

Each curve in Figure I-12 represents the measured average speed by lane for a particular site from the Volpe Center's dataset. As expected, the curves show slower moving vehicles on the outer lane (Lane 1) and faster moving vehicles on the inner lane (Lane 4). The study team calculated lane-average speeds and developed the speed distribution curve for an 8-lane facility with an average directional speed of 65 mph as shown in Table I-7.

Table I-7. Average Vehicle Speeds by Lane for 8-lane Highways

	Lane				
	All	**1**	**2**	**3**	**4**
Average speeds by lane (mph) based on Volpe Center data for representative 8-lane highways	69	65	69	71	72
Relative speeds by lane (mph)	0	-5	0	2	3
Speeds by lane for an average directional speed of 65 mph	65	60	65	67	68

The average speeds by lane in Table I-7 were combined with the non-uniform traffic (volume) distributions for the three 8-lane scenarios (at-grade, depressed, and elevated highways) described in previous sections and then compared to the corresponding reference scenario (traffic volumes and speeds evenly distributed across all lanes in each direction). The effects of modeling a non-uniform speed distribution were negligible. While TNM users may want to consider modeling non-uniform traffic (volume) distributions, there is no need to model non-uniform speed distributions. The study team recommends using the average speed for the directional traffic flow that corresponds to the modeled vehicle volume and mix (i.e., if traffic data are based on LOS volumes, use the corresponding FFS; if traffic conditions are based on DHV, use either the design speed or the posted speed).

Best Practices for Developing Traffic Data

As shown in the previous sections, the effects of a non-uniform traffic distribution for a multiple-lane highway are generally less than 1 dBA. Because other factors affecting sound propagation (e.g., rows of buildings, noise barriers, tree zones, etc.) have larger effects on calculated sound levels, traffic distributions across the lanes of multiple-lane highways may be ignored for environmental noise studies prepared in support of the permitting process under the National Environmental Protection Act (NEPA). One of the objectives of a traffic noise study performed in support of the NEPA process is to compare the extent of noise impact and preliminary noise abatement costs for multiple alternatives to the Proposed Action. The return on the investment of extra resources to develop traffic distributions across the lanes of a multiple-lane highway is negligible at the planning stage of a project. Although the effect of a non-uniform traffic distribution is small, it deserves consideration during the final design stage of a highway project, when final decisions about noise barriers will be made.

The recommended Best Practices for modeling non-uniform traffic distributions on a multiple-lane highway are summarized as follows:

- For NEPA noise studies, it is not necessary to model non-uniform traffic distributions for multiple-lane highways. This recommendation applies to freeway sections that are up to 12 lanes wide. While similar results are expected for freeway sections with more than 12 lanes, such facilities were not included in the sensitivity testing.
- For final noise abatement design studies, consider modeling non-uniform traffic distributions for multiple-lane highways if all of the following conditions are met:
    - The facility is 8 general-purpose lanes or more;
    - Sound propagation occurs over soft ground;

  - There is a high percentage of heavy trucks in the vehicle mix (20% or more); and
  - The freeway is either elevated or depressed, such that intervening terrain blocks the line of sight between any number of lanes and receivers of interest.

- If traffic distributions are not developed for the project, use the typical distributions that were developed for this study, as shown in Tables I-4 and I-5. Interpolate the lane distributions for highway cross-sections that are not represented in the table.
- There is no need to develop a non-uniform speed distribution for multiple-lane highways.

As required by FHWA and all SHAs, a highway noise analysis is performed for the loudest hour of the day. The loudest hour of the day is dependent upon traffic conditions – vehicle volume, operating speed, and number of trucks – that combine to produce the highest hourly noise levels adjacent to the highway corridor. According to FHWA guidance, the "worst hourly traffic noise impact" usually occurs at a time when truck volumes and vehicle speeds are the greatest, typically when traffic is free flowing and at or near LOS C conditions. Based on this guidance, the use of traffic data that are based on LOS is the preferred approach. However, realizing that detailed traffic projections are not necessarily developed for all highway projects, this report offers the following recommended Best Practices for the use of traffic data in highway noise studies:

- If hourly traffic data (for a typical 15- or 24-hour period) are developed for the project, conduct a loudest-hour analysis, as described below:
  - Determine hourly breakdown of vehicle volumes and corresponding speeds for each mainline section of the highway.
  - Develop a generic TNM model for the highway and compute hourly equivalent sound levels (L_{eq}) at a few representative distances from the highway, using the traffic conditions from the previous step.
  - If the traffic data exhibit strong directional characteristics, consider including representative receivers on both sides of the highway in the generic TNM model.
  - Identify the traffic conditions (and the hour(s)) that produce the highest noise levels at the representative receivers, then:
    - Either use the traffic conditions that produce the loudest hourly noise levels; or
    - Explicitly model the highway geometry in the FHWA TNM for the "top" two hours, for a small number of actual receivers. Use the traffic conditions that produce the highest noise levels for the study-wide prediction of traffic noise levels.

- If hourly traffic data are not developed for the project:
  - Consider a long-term (minimum 15 to 24 hours) noise monitoring program to measure traffic noise levels at representative noise-sensitive sites adjacent to the highway corridor. Identify the hour that produced the highest measured noise levels. Determine traffic conditions for that hour for use in the FHWA TNM. However, if future build alternative speeds during the hour are projected to be lower than the posted speed, use the posted speed along with the projected volumes in the build alternative for TNM modeling.
  - Use the DHV and the design speed for the highway; where the design speed is approximately the posted speed plus 10 mph. Note that depending upon the actual design parameters for a highway, this approach has the potential to overestimate the extent of noise impact in the community.
  - Alternatively, use the DHV and the posted speed for the highway. Note that depending upon the actual design parameters for a highway, this approach has the potential to underestimate the extent of noise impact in the community.
  - If the DHV is not provided for a highway project, follow procedures in the HCM to estimate hourly volumes by using the ADT and the K-factor. Several states have traffic count data, expressed in terms of ADT, available on public websites.

II. Best Practices for Noise Barrier Optimization

Introduction

While every state highway agency (SHA) has established a policy to identify what constitutes a feasible and reasonable noise barrier design, few have established the methods and procedures to identify the optimum noise barrier design. The acoustical benefits provided by a noise barrier generally increase with increased barrier height, but only up to a point. A point of diminishing returns is met when further increases in barrier height yield little or no increase in acoustical benefit. The optimum noise barrier design is the design that provides the best balance between barrier cost and acoustical benefit. The process used to identify the optimum design is called *noise barrier optimization*.

Although the FHWA Traffic Noise Model (TNM) includes a Barrier Analysis module to aid in the design of a noise barrier, it lacks a straight-forward method for users to optimize the design. Noise barrier design is a balance among several factors, and for a given situation, TNM users may identify any number of noise barrier designs that meet the SHA's design criteria. The range of possible noise barrier designs extends from those that provide "the minimum acoustical benefit for the minimum cost" to those that provide "the maximum acoustical benefit while still meeting the cost-effectiveness limit." This range of possible outcomes in the barrier design process often leads to conflicts, especially on some Design-Build projects. The conflicts arise when the SHA and Design-Build team have competing views on what constitutes the optimum design. At other times, conflicts may arise when impacted communities petition the SHA to build a noise barrier that spends the maximum amount available per benefited receptor. However, such a design may not represent the best balance between cost and acoustical benefit. The development of a noise barrier optimization tool will guide SHAs in developing optimum designs, and hopefully lead to resolutions to these types of conflicts.

Prior to designing a noise barrier optimization tool, the study team conducted independent research and received information from many SHAs concerning current policies and practices for noise barrier design and optimization. The information provided by the SHAs helped guide the development of a noise barrier optimization tool.

The noise barrier optimization tool developed in this study allows TNM users to quickly determine the appropriate balance between a low-cost noise barrier design that meets the minimum acoustical requirements and a barrier design that provides the most benefits within the state's cost-effectiveness limit. To a large degree, this balance will be guided by the goals and design objectives contained in each state's noise abatement policy and guidance document. The noise barrier optimization tool presented below will help ensure that all goals and metrics are referenced and presented to the user during the design process. In addition, the noise barrier optimization tool computes an Effectiveness/Cost (E/C) metric for each barrier design, based on the SHA-specific goals and criteria, to help guide the user toward a noise barrier design that provides the desired balance between acoustical benefit and barrier cost. While the E/C metric will prove to be useful for noise barrier optimization, it is still up to TNM users to fully comprehend SHA policies related to the feasibility and reasonableness determination for a noise barrier design.

This report presents the methods for noise barrier design optimization and a Microsoft Excel-based tool that allows users to quickly determine whether feasibility and reasonableness criteria are met. The noise barrier optimization tool also provides an easy side-by-side comparison of alternative noise barrier designs, as well as an E/C metric to help guide the selection of an optimum barrier design among several alternative designs. The noise barrier optimization tool has the flexibility to allow each SHA to enter its state-specific parameters for feasibility requirements, noise abatement design goals, and cost-effectiveness.

Current Best Practices for Barrier Design and Optimization

The study team surveyed many SHAs for current policies and practices for noise barrier design, and also asked whether and how states optimize noise barrier designs. Eleven SHAs responded to the information request. The respondents represented states with large noise barrier design and construction programs, as well as states with more modest programs. Based on the information received, the study team observed that some SHAs follow an approach whereby they try to minimize barrier height and cost, while still achieving the state's noise reduction design goal (NRDG). Other states attempt to maximize a barrier's height and acoustical benefit while staying within the cost-effectiveness limits. Some such states initially propose noise barrier designs that meet the reasonableness criteria at the SHA's maximum allowable height, and then reduce heights from a maximum based on the public involvement process. In its experience, the study team has observed that some communities are willing to give up some amount of acoustical benefit based on their desire to have a shorter wall height. In contrast, some other SHAs indicated that they start with a minimum-height design that meets the noise reduction goals, and then incrementally increase the barrier height, as long as the design accrues significant acoustical benefits relative to cost. More than one SHA indicated that it attempts to determine the point of diminishing return in a barrier design, where the acoustical benefits cease to accrue with increased barrier heights (and cost), and then selects that design as representing the best balance between cost and benefit.

Finally, other SHAs incorporate different elements into the noise barrier design process. For example, some SHAs indicated that they attempt to develop noise barrier profiles that are smooth and relatively uniform to achieve a more aesthetic design.

Noise Barrier Optimization Tool

For this project, the study team expanded and generalized a spreadsheet-based barrier optimization tool that it customarily uses on TNM-based highway noise barrier design projects. Over the years, the spreadsheet tool had been customized to include the feasibility and reasonableness goals, metrics, and criteria for a modest number of SHAs. For this project, the spreadsheet tool was expanded to accommodate the policies, goals, and cost-effectiveness criteria for SHAs across the country. The noise barrier optimization tool is based on a Microsoft Excel® workbook and includes a worksheet (tab) that provides a condensed listing of each SHA's feasibility and reasonableness goals and criteria, which is current as of May 2015.[25] While the noise barrier optimization tool has been generalized to accommodate each SHA's policy, it also can be customized to fit the needs of individual TNM users.

Overview

To utilize the Noise Barrier Optimization Tool (NBOT) most effectively, the study team recommends that TNM users create noise barriers with a reasonable number of barrier height perturbations, considering the trade-offs between run-time and the objectives of the analysis. Then, using TNM's Barrier Analysis Module, the analyst should step through the barrier design process, by creating one Barrier Analysis for a uniform-height noise barrier at each height perturbation. That is, with the Barrier View window open, the user would select the entire noise barrier and uniformly perturb the barrier heights up, from the minimum barrier height to the maximum height. With the Barrier View window open, the user arranges the Sound-level Results table, the Barrier Segment Descriptions table, and the Barrier Descriptions table in the FHWA TNM. The user would copy the information in these tables from the FHWA TNM, and then paste it into specific locations in worksheets of the Microsoft Excel® workbook, with one worksheet for each noise barrier design. Then, the NBOT computes the impacts, benefits, and all of the other metrics needed to evaluate each barrier design and places these results side-by-side in the "Summary" worksheet, or **[Summary]**, for easy comparison. Note that for the remainder of this report, the **[Worksheet Name]** notation will be used to designate individual worksheets within the Excel® workbook that is the NBOT. Likewise, the {TNM Table Name} notation will be used to designate one of the standard tables within the FHWA TNM.

In addition to the customary metrics and criteria, the NBOT computes some additional metrics that factor into the computation of the E/C metric, which assists in barrier optimization, including:

1. "Benefit" – the total number of receptors (including non-impacted receptors) benefited by the barrier divided by the number of receptors exposed to impact behind the barrier with no barrier in place
2. "% meet NRDG" – the percentage of impacted receptors that meet or exceed the NRDG with the barrier in place

These two metrics are multiplied together to equal "Effectiveness" in the E/C metric. The "Cost" is simply the surface area of the barrier in square feet, divided by a constant of 10,000 to make the resultant E/C value in a reasonable range. In developing the E/C metric, the study team found that it was appropriate to use both the total Benefit normalized by total impact, as well as the percentage of impacts meeting the NRDG, to properly credit the barrier designs that largely achieve the NRDG. This was important, because many states attempt to achieve the NRDG at as many receptors as possible, within the allowable cost constraints.

To help identify the noise barrier design that represents the "point of diminishing returns" from among the uniform-height barrier designs, the user simply selects the design with the highest E/C ratio that also meets the SHA's NRDG and cost-effectiveness criterion. Each barrier design should be saved as a unique Barrier Analysis in the FHWA TNM, and the corresponding TNM tables should be copied to individual worksheets in the NBOT. The spreadsheet computes all of the metrics for the feasibility and reasonableness determination and compares calculated metrics across multiple noise barrier designs. Note, however, that at this point in the process the user has not yet identified the optimum noise barrier design. The user must take additional steps to refine the noise barrier design. Starting with the

[25] The condensed listing of SHA policies in the noise barrier optimization tool is provided for informational purposes only. TNM users are expected to have a thorough understanding of the noise abatement policies for the state in which their project is located.

uniform-height barrier that achieved the highest E/C ratio, the analyst should consider dropping ineffective or unnecessary barrier segments, such as those at the ends of the noise barrier, or re-running the FHWA TNM for a noise barrier with smaller height increments. The following example illustrates the next steps that may be taken to identify the optimum design.

Example: Consider a scenario in which the user created a noise barrier with a base height of 10 feet, with five “up” perturbations, no “down” perturbations, and a height increment of 2 feet. Following the recommended approach, the user would systematically evaluate barrier designs with uniform heights from 10 to 20 feet, and then select the barrier design that not only yields the highest E/C ratio, but is also reasonable. For the sake of this example, assume that the uniform-height barrier with the highest E/C ratio is 16 feet high and 1,500 feet long. To find the optimum noise barrier design, the user would then consider re-running the FHWA TNM for a noise barrier with a base height of 16 feet, three “up” perturbations, three “down” perturbations, and a height increment of 1 foot. In this case, it is suggested that the user create a new version of the NBOT to document the barrier optimization process. Ultimately, the optimum noise barrier will be the design that yields the maximum value of the E/C ratio from this refined TNM run – say for example, a barrier that is 13 to 15 feet high and 1,450 feet long (and reasonable).

Details and Functionality

The study team created two versions of the NBOT – one with basic metrics (“Basic NBOT”) and one with more advanced metrics (“Advanced NBOT”). The latter version is intended for use in states that might require analysis of front row receivers, or other specialized analyses. This section provides details about the NBOT and its functionality.

The tool includes **[Instructions]** with detailed instructions for user entry and use of the subsequent worksheets. First-time users of the NBOT should take the time to become familiar with this worksheet.

A condensed listing of SHA criteria and metrics for feasibility and reasonableness can be found on **[SHA Policies]**. This listing is provided for informational purposes only, and should not be used alone or as a reference for the noise study. The user should refer to the SHA’s noise abatement policy and supporting guidance to fully understand the criteria for barrier analysis and as a source for up-to-date and current design metrics.[26] The user should refer to the SHA’s noise abatement policy when entering criteria on **[Global Variables]**. If desired, the user may choose to periodically check SHA websites of interest and update **[SHA Policies]** to maintain it as a useful reference. The workbook itself can be edited by the user at any time in order to stay up-to-date with each SHA noise policy. A password-protect feature has been added to the tool, however, to ensure that any edits made to spreadsheet equations are intended by the user.

The project name, project / contract number, FHWA TNM run name, barrier name, organization, analyst, and analysis date should be entered on **[Global Variables]**, where additional project-specific information also is entered. This includes the specific metrics, goals, and criteria for feasibility and reasonableness determinations that have been established by the SHA.

The layout of the workbook requires that the user enter the necessary SHA metrics and TNM tables for individual barrier designs into different worksheets. **[Summary]** then calculates the results of each barrier analysis and compares results across different designs. The NBOT is meant to be used in conjunction with TNM’s Barrier Analysis Module. The user starts by selecting the barriers and

[26] FHWA does not intend to maintain the listing on [SHA Policies]. The listing is current as of May 2015.

receivers of interest and creating a new barrier analysis in the FHWA TNM. For each barrier design, the Sound-level Results table, the Barrier Segment Descriptions table, and the Barrier Descriptions table are copied from the FHWA TNM into specific locations on **[Receiver-Barr Input]**, **[NoBarrier]**, and **[Analysis1]** to **[Analysis15]**, as needed. The Receiver Input table, along with other receiver information such as existing sound level, row, and FHWA Noise Abatement Category, must be entered into **[Receiver-Barr Input]**. The Barrier Input table from the FHWA TNM also should be added to **[Receiver-Barr Input]**. If the study is being completed for a state that uses a sliding scale to determine substantial increase impact, the user can enter the required information into **[Global Variables]** and **[Receiver-Barr Input]** for the scale to be referenced. The user is instructed to enter "SS" on **[Global Variables]** into cell C14 if the substantial increase threshold is based on a sliding scale. After "SS" is entered, the user is instructed to enter more information on **[Receiver-Barr Input]**. On this worksheet, the user enters a "Y" in cell P14 and chooses the appropriate SHA.

On **[NoBarrier]** and **[Analysis1]** to **[Analysis15]**, the Sound-level Results table, the Barrier Segment Descriptions table, and Barrier Descriptions table for each respective barrier analysis should be pasted. On **[NoBarrier]**, all barrier segments should be placed at a height of 0.0 feet before copying and pasting the applicable TNM tables. **[Summary]** pulls the sound levels and barrier parameters from each analysis worksheet so that impacts, benefits, and barrier costs can be calculated and displayed for each barrier analysis, all in one sheet. This allows the user to easily make comparisons across all of the barrier designs that have been considered on **[Summary]** so that the most appropriate barrier options can be recommended. **[Analysis1]** to **[Analysis15]** also include areas for a TNM image of the barrier design and the barrier's profile in graphical form to aid in the aesthetics of the design.

As discussed earlier, many SHAs desire to design and recommend noise barriers that provide the significant benefit for impacted receptors as well as non-impacted receptors while still being feasible and reasonable. Through the NBOT, the user can choose the most optimal barrier design by looking at the many various metrics that are computed. The E/C ratios, which reach a maximum value for the most cost-efficient barrier designs that also provide substantial benefit, are shown in Row 7 on **[Summary]**.

Generally, areas for user input are symbolized with light green shaded cells and/or red bold underlined column headers. In the Basic NBOT, there are no user input cells on **[Summary]**. In the Advanced NBOT, **[Summary]** requires the user to enter specific information. The Advanced NBOT also contains metrics that calculate the percent of front row impacts, or benefits, as required for some SHA's feasibility and reasonableness criteria. In the Advanced NBOT, **[Summary]** also contains a flag to switch the reasonableness metrics to include cost or surface area per decibel of average noise reduction per benefited receptor. Flags for front row feasibility and reasonableness metrics and per decibel reasonableness metrics are symbolized as light green shaded cells with red bold underlined headers directing the user to enter "Y" into the cell.

[Summary] includes a flag for each type of impact, such as approaching or exceeding the Noise Abatement Criteria (NAC), or causing a substantial increase (SI) over existing levels. Column E contains the No Barrier Build Sound level, which is bold and red if it is over the threshold for impact. Column F contains a bold red "Y" flag if there is a substantial increase impact. Column G is an "impact" flag that signifies whether the receiver is exposed to noise impact (without a noise barrier). The impact tally summary above this section shows the total number of impacts, the number of impacts for each type (NAC or SI), as well as the total number experiencing both types of impact. Each section under the barrier analysis headers (Analysis1, Analysis2, etc.) contains a tally of the total benefited receivers, the number of benefits that are impacted or not impacted, and the number of impacts and benefits achieving the NRDG.

Cost-reasonableness checks are given for each Analysis section below the number tallies. There are cells that show the percentage of impacts being benefited and the benefits achieving the NRDG, as well as a "Yes" or "No" Cost-Reasonable check, which signifies whether the cost or surface area per benefit meets the appropriate criterion. These cells are conditionally formatted to be green if the criterion is being met and red if it is not. The NBOT is currently set up to notify the user if more than one reasonableness criterion is entered, mainly to avoid user error and because most SHAs have only one. However, if the user is working for a SHA with both types of criteria, the cost reasonableness formula will return a "Yes" if either criterion meets the threshold.

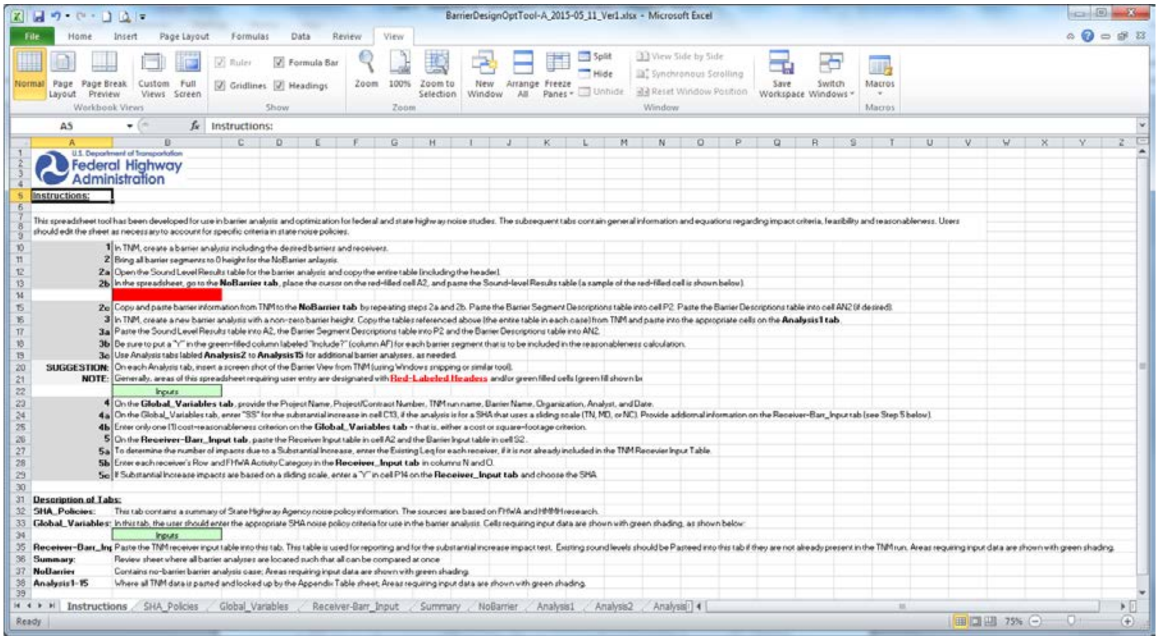
If the SHA requires the number (rather than percentage) of impacted receivers being benefited, or the number of benefited receivers achieving the NRDG, such as one (1) impacted receptor, then the user should leave the percentage inputs on **[Global Variables]** blank and use the number tallies on **[Summary]**. Some analysts include measurement sites in TNM runs. In such cases, dwelling units may, or may not, be assigned to the receiver in the FHWA TNM. If measurement sites are included in the barrier analysis, the NBOT will calculate impacts properly if the sites are assigned an FHWA Activity Category. If the measurement sites are not intended to represent noise-sensitive land use for the purpose of the noise impact assessment, users should assign a value of zero (0) dwelling units to those receivers that represent measurement sites.

Barrier parameters such as surface area, height range, length, and total cost also are included in each analysis section on **[Summary]**. Barrier parameters are pulled from information on **[Analysis1]** to **[Analysis15]** in the Barrier Segment Descriptions section of the worksheet. On **[Analysis1]** to **[Analysis15]**, the user can enter "Y" in Column AF for each barrier segment that should be included in that analysis.

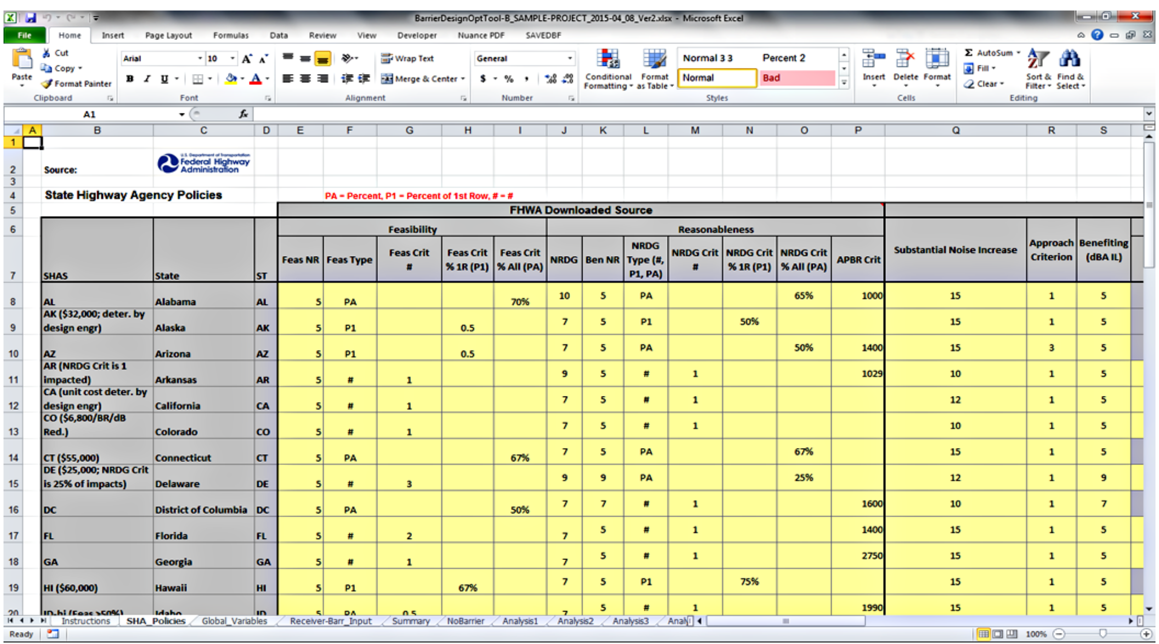
Step-by-step Instructions for using the Noise Barrier Optimization Tool

This section provides step-by-step instructions for using the NBOT. Users should be familiar with Microsoft Excel® workbooks and have a thorough understanding of the state noise abatement policy that applies to the Project.

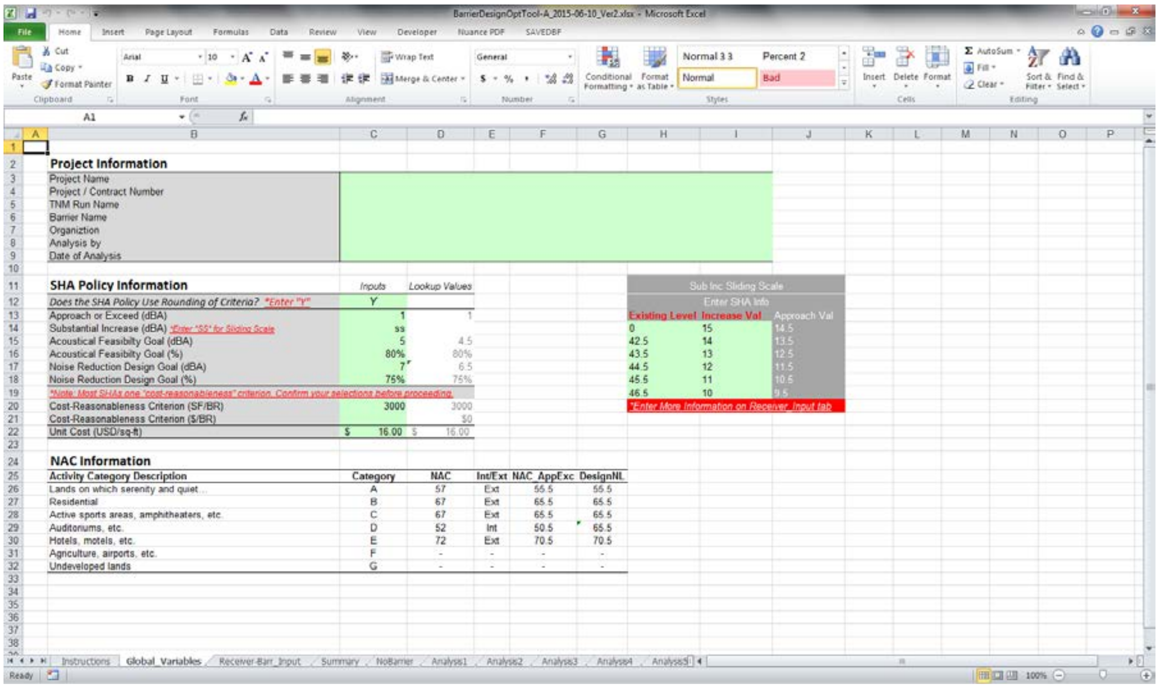
Step 1. Review [Instructions].



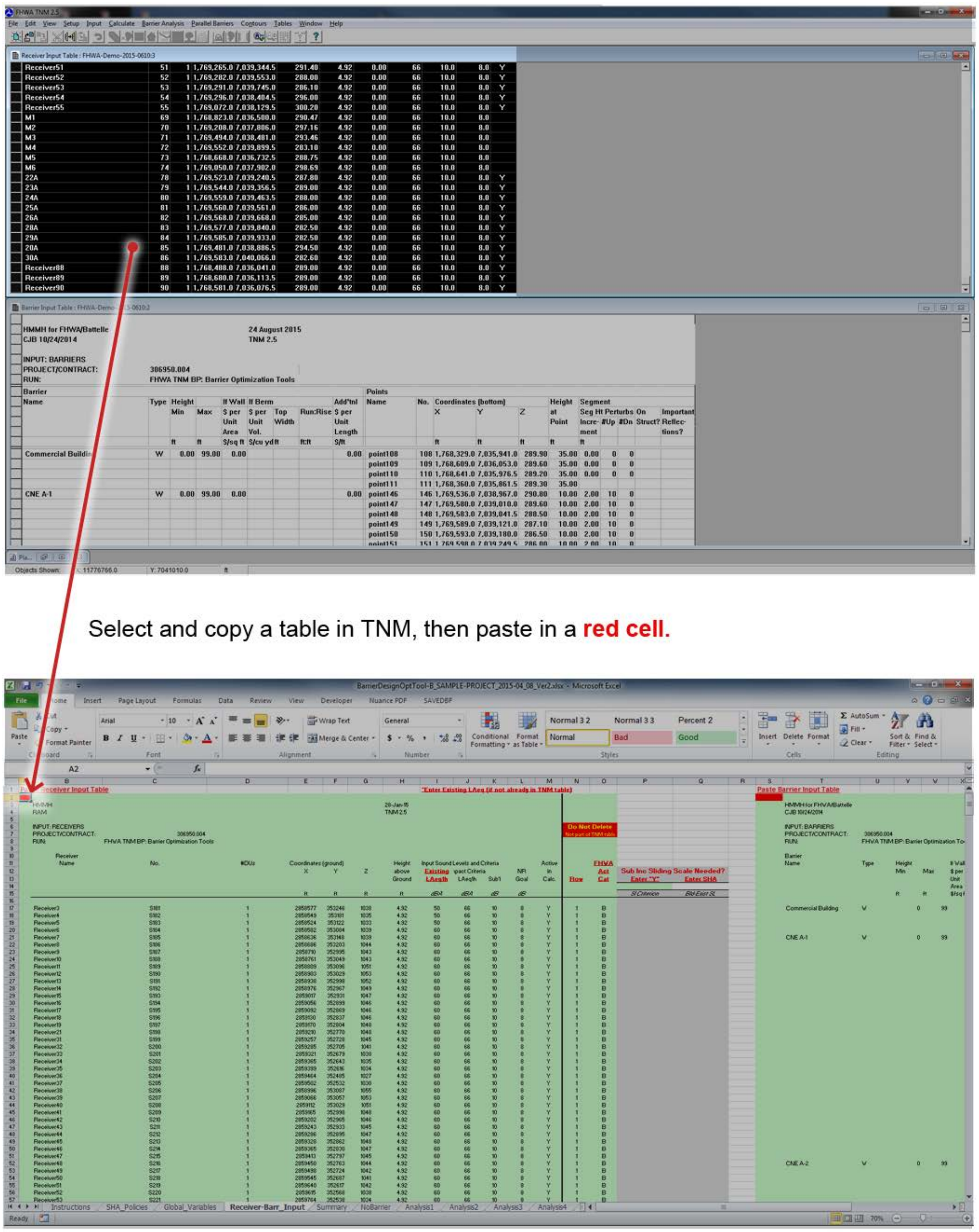
Step 2. Review the feasibility criteria and design goals for the SHA on [SHA_Policies]. This worksheet is for informational purposes only. It is expected that users have a thorough understanding of the state Noise Abatement Policy that applies to their project.



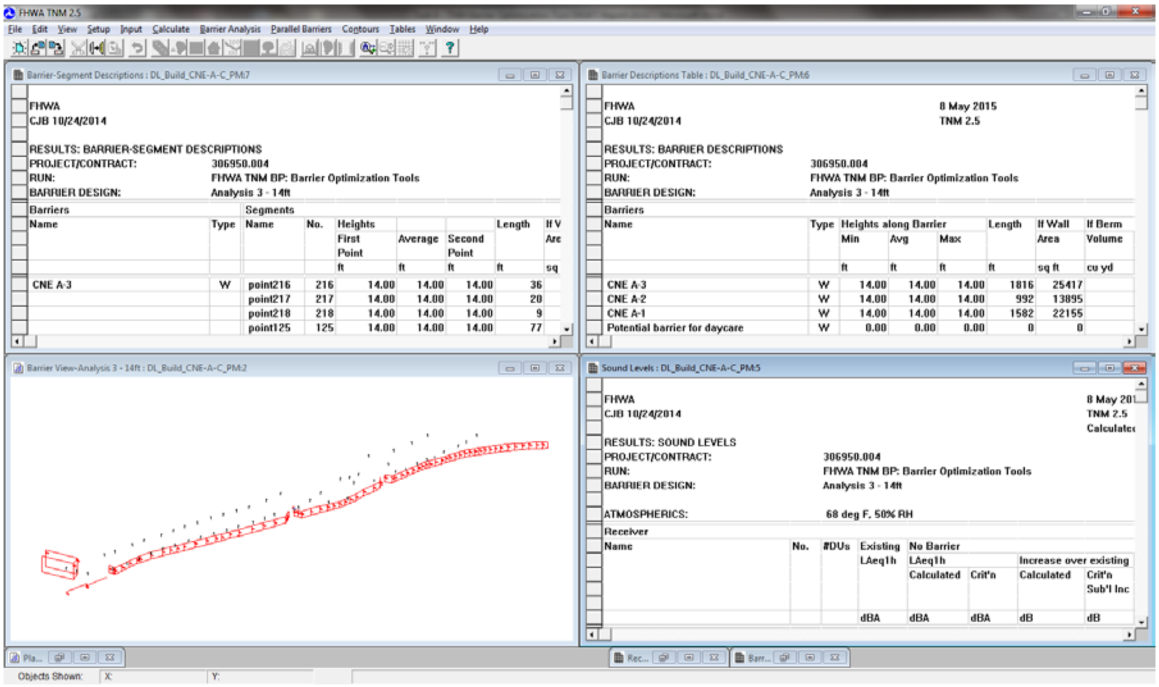
Step 3. Enter project-specific information on [Global_Variables], including the SHA definitions for Approach or Exceed, Substantial Increase, the acoustical feasibility goal, the number or percent of receptors that must achieve the feasibility goal, the NRDG, the number or percent of receptors that must achieve the NRDG, the cost reasonableness criterion, and the unit cost for noise barriers. Users must enter the required information in the cells with green shading.



Step 4. In TNM, open the {Receiver Input Table}. Select the table in its entirety and copy. Go to [Receiver-Barr Input] in the NBOT. Place the cursor in the applicable red-shaded cell (cell A2) and paste. Repeat the process for the {Barrier Input Table} and paste into cell S2. Enter a "Y" in cell P14 on [Receiver-Barr Input] if the SHA uses a sliding scale to determine noise impact based on a Substantial Increase. Currently, only three SHAs use a sliding scale (MD, NC, and TN). In cell Q14 on [Receiver-Barr Input], select one of the three SHAs from the pull-down.



Step 5. In TNM, close or minimize the {Receiver Input Table} and the {Barrier Input Table}. Select the receivers and noise barriers of interest and create a new barrier analysis. Minimize the Plan View. With the Barrier View active in TNM, open the {Sound Levels} results table, the {Barrier-Segment Descriptions} table, and the {Barrier Descriptions Table}; then from the pull-down menu in TNM, select "Window | Tile Vertical" or "Window | Tile Horizontal" to arrange the items as shown.



Step 6. Perturb the heights of all noise barrier segments to be evaluated to a height of zero (0.0) feet. In turn, copy and paste the {Sound Levels} results table and the {Barrier-Segment Descriptions} table to the applicable red-shaded cells on [NoBarrier] in the Barrier Optimization Tool. The {Sound Levels} results table is pasted to cell A2, the {Barrier-Segment Descriptions} table is pasted to cell P2, and the {Barrier Descriptions Table} is pasted to cell AL2.

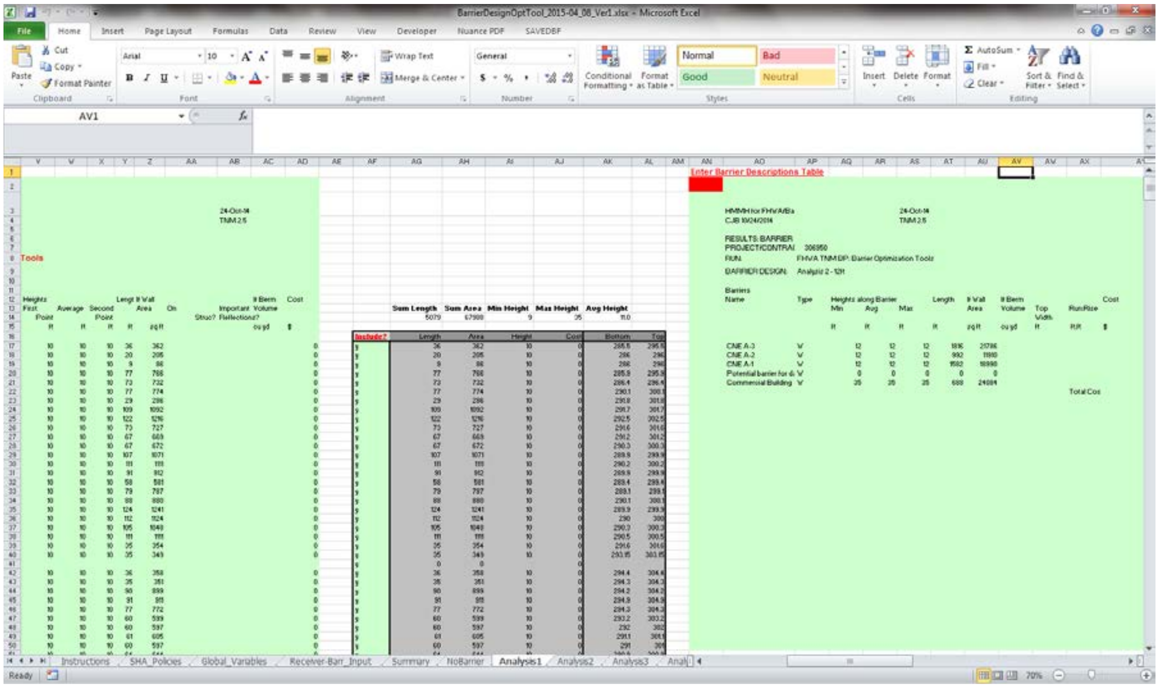
(Tip: don't forget to 'Remember" each barrier analysis in TNM.)

In TNM, increase the height of all noise barrier segments to be evaluated to the first barrier height perturbation. In turn, copy and paste the {Sound Levels} results table, the {Barrier-Segment Descriptions} table, and the {Barrier Descriptions Table} to the applicable red-shaded cells on [Analysis1]. In column AF on [Analysis1], place a "Y" or "y" in the row for each barrier segment that is to be included in the evaluation. The {Sound Levels} results table is pasted to cell A2, the {Barrier-Segment Descriptions} table is pasted to cell P2, and the {Barrier Descriptions Table} is pasted to cell AN2.

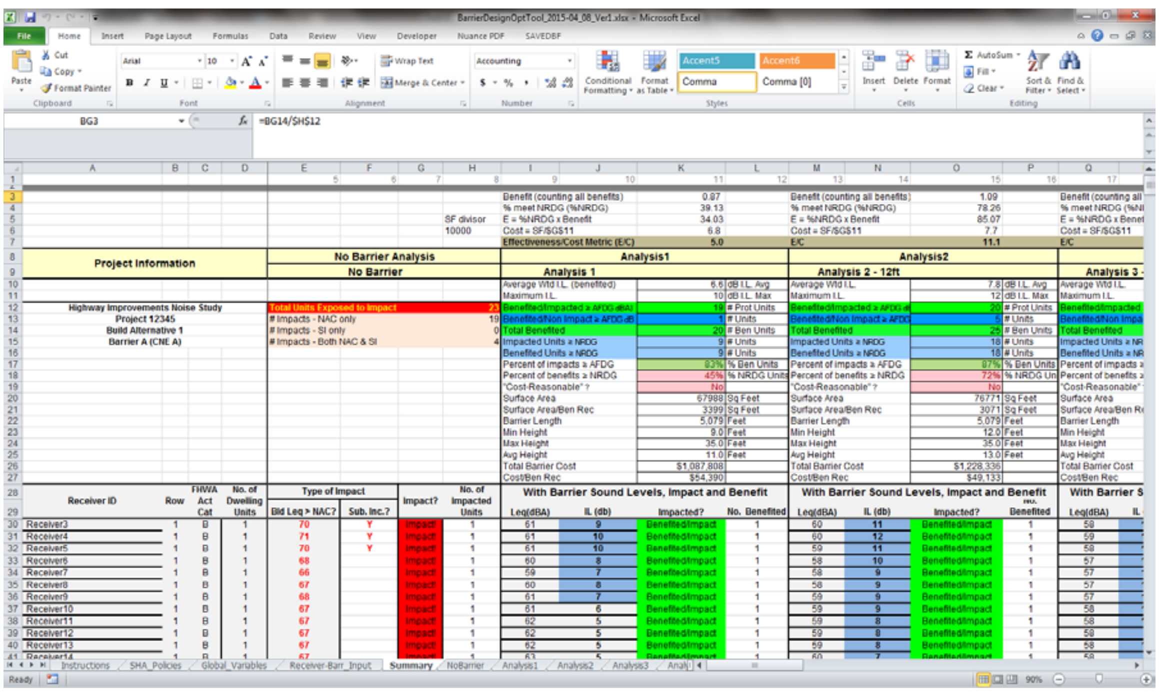
(Tip: Copy and paste the Plan View from TNM in column BA.)

Repeat the process for additional barrier height perturbations, copying and pasting tables from TNM to the applicable red-shaded cells in [Analysis2] to [Analysis15], as needed. The

{Sound Levels} results table is pasted to cell A2, the {Barrier-Segment Descriptions} table is pasted to cell P2, and the {Barrier Descriptions Table} is pasted to cell AN2.



Step 7. Review the results of the barrier analyses on [Summary] in the NBOT. [Summary] provides all of the relevant information about each barrier design that is required to make the feasibility / reasonableness determination.



III. Best Practices for Quality Assurance of TNM Input and Results

Introduction

Quality assurance / quality control (QA/QC) of a product or service, such as an environmental noise assessment or a noise abatement design report, depends upon the processes and procedures that the responsible organization (state highway agency [SHA], engineering firm, acoustical consulting firm, etc.) has set in place. That is, quality assurance depends upon the organization's Quality Management System (QMS). This report provides guidance to those organizations looking to incorporate QA practices into highway noise studies or to enhance policies already in place, and provides examples of simple processes and/or tools that may be used for QA. The recommended processes and tools include the use of spreadsheets and special views within the FHWA TNM to verify the accuracy of vertical geometry, as well as the use of checklists to document not only the development and review of TNM object input, but also the development and review of noise study reports and noise abatement design reports.

The recommended Best Practices for Quality Assurance are designed to improve the quality of TNM models and noise analysis reports that are required under 23 CFR 772.

This chapter presumes the highway noise analyst has a thorough understanding of FHWA guidance for the application of 23 CFR 772 in the analysis and abatement of highway noise.[27] Highway noise analysts also should become familiar with the recommended Best Practices for the application of the FHWA TNM to "non-routine" scenarios.[28]

The following sections provide an overview of QA concepts and some of the components of a QMS that are applicable to highway noise studies, a sample QA plan, recommended QA processes for the development and review of TNM object input, recommended QA processes for the review of TNM-computed sound levels and noise barrier results, sample checklists for the development and review of TNM noise analysis reports, and additional resources for noise study report guidance and checklists. The appendices contain a copy of the Florida DOT's QC checklist for the review of TNM input files and a copy of the Virginia DOT's "Noise Report Guidance and Accountability Checklist" and a project close-out form.

[27] U.S. Department of Transportation, Federal Highway Administration, "Highway Traffic Noise: Analysis and Abatement Guidance," FHWA-HEP-10-025, December 2011. Available at: http://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/

[28] National Cooperative Highway Research Program, "NCHRP Report 791: Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)," 2014. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_791.pdf

Overview of Quality Assurance (QA) Concepts

The International Organization of Standardization (ISO) develops voluntary technical standards for the purpose of adding value to a variety of business operations by supporting "the development, manufacturing and supply of more efficient, safer and cleaner products and services." The ISO 9000 family of standards provides the basic requirements for a QMS that an organization must fulfill to provide products and services that meet customers' expectations and applicable regulatory requirements.[29] The recommended QA processes described in the following sections are largely based on and strive to be consistent with the concepts presented in the ISO 9000 family of standards. The general requirements for a QMS are identified in ISO 9001 and are quite extensive.[30] For the purposes of developing QA processes for TNM models and noise analysis reports, the study team selected those requirements from ISO 9001 that are the most relevant to the objectives of this study. Therefore, while the recommended QA processes are based on the ISO standards, adoption of and adherence to these QA processes does not fulfill all of the requirements for certification and/or registration of an organization's QMS by ISO.

The components of a QMS that form the basis of the recommended QA procedures in this document are as follows:

- Documented statements of a quality policy and quality objectives embodied in a QA Plan,
- The processes needed for QA of TNM models and noise study reports, and their application,
- The sequence and interaction of the processes, and
- Documents and records, in the form of checklists, necessary to ensure effective planning, operation, and control of the QA processes.

As always, the highway noise analyst is encouraged to check with the SHA staff in their state or district before embarking on a noise study or adopting any of the QA processes identified herein. Research undertaken for this study revealed that several SHAs already have QA/QC-related procedures and policies in place. Several SHAs are using checklists for the content and format of noise analysis reports.

Sample Quality Assurance Plan

The implementation of quality assurance into an organization's processes requires the preparation of a QA Plan. In its most basic form, the QA Plan documents the established procedures and processes for implementing the QA Plan and identifies the objectives of the QMS. The QA Plan also may identify management's responsibilities in the QA process and minimum requirements for staff working on a highway noise study. Of course, there is no "one size fits all" approach to adopting a QA Plan. The size and scope of the QA Plan depends on a number of factors, including the size of the organization implementing the Plan and the complexities of the QA processes.

[29] International Organization for Standardization, "Selection and use of the ISO 9000 family of standards," 2009.

[30] ISO 9001, "Quality management systems – Requirements," Fourth Edition, corrected version, 2009-07-15.

All members of the team shall commit to the policies and objectives of the QA Plan.

It is the responsibility of the Principal Investigator (PI) and/or Project Manager (PM) to communicate the goals and objectives of the QA Plan to all team members working on a highway noise study. The QA Plan should be reviewed and updated on a periodic basis to ensure that its goals and objectives are consistent with applicable state and Federal policies and regulations. For example, organizations may elect to review and update the QA Plan and any supporting documents (e.g., checklists) on a schedule that coincides with the SHA's revisions and updates to the State Noise Abatement Policy.

Appendix E contains a sample QA Plan that presents some concepts that organizations may wish to consider when drafting a QA Plan. Note that this sample QA Plan is provided solely as an example and that the language appearing in it is not mandated by the FHWA. For instance, although some state SHAs may wish to do so, the FHWA is not mandating the amount of experience for different levels of staff who may work on a highway noise study. The sample QA Plan is based on one organization's approach to QA.

QA Processes for TNM Input

The recommended QA/QC processes in this section apply to the data used as input (coordinates, roadway details, topographic data, land use, traffic, etc.) to generate TNM objects.

Project Plans, Profiles, and Cross-sections

The SHA's Highway Design Manual (HDM) provides current requirements and guidance on highway design methods to ensure uniformity of design practice throughout the highway system under its jurisdiction. It is the primary source of guidance for the design of highway facilities from scoping to preliminary design. The HDM not only contains design criteria for different classifications of highway facilities, as well as for interchanges and signalized intersections, but also typically contains standards and procedures for computer aided design (CAD). The CAD standards and procedures assure uniformity of practice and the creation of electronic data for projects designed by or for the SHA. The HDM provides guidance and standards for the use of engineering software used for highway design, and specific configuration settings for the engineering software.[31] While a thorough understanding of the HDM is not a prerequisite for highway noise analysis, the HDM can be a resource for the highway noise analyst. The highway noise analyst should coordinate with the highway designers.

At a minimum, the project plans and cross-sections provided to the highway noise analyst should contain the following design features for both the existing highway and the proposed highway. In general, if the project plans, profiles, and cross-sections were developed according to the SHA's HDM, these design features should be available to the highway noise analyst. The following design features are applicable to project and non-project roadways alike, to the extent that data are available for the latter:

- Project limits,
- Locations of general purpose lanes, special use lanes (e.g., high occupancy vehicle lanes, special tolling lanes, etc.), acceleration and deceleration zones for ramps, shoulders,
- Locations where the highway would be on structure and on fill,

[31] See the electronic version of the New York State Department of Transportation "Highway Design Manual" available at https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm?nd=nysdot.

- Limits of construction, including toe of slope and top of cut,
- Edge of pavement,
- Rights-of-way,
- Civil station numbering baseline,
- Rest areas and truck weigh stations,
- Existing noise barriers,
- Locations of jersey barriers, and
- Lane striping.

As necessary, the project plans should contain information about other project features, including:

- Bodies of water (rivers, ponds, lakes, etc.) including wetland resources and buffer zones,
- Storm water management basins,
- Other transportation facilities (railroads, bike paths, shared use paths, etc.)
- Utilities (natural gas, telecommunications, water, electricity, etc.),
- Existing development along the highway corridor, and
- If available, future proposed development within the project corridor.

The most commonly used coordinate system for highway projects is the State Plane Coordinate System (SPCS) based on the North American Datum of 1983 (NAD 83). Elevation data are commonly referenced to the North American Vertical Datum of 1988 (NAVD 88).[32] Of course, the highway noise analyst should check with the project's designers or the SHA noise specialist to verify the preferred coordinate system for the project. When reviewing the project plans/profiles/cross-sections, the highway analyst should:

- Identify/verify the coordinate system,
- Identify/verify the vertical datum, and
- Obtain the metadata[33] for the project plans/profiles/cross-sections.

Topographic Data and Land Use

Typically, the plans, profiles, and cross-sections prepared for a highway project provide information that is limited to within the right-of-way. Although some SHAs and/or highway designers may develop plans that provide useful information about the project's environs beyond the limits of the right-of-way (e.g., topographical features, land use, locations of non-project roads and other transportation facilities, etc.), this is not always the case. In such cases, the highway noise analyst must supplement

[32] The National Geodetic Survey (NGS) is planning to replace NAD 83 and NAVD 88 with new horizontal and vertical datums in 2022. For more information and to track the progress of this effort, see the NGS web site at http://www.geodesy.noaa.gov/datums/newdatums/index.shtml.

[33] According to ESRI's on-line GIS dictionary (http://support.esri.com/en/knowledgebase/GISDictionary/search) *metadata* is defined as "information that describes the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial data may describe and document its subject matter; how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to some standard."

the project plans, profiles, and cross-sections with information from third parties. Such third-party information includes topography, land use, locations of bodies of water, forested lands, and orthographic aerial imagery.

See Chapter I for information on reliable sources of geospatial data.

Geospatial data are currently available through a variety of clearinghouses, catalogs, and portals, which are hosted by a broad range of partners/stakeholders, including various federal, state, local, and tribal governments through their agencies, as well as academia and the private sector. Refer to Chapter I for sources of publicly available elevation data and examples of other sources of geospatial data from various governmental agencies.

In addition to the sources referenced above, high-quality orthographic aerial imagery is available from applications such as Google Earth, Google Maps, and Bing Maps Land. These readily available applications provide aerial photographs, as well as "Street" or "Bird's eye" views, with ever-increasing coverage of the conterminous United States.[34] Visual inspection of the aerial photographs and other imagery obtained from these sources provides a means to determine land use along a highway corridor with a reasonable amount of accuracy. However, the ease with which land use can be derived from such sources depends on the quality of the imagery, which often varies from state to state and even within a state. Even if high quality aerial photographs and/or other geospatial data are available, a "windshield" survey, performed by personnel in the field, should be included as part of every highway noise study to verify land use along a project corridor. During a windshield survey, field personnel should identify the following land use details:

- FHWA Activity Category for all properties along the highway corridor, within 500 to 1,000 feet of the project limits,
- For multi-family residences, the number of dwelling units associated with each building and the locations of "exterior areas of frequent human use" such as patios, balconies and common areas,
- For FHWA Activity Category C land use, the locations of "exterior areas of frequent human use" (e.g., the locations of picnic tables, playground equipment, athletic fields, etc.),
- For FHWA Activity Category D land use, the construction of the building structure (e.g., wood frame, masonry, etc.) containing noise-sensitive activities,
- For FHWA Activity Category E land use, the locations of "exterior areas of frequent human use" (e.g., the locations of outdoor tables at restaurants, pools at motels, sitting areas, playground equipment, athletic courts), and
- While not necessarily a part of a windshield survey, the highway noise analyst should contact the local planning department to obtain site plans for proposed future planned development for undeveloped lands that are permitted for FHWA Activity Categories B, C, or E.

[34] Users should check the Terms and Conditions of Use for the proper use of services and materials obtained or derived from such software applications.

Loudest-hour Traffic

In accordance with 23 CFR 772.9(d), “in predicting noise levels and assessing noise impacts, traffic characteristics that would yield the worst traffic noise impact for the design year shall be used.” Research conducted in conjunction with this study revealed that SHAs have different views as to what constitutes the traffic characteristics that yield the “worst noise hour” or the “loudest hour of the day.” For example:

- The majority of SHAs use Design Hourly Volumes (DHV) along with the corresponding speeds,
- One SHA uses either Level-of-Service (LOS) C traffic volumes, or DHV, with posted speeds limits,
- Another SHA calculates hourly vehicle volumes (over a 15- or 24-hour period) based on the equations contained in the latest version of the Highway Capacity Manual (HCM), combined with either posted speed limits or operational speeds, and then identifies the single hour that produces the highest traffic noise level along a particular stretch of the highway.

Some SHAs have published detailed procedures for the development of traffic data (vehicle volumes, speeds, and classifications) for use in highway noise studies. Two examples are Florida DOT and Virginia DOT. Their procedures are summarized below:

- In May 2015, the Florida DOT (FDOT) published a new guidance document to assist highway noise analysts “in the prediction of existing and future traffic noise levels and the evaluation of the effectiveness of noise barriers while providing consistent, predictable, and repeatable noise studies.”[35] The FDOT Handbook provides references to more detailed guidance[36,37] on the development of traffic conditions that are representative of the “worst case” noise condition. For FDOT noise studies, the “worst case” traffic noise condition is based either on LOS C volumes and posted speed limits or Directional Demand Hourly Volumes (DDHV). The FDOT Handbook provides guidance on the calculation of DDHV in the event that traffic volumes are provided in the form of Annual Average Daily Traffic (AADT).
- The Virginia DOT (VDOT) considers hourly traffic volume, speed, and vehicle mix for both peak hours and off-peak hours, to the extent that such data are available, to determine the worst noise hour of the day. The Virginia DOT experience is that while the *peak traffic hour* often coincides with the *worst noise hour,* it is not always the case. For example, when peak-hour traffic volumes approach the capacity of a highway facility, operating speeds may be affected, causing the worst noise hour to differ from the peak traffic hour. In addition, off-peak truck percentages or atypical hourly traffic distributions may have the same effect. The Virginia DOT has found

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[35] Florida Department of Transportation, “Traffic Noise Modeling and Analysis Practitioners Handbook,” Environmental Management Office, May 5, 2015. Available at: http://www.dot.state.fl.us/emo/pubs/Traffic%20Noise%20Modeling%20and%20Analysis%20Practitioners%20Handbook.pdf.

[36] Florida Department of Transportation, “Project Traffic Forecasting Handbook,” 2014. Available at: http://www.dot.state.fl.us/planning/statistics/trafficdata/ptf.pdf

[37] Florida Department Transportation, “Project Traffic Forecasting,” Topic No. 525-030-120-h, effective April 17, 2012. Available at: http://www.dot.state.fl.us/planning/statistics/tmh/project_traffic_forecasting_proc.pdf

that the worst noise hour may coincide with off-peak hours due to peak-hour congestion, especially on predominantly commuter routes.[38]

As demonstrated by the different approaches used in the previous examples, the highway noise analyst should verify the established procedures for developing worst case traffic conditions, if any, with the noise specialist at the SHA in which the highway project is located. When developing the worst noise hour traffic for a highway project, the following Best Practices also should be considered:

- Traffic data should be developed for major non-project roadways within the study area; non-project roadways may dominate the noise environment at a receiver of interest and consequently limit the effectiveness of a noise barrier.
- If hourly traffic data are available, conduct a "loudest hour" analysis to determine the hourly traffic conditions (vehicle volume, speed, and mix) that combine to produce the worst noise hour of the day. Experience has shown that the loudest hour does not always coincide with either of the peak traffic hours. In some cases, off-peak hours may be the worst case for noise.
- If the traffic for the worst-case noise hour is based on a capacity-related approach, ensure that the vehicle speeds are not representative of a congested roadway. The traffic conditions for the worst noise hour should represent free-flow traffic conditions and not conditions for a congested facility.
- If the worst noise hour is based on DHV and speeds, evaluate the effect of directional splits for the peak traffic hours on computed noise levels adjacent to the highway. Directional splits can have non-negligible effects on computed noise levels, especially for commuter roadways. If the effect of directional split is more than 1 decibel, consider modeling different peak traffic hours for noise-sensitive land use on opposite sides of the highway.
- Long-term noise monitoring, for a minimum of 24 consecutive hours, often is used to identify the worst noise hour for existing conditions. The long-term noise measurement data along with 24-hour traffic data can inform the loudest hour determination for the future Design Year scenarios.
- Consider the recommended Best Practices for the distribution of traffic across lanes of a multiple-lane highway that are described in detail in Chapter I.

QA Processes for TNM Objects

These QA processes presume that the underlying data used to create the TNM objects are accurate and obtained from reliable sources. Upon the completion of a TNM model and prior to calculating sound levels, the highway noise analyst should verify that the input data were used to produce an accurate model of highway traffic noise. There are no shortcuts when conducting a review of TNM object input. The QA processes described below require careful attention to detail and a methodical approach on the part of the reviewer. The following table provides some items to consider when reviewing TNM objects.

[38] Virginia Department of Transportation, "Highway Traffic Noise Impact Analysis Guidance Manual," Version 6, updated July 14, 2014. Available at: http://www.virginiadot.org/projects/resources/noisewalls/Highway_Traffic_Noise_Impact_Analysis_Guidance_Manual.pdf

Table III-1. Reviewing TNM Objects

TNM Object	Feature	Comments
All objects	Object Name	For larger, more complex projects, use logical naming conventions for TNM objects (especially for roads, noise barriers, and receivers).
	Coordinates	Ensure the coordinate system (and units) are consistent with the project plans, profiles, and cross-sections. The preferred coordinate system is the SPCS NAD 83.
	Elevations	Check for gross errors in vertical geometry by using the visualization tools in the FHWA TNM. Other tools may be required for a more thorough review.
Roads	Traffic	Ensure all project roads are modeled with the appropriate traffic conditions. Review the TNM Traffic Input Table.
	Structure roads	Check the structure roadway assignments.
	Grade/profile	Check for gross errors in vertical geometry by using the visualization tools in the FHWA TNM. Spreadsheet-based tools may be required for a more thorough review. Check for grades that are 1.5 percent or more. Check the change of slope along the highway.
	Elevation	Check the elevations of all roadway segment endpoints in the vicinity of an overpass – especially if the roadway elevations were determined by “snapping” points to a DGM or TIN.
Receivers	Heights	Check receiver heights, especially for upper stories of a multi-floor building. If no information is available, assume a story is 10 feet high.
Barriers	Perturbations and height	Check for noise barriers that are non-perturbable and for barriers that have a zero (0.0) height.
	Structure barriers	Check the structure barrier/roadway assignments.
Terrain lines	Location	Consistent with other FHWA guidance, check the horizontal spacing of terrain lines. For elevated roadways on fill or on structure, ensure that terrain lines are appropriately located just outside the edge of pavement or at the toe of slope.
Ground zones	Type	Check that the appropriate ground type is used.
Building rows	Heights	Check for building rows with a zero (0.0) height. Check the building percentages.
Tree zones	Heights	Check for tree zones with a zero (0.0) height.

TNM Skew Sections, Profiles, and Perspective Views

The PI, PM, or highway noise analyst conducting a review of a completed TNM run should make use of the visualization tools that are available in the FHWA TNM to check the vertical geometry of TNM objects. TNM’s skew sections, profiles, and perspective views provide a quick way to check gross errors in vertical geometry. The visualization tools within the FHWA TNM are somewhat limited in functionality, especially with respect to Version 2.5. Therefore, more often than not, a more detailed review of the vertical geometry may be required.

Spreadsheets and GIS- or CAD-based Methods

The PI, PM, or highway noise analyst conducting a review of a completed TNM run should make use of the spreadsheet-based tools and the functionality of CAD and/or GIS applications to check the project geometry, especially for larger, more complex projects. Such tools allow for a more thorough examination of roadway profiles and grades, and allow the highway analyst to calculate roadway grade explicitly.

CAD and GIS applications also allow the highway analyst to check the proximity of various TNM object points to one another. CAD- and GIS-based tools allow highway noise analysts to code very detailed complex and geometry with relative ease. However, experience has found that automated methods for object creation can result in extraneous points in the database caused by “double-clicks” during the digitizing process. Spreadsheet tools, as well as CAD- and GIS-based tools can help users identify extraneous points and eliminate them from a TNM run, thereby minimizing potential issues with the FHWA TNM database. Note that TNM’s “Input Check” (version 2.5) has been found to miss instances of points that are too close to one another.

Sample Checklist for TNM Input

The Florida DOT has developed a checklist for the review of TNM objects and TNM input. A copy of the QA checklist is provided in Appendix F.

QA Processes for TNM Results

This section provides recommended QA processes for the review of TNM sound-level results and noise abatement designs. QA processes are described for three different scenarios: sound-level results from a single TNM run (without noise barriers for abatement); sound-level results where more than one TNM run is used to compute sound levels (i.e., for comparing sound-level results across multiple alternatives of a NEPA noise study); and sound-level results for noise barrier design.

This section presumes that the highway noise analyst has performed a noise model validation and has demonstrated that predicted traffic noise levels are within +/- 3 dBA of monitored traffic noise levels at each of the noise measurement sites.

Sound-Level Results from a Single TNM Run without Noise Barriers for Abatement

These QA processes apply to sound-level results from a single TNM run that does not contain noise barriers for abatement (but may contain noise barriers used to represent large buildings). The purpose of such a TNM run is to determine the extent of noise impact within a common noise environment and whether noise barriers are warranted.

- Review results graphically, preferably with GIS, with sound levels displayed adjacent to receiver locations on a base map showing buildings, terrain, existing roads, and any proposed roadways.
- Observe and make note of overall trends in sound levels with distance.
- Use color codes for the symbols that represent the receiver locations to convey information about noise impact and/or use labels to show sound levels at receiver locations to help determine the most important receivers.

- Look for outliers with unusually high or low sound levels, then investigate each one to see that the predicted sound level is justified (or not.). For such receivers with sound levels that do not follow the overall trends, look for the following elements in the TNM run that may be responsible for differences:
  - Shielding by nearby buildings will tend to reduce sound levels, whether the buildings are coded as building rows or as fixed-height barriers.
  - Elevation differences between the source roadways and the receiver often will affect sound levels. Higher elevation often means higher sound levels unless the roadway is in a cut and the top of cut provides noise shielding.
  - Ground type will affect sound levels such that significant areas of pavement or water between the roadways and receivers will tend to increase predicted sound levels.

Sound-Level Results where more than one TNM Run is used to Compute Sound Levels at the Same Receivers

These QA processes apply to TNM models and results that are prepared for an environmental document, where sound levels are computed for the existing conditions, along with the Design-year No-build and Build alternatives. These procedures do not consider noise barriers for abatement.

- A graphical review of the sound levels from each TNM run at each receiver is helpful. They should be color coded or ordered to make identification of the alternative that produced the results easy (round sound levels to whole decibels for ease of quick review and determining differences).
- Another very useful approach for finding trends and outliers is to compute differences in the sound levels between the different alternatives in a spreadsheet. Outliers can be spotted easily by scanning the difference lists of sound levels.
- All trends and outliers in sound-level differences by receiver between alternatives should be investigated and should appear reasonable based on knowledge of differences between the alternatives being compared in the areas of:
  - Traffic (particularly important when comparing existing and future no-build alternatives, as the roadway geometry is usually the same).
  - Receiver distances to roadways – differences in build case alternatives should have logical differences in receiver sound levels.
  - Roadway geometry and elevation – differences in elevation or the introduction of new ramps will change sound levels; such differences should be logical based on the geometric differences.

Sound-Level Results where Noise Barriers are being Evaluated for Abatement

The highway noise analyst should consider using the Noise Barrier Optimization Tool (NBOT) described in Chapter II. Its use helps to ensure consistency in the presentation of results and barrier calculations, and serves to document the noise barrier design process that yields the most cost-effective noise barrier design that meets the SHA's acoustical feasibility and design goals. The NBOT also provides a quick and effective way to review the TNM-computed sound-level results across multiple barrier analyses. Use of the spreadsheet also helps to ensure that the physical dimensions of noise barriers are calculated accurately. The following QA processes are recommended for the review of sound-level results for noise barriers:

- A graphical review of the no-barrier and with-barrier sound levels along with insertion loss by receiver is a very fast and effective way to determine if trends are appropriate and to spot any outliers. Barrier-insertion loss values generally decrease with increasing distance from the barrier and toward the ends of the barrier. In concert with that trend, with-barrier sound levels may not change very much with increasing distance from the barrier for a fairly broad area behind the barrier.
- All else being equal, increases in receiver elevation behind a barrier will result in lower insertion loss values than at other nearby receivers with lower elevation. The converse is also often true, where lower elevation receivers will usually have higher insertion loss values than surrounding receivers. This trend can be reversed in cases with elevated roadways where edge-of-pavement shielding is significant for lower-elevation receivers, already reducing noise levels. Observing the trend in no-barrier sound levels will help identify these situations.
- When reviewing different barrier designs, higher and longer barriers should result in lower with-barrier sound levels and increased insertion loss, unless other roadway sources behind the barrier become the dominant sources of noise at those receivers.

Noise Study Report Guidance and Sample Checklists

The QA processes for noise analysis reports include recommended content and level of detail appropriate for the type of study and scale of the noise analysis report. This section provides sample checklists designed to assist acoustical consultants and design engineers in the preparation of environmental noise studies and design reports prepared for SHAs. The sample checklists provide:

1. Additional information on elements to be included in noise studies that are not covered in the SHA's Policies and Procedures manual,
2. Detailed lists of the sections and contents required for noise study reports prepared for environmental document studies under the National Environmental Protection Act (NEPA) and/or applicable state environmental laws and regulations, and
3. Detailed lists and contents of reports prepared to document the results of a noise abatement design study.

The following paragraphs describe some of the elements that need to be included in SHA noise study reports (corresponding sample checklists are discussed in the next two sections). There are two fundamentally different types of noise studies and reports that are conducted for an SHA.

The first type of noise study report contributes to and supports environmental documents under NEPA and/or applicable state environmental laws and regulations, such as Environmental Assessments (EAs) and Environmental Impact Statements (EISs). These Type I studies are conducted in conjunction with a roadway improvement project. The purpose of these studies is to evaluate potential noise impacts from the proposed project, and to determine if noise abatement to mitigate those impacts would be feasible and reasonable according to FHWA and SHA policy. Portions and/or conclusions from these reports are used in the body of the Affected Environment and Environmental Consequences sections of environmental documents such as EAs and EISs. The complete noise technical report is published as an appendix to the environmental document, and is reviewed by state and federal agencies and often by members of the public through online access or at public hearings.

The second type of noise study produces a Noise Abatement Design Report. This type of study evaluates the feasibility and reasonableness of noise abatement measures and develops the acoustical design parameters for those measures. A noise abatement design study may be conducted either subsequent to an environmental document noise study, during the design phase of a Type I project, or as part of a separate Type II noise abatement project. In this latter case, the SHA often conducts a study that is a preliminary evaluation of the feasibility and reasonableness of noise abatement along the facility of interest or across the entire system. Such preliminary studies typically do not include detailed acoustical design information. In these cases, if the noise abatement measure(s) would qualify for construction, according to the state's Type II policy, a more comprehensive noise abatement design study is conducted with a more detailed noise model.

These studies report the acoustical design details of the noise abatement measures. The reports are used to assist in public involvement and to help survey public opinion on the noise abatement measures under consideration for their neighborhoods. The reports also are used by engineers to design the barriers and develop the plans and specifications for construction. Customarily, one Noise Abatement Design Report is produced for each noise barrier being evaluated, unless two or more barriers are being evaluated together as part of a system for one Common Noise Environment with one cost-effectiveness metric. For projects with several separate noise barriers, after each barrier and its report are submitted to the SHA and then reviewed and finalized, an overall barrier summary report may be produced that includes all of the separate Noise Abatement Design Reports as well as a discussion of the public involvement process.

The sample checklists discussed in the following sections provide general guidance for organizations (SHAs, engineering firms, acoustical consulting firms, etc.) that are considering the use of checklists as a means to achieve quality assurance. At the time of this report, a few SHAs have implemented checklists for the production of noise study reports. The highway analyst is encouraged to contact the noise specialist at the SHA at the outset of a project to see if checklists are being used and to request copies, as necessary.

Additional resources for the preparation of noise analysis reports are provided at the end of this chapter. See the SHA noise analysis policies and procedures guidance documents, as well as FHWA's Highway Traffic Noise: Analysis and Abatement Guidance document[39] for more information.

Sample Checklist for Noise Study Reports Supporting Environmental Documents

A sample checklist for noise study reports supporting environmental documents is provided in Appendix G. The checklist includes the sections of the report that are to be included, with check boxes for major sections with further explanation about the contents of those sections.

The checklist is to be completed by the report preparer and submitted with the report to the project manager/supervisor for review and signature. The signed checklist may be submitted with the report to the SHA for review.

[39] "Highway Traffic Noise: Analysis and Abatement Guidance," Federal Highway Administration, U.S. DOT, June 2010, revised January 2011.
http://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/analysis_and_abatement_guidance/revguidance.pdf

Sample Checklist for Noise Abatement Design Reports

A sample checklist for noise abatement design reports is provided in Appendix H. The checklist includes the sections of the report that are to be included, with check boxes for the elements. One Noise Abatement Design Report customarily is produced for each noise barrier evaluated, unless two or more barriers are being evaluated together as part of a system for one Common Noise Environment with one cost-effectiveness metric. For projects with several separate noise barriers, after each barrier and its report are finalized, an overall barrier summary report may be produced that includes all of the separate Noise Abatement Design Reports.

The checklist is to be completed by the report preparer and submitted with the report to the project manager/supervisor for review and signature. The signed checklist should be submitted with the report to SHA for review.

Additional Resources for Noise Study Report Guidance and Checklists

Many SHAs have developed suggested report outlines and checklists much like those presented in the previous section. This section of the report provides information on and links to some SHA resources thought to be of greatest potential value.

- VDOT has developed what may be the most comprehensive noise study report guidance document and checklist available in the U.S. The guidance document includes substantial detail on the contents of reports including example graphics. That checklist is provided in Appendix I of this document. Both the "Noise Report Guidance Accountability Checklist" and "Noise Report Development Guidance Document" are available for download at: http://www.virginiadot.org/projects/pr-noise-walls-about.asp.
- The California DOT (Caltrans) Technical Noise Supplement (TeNS) document provides much insightful guidance on many aspects of highway noise analysis and abatement, including reporting. Section 6 of the TeNS document is on the Noise Study Report and provides an outline followed by detailed information on what should go in each section. It includes examples of the various tables of results that go in the reports. The TeNS document is available at: http://www.dot.ca.gov/hq/env/noise/.
- FDOT has prepared the "Traffic Noise Modeling and Analysis Practitioners Handbook" to assist analysts in the prediction of existing and future traffic noise levels and the evaluation of noise barriers with the overarching goal to provide consistent, predictable, and repeatable noise studies. The FDOT handbook was published in 2015 and is available on the following webpage: http://www.dot.state.fl.us/emo/publications.shtm.
- Oregon DOT provides supplemental guidance on reporting including an outline for noise study reports (NSRs) followed by separate NSR QC and reviewer's Checklist in Appendix I of its guidance document. The QA/QC policy is in Section 10.4. The document is available at: ftp://ftp.odot.state.or.us/techserv/Geo-Environmental/Environmental/Procedural%20Manuals/Air%20and%20Noise/ODOT%20Noise%20Manual.pdf.

- Michigan DOT has developed outlines of both noise study reports for environmental documents and for noise barrier design studies, with details on table headings and what is needed in the noise study graphics. They are given in Section 7.0 of its noise guidance document at: http://michigan.gov/documents/mdot/MDOT_HighwayNoiseAnalysis_and_AbatementHandbook_358156_7.pdf.
- Minnesota DOT's 2011 guidance document, Appendix D, provides an outline with additional guidance on noise report content, including an example sound-level table. It is available at: http://www.dot.state.mn.us/environment/noise/index.html.
- North Carolina DOT (NCDOT) provides a detailed discussion of the reporting requirements in Section 12 of its guidance document, including example tables. NCDOT's reporting requirements are available at: https://connect.ncdot.gov/resources/Environmental/Compliance%20Guides%20and%20Procedures/NCDOT%20Traffic%20Noise%20Analysis%20and%20Abatement%20Manual.pdf.
- Washington State DOT has prepared a checklist for noise study reports and a very complete Word template for reports. The template includes much of the language common to all reports, as well as tables formatted for results that go in different sections of the report. Both the checklist and template are available at: http://www.wsdot.wa.gov/Environment/Air/Noise.htm.

Appendix A. List of Acronyms

3D	Three Dimensional
3DEP	3D Elevation Program
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AG	At-grade
AGL	Above Ground Level
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
BTS	Bureau of Transportation Statistics
CAD	Computer Aided Design
Caltrans	California Department of Transportation
CGIA	Center for Geographic Information and Analysis
CONUS	Conterminous United States
CNE	Common Noise Environment
DASC	Data Access & Support Center
dB	Decibel
dBA	A-weighted Decibel
DDHV	Directional Demand Hourly Volumes
DE	Depressed
DEM	Digital Elevation Model
DHV	Design Hourly Volume
DOC	Department of Commerce
DOI	Department of Interior
DOT	Department of Transportation
DRGs	Digital Raster Graphics
DSM	digital surface model
DTM	Digital Terrain Model
EA	Environmental Assessments
EB / WB	East Bound / West Bound
E/C	Effectiveness/Cost
EIS	Environmental Impact Statement
EL	Elevated
EROS	Earth Resources Observation and Science
ESRI	Environmental Systems Research Institute
FDOT	Florida Department of Transportation

FFS	Free Flow Speed
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
FSA	Farm Service Agency
GDG	Geospatial Data Gateway
GIS	geographic information systems
HCM	Highway Capacity Manual
HDM	Highway Design Manual
HOV	High Occupancy Vehicle
Ifsar	interferometric Synthetic Aperture Radar
ISO	International Organization of Standardization
Leq	Equivalent Sound Pressure Level
LiDAR	Light Detection and Ranging
LOS	Level of Service
MassGIS	Massachusetts Office of Geographic Information
mph	Miles per Hour
NAC	Noise Abatement Criteria
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NBOT	Noise Barrier Optimization Tool
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NED	National Elevation Dataset
NEPA	National Environmental Protection Act
NOAA	National Oceanic and Atmospheric Administration
NRDG	Noise Reduction Design Goal
NSDI	National Spatial Data Infrastructure
NSR	Noise Study Report
ORI	Orthorectified Radar Intensity Image
PCE	Passenger Car Equivalent
PI	Principal Investigator
PIC	Principal in Charge
PM	Project Manager
QA	Quality Assurance
QA/QC	Quality Assurance / Quality Control
QL	Quality Level
QMS	Quality Management System
SHA	State Highway Agency

SI	Substantial Increase
SPCS	State Plane Coordinate System
TeNS	Technical Noise Supplement
TIN	Triangulated Irregular Network
TNM	Traffic Noise Model
TRB	Transportation Research Board
U.S.	United States
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
USGS	U.S. Geological Survey
VDOT	Virginia Department of Transportation
vph	Vehicles per Hour

Appendix B. A Small Sample of Additional Sources for Geospatial Data

Table B-1. Sample of the Sources of Geospatial and Elevation Data used by State Highway Agencies for Traffic Noise Studies

State	Data Type	Fee	Data Source (URL if available)
FL	GIS	None	Florida Geographic Data Library http://www.fgdl.org/metadataexplorer/explorer.jsp
KS	Elevation and LiDAR (limited coverage), imagery and raster	None	State of Kansas GIS Data Access & Support Center (DASC) http://kansasgis.org/
MA	MassGIS Topo Layers	Und.[1]	Office of Geographic Information (MassGIS) http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
MT	1-Kilometer Digital Elevation Model (1992)	Free	Office of Geographic Information (MassGIS) http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
	1:250,000 scale digital elevation model	Free	Montana State Library / Defense Mapping Agency http://mslapps.mt.gov/Geographic_Information/Data/DataList/datalist_Details.aspx?did={81782118-6B47-4E55-B1A8-358A193CC899}
	USGS MTTopographic Quadrangle Images (1998): 24k, 100k, and 250k Digital Raster Graphics (DRGs).	Free	Montana State Library http://mslapps.mt.gov/Geographic_Information/Data/Topographic/Default.aspx
	USGS 24k and 100k quadrangles in DRGs	Free	Montana Topographic Map Finder: View and Download http://mslapps.mt.gov/Geographic_Information/Applications/DigitalAtlas/Default.aspx
NH	DEM and LiDAR (upon request, where available)	Free	New Hampshire's Statewide GIS Clearinghouse http://www.granit.unh.edu/
OH	Point elevations	Und.[1]	Daft Logic (appears to be of very limited use; able to check elevation on a point-by-point basis; doesn't appear that topographic data can be downloaded) http://www.daftlogic.com/sandbox-google-maps-find-altitude.htm

State	Data Type	Fee	Data Source (URL if available)
TN	Shapefiles	Free	http://viewer.nationalmap.gov/viewer/
	DGN Files	$75 per tile[2]	Metro Nashville TN GIS http://www.nashville.gov/Planning-Department/Mapping-and-GIS/Map-and-Data-Sales.aspx
	Shapefiles or DWG	$100 per map sheet[2]	Knoxville TN GIS (KGIS) http://www.kgis.org/portal/Products/DigitalData/PurchaseInformation.aspx
	Shapefiles or DWG	Variable	Hamilton County TN http://gis.hamiltontn.gov/
	On-line GIS	Free	Shelby County, TN Register of Deeds (2' Contours) http://gis.register.shelby.tn.us/
	On-line GIS	Free	Metro Nashville, TN GIS (2' Contours) http://maps.nashville.gov/propertykiva/site/main.htm
	On-line GIS	Free	Knoxville, TN (4' Contours) GIS http://www.kgis.org/KGISMaps/Map.htm
	On-line GIS	Free	Hamilton County, TN GIS (2' Contours) http://gis.hamiltontn.gov/
	On-line GIS	Free	Williamson County, TN GIS (5' Contours) http://www.williamsoncounty-tn.gov/index.aspx?NID=371
	On-line GIS	Free	Wilson County GIS (5' Contours) http://geopowered.wilson.wilsontngis.com/
VA	LiDAR (limited coverage)	Und.[1]	Virginia LiDAR www.virginialidar.com (note that this site was undergoing an update at the time this report was published.)
	DEM	Und.[1]	Via ArcGIS online (check ESRI web site)
WA	In-Roads contours	None	None, Topographic Details are surveyed by project design offices.
	Community Planning, Traffic, Other Geospatial	None	WSDOT Online Map Center http://wsdot.maps.arcgis.com/home/
	Other WSDOT GIS Data	None	WSDOT GeoData Distribution Catalog http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm

State	Data Type	Fee	Data Source (URL if available)
U.S.	USGS NED		National Elevation Dataset (NED) http://ned.usgs.gov/faq.html
	USGS National Map		http://viewer.nationalmap.gov/viewer http://nationalmap.gov/factsheets.html State 3DEP Fact Sheets; "The 3D Elevation Program (3DEP) initiative is being developed to respond to growing needs for high-quality topographic data and for a wide range of other three-dimensional representations of the Nation's natural and constructed features."
	The USGS Store: Download 7.5 minute, 15 minute, 30 minute and larger DRGs.	Free – To download DRGs; $15.00 for Hard Copy Maps	http://store.usgs.gov/b2c_usgs/usgs/maplocator/(xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT)/.do

[1] "Und" = undetermined

[2] Fee may be waived per agreement

Note: The URLs for the sources of geospatial and elevation data shown in this table were provided by the SHAs in early 2015. In mid-2015, the USGS updated several links to the *The National Map* and other related web pages. The reader is directed to the following URL which provides links to the *The National Map* and other sources for geospatial and topographic data and information: http://nationalmap.gov/.

Table B-2. Other Examples of Sources for Geospatial Data

State	Data Source (URL if available)
California	State of California Geoportal http://portal.gis.ca.gov/geoportal/catalog/main/home.page
Connecticut	Connecticut Geospatial Information Systems Council http://www.ct.gov/gis/site/default.asp
Iowa	Iowa Department of Natural Resources: Mapping and GIS http://www.iowadnr.gov/Environment/GeologyMapping/MappingGIS.aspx Natural Resources Geographic Information Systems Library https://programs.iowadnr.gov/nrgislibx/
North Carolina	Center for Geographic Information and Analysis (CGIA) http://www.cgia.state.nc.us/ or http://www.cgia.state.nc.us/DataResources/tabid/55/Default.aspx or North Carolina Department of Transportation https://connect.ncdot.gov/resources/gis/Pages/default.aspx https://connect.ncdot.gov/resources/gis/Pages/Cont-Elev_v2.aspx
North Dakota	North Dakota GIS Hub Data Portal https://apps.nd.gov/hubdataportal/srv/en/main.home
Rhode Island	http://www.edc.uri.edu/rigis/
South Carolina	South Carolina Geographic Information Systems http://gis.sc.gov/data.html Department of Natural Resources http://www.dnr.sc.gov/gis.html
Wyoming	Wyoming Geographic Information Science Center http://www.uwyo.edu/wygisc/ Wyoming Geospatial Hub http://geospatialhub.org/

Table B-3. Additional Sources of Geospatial Data for the State of Florida

Content Title	Filename	Publisher / On-line Link	Extent
FIVE-FOOT CONTOUR LINES (TOPOGRAPHY)	TOPO	Florida's Water Management Districts and U.S. Geological Survey	COUNTY
FLORIDA 2FT CONTOUR LINES BY COUNTY – 2009 (FILE GEODATABASE FORMAT)	TOPO2FT_GDB	Florida Division of Emergency Management	COUNTY
FLORIDA DIGITAL ELEVATION MODEL (DEM) MOSAIC – 5-METER CELL SIZE – ELEVATION UNITS FEET	FLIDAR_MOSAIC_FT	University of Florida GeoPlan Center	STATE
USGS 1:250,000 DIGITAL ELEVATION MODEL	USGSDEM	U.S. Geological Survey	STATE
HORIZONTAL AND VERTICAL GEODETIC CONTROL DATA FOR FLORIDA – MAY 2014	NGS_POINTS_MAY14	National Oceanic and Atmospheric Administration, National Geodetic Survey	STATE
FLORIDA DIGITAL ELEVATION MODEL (DEM) MOSAIC – 5-METER CELL SIZE – ELEVATION UNITS INCHES	FLIDAR_MOSAIC_IN	University of Florida GeoPlan Center	STATE
FLORIDA DIGITAL ELEVATION MODEL (DEM) MOSAIC – 5-METER CELL SIZE – ELEVATION UNITS CENTIMETERS	FLIDAR_MOSAIC_CM	University of Florida GeoPlan Center	STATE
US SEABED CALCULATED DATA – ATLANTIC OCEAN	SEABED_ATL_CLC_2005	U.S. Geological Survey	STATE
FLORIDA DIGITAL ELEVATION MODEL (DEM) MOSAIC – 5-METER CELL SIZE – ELEVATION UNITS METERS	FLIDAR_MOSAIC_M	University of Florida GeoPlan Center	STATE
FLORIDA 2FT CONTOUR LINES BY COUNTY – 2009 (SHAPEFILE FORMAT) **Note: More counties are available in Geodatabase format due to size limitations. See the layer TOPO2FT_GDB	TOPO2FT_SHP	Florida Division of Emergency Management	COUNTY
BATHYMETRIC CONTOURS FOR THE STATE OF FLORIDA AND SURROUNDING AREAS	BATHYM	National Oceanic and Atmospheric Administration, Coastal Services Center	STATE

Appendix C. Detailed Traffic Distributions

	Area:	ALL						Rural						Urban											
	Facility:	4-Lane		8-Lane				4-Lane		8-Lane				4-Lane		8-Lane				12-Lane (all GP) SEE NOTE					
	Lane:	1 (out)	2	1 (out)	2	3	4	1 (out)	2	1 (out)	2	3	4	1 (out)	2	1 (out)	2	3	4	1 (out)	2	3	4	5	6
ALL	Lane % MT+Bus	81.8	18.2	43.5	36.4	16.1	3.9	85	15	42	46.9	10	1.2	65.1	34.9	43.7	35.1	16.8	4.3	17.8	18.1	34.9	25.7	1.9	1.7
	Lane % HT	75.5	24.5	43.7	44.3	10.4	1.6	81.4	18.6	55.6	44.2	0.2	0	48.4	51.6	42.2	44.3	11.7	1.8	8.3	17.1	37.1	34.1	1.9	1.6
	Lane % Trucks	76.8	23.2	42.9	42.1	12.4	2.5	82.1	17.9	50.5	45.1	4	0.4	52.6	47.4	42	41.8	13.5	2.8	10.8	17.5	36.8	31.3	1.9	1.7
	Lane % Car	56.4	43.6	31.4	26.5	28.3	13.8	59	41	29.8	21.3	29.4	19.4	50.8	49.2	31.6	27.1	28.1	13.1	12.1	16	22.4	21.6	15.1	12.9
	% Total Traffic	60	40	32.6	28.6	26.4	12.4	62.6	37.4	31.2	23	27.7	18.1	51	49	32.8	29.3	26.2	11.7	12	16.1	23.7	22.3	13.9	11.9
N in Dataset		16		18				12		2				2		16				4					
With Lower (Typical) Truck Percentage	Lane % MT+Bus	81.8	18.2	38.1	40.5	17.3	4.1																		
	Lane % HT	76.9	23.1	49.4	35.8	11.8	3.1																		
	Lane % Trucks	77.7	22.3	44.2	38.5	13.7	3.6																		
	Lane % Car	53	47	30.4	26.5	29.1	14																		
	% Total Traffic	55.3	44.7	31.5	27.6	27.8	13.1																		
Dataset Truck Percentages		7-14%; 10% avg		6%-9%; 8% avg				7%-14%		Minimum: 6%				14%		Minimum: 6%				Minimum: 8%					
With Higher Truck Percentage	Lane % MT+Bus	82.8	17.2	49	32.3	14.9	3.8																		
	Lane % HT	74.7	25.3	38.1	52.7	9	0.2																		
	Lane % Trucks	76	24	41.6	45.8	11.2	1.4																		
	Lane % Car	55.3	44.7	32.4	26.5	27.4	13.7																		
	% Total Traffic	60.6	39.4	33.7	29.6	25	11.7																		
Dataset Truck Percentages		24-34%; 29% avg		12%-19%; 16% avg				24%-34%		Maximum: 7%				17%		Maximum: 19%				Maximum: 12%					
Speed	Posted Speed	60	60	60	60	60	60	65	65	65	65	65	65	55	55	55	55	55	55	55	55	55	55	55	55
	LOS C Speed																								
	Design-Hour Speed																								

Note: % Trucks = % MT + Bus + HT; % Car = % Auto + MC

Typical Truck Percentage[1]	4.30%
High Truck Percentage[1]	25%

1 Freight Facts and Figures, 2013. Pgs 17, 38. http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/13factsfigures/pdfs/fff2013_highres.pdf

Appendix D. Tabulated Noise Levels for the Modeled Scenarios using FHWA TNM 2.5

		Hard Ground Cases																	
		4-Lane At-Grade						4-Lane Depressed Rd						4-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff
50ft-5ft	5	80.4	80.2	0.2	77.4	77.4	0.0	73.4	73.5	-0.1	69.2	69.3	-0.1	73.8	72.9	0.9	68.5	67.9	0.6
100ft-5ft	5	77.8	77.7	0.1	75.0	74.9	0.1	67.8	67.9	-0.1	63.9	64.0	-0.1	72.8	72.7	0.1	68.6	68.5	0.1
200ft-5ft	5	75.0	75.0	0.0	72.1	72.1	0.0	64.1	64.2	-0.1	60.2	60.2	0.0	71.7	71.7	0.0	67.8	67.8	0.0
300ft-5ft	5	73.3	73.2	0.1	70.3	70.3	0.0	62.1	62.1	0.0	58.1	58.1	0.0	71.0	71.0	0.0	67.6	67.6	0.0
400ft-5ft	5	71.8	71.9	-0.1	68.8	68.8	0.0	60.5	60.5	0.0	56.4	56.5	-0.1	70.1	70.1	0.0	66.7	66.7	0.0
500ft-5ft	5	70.7	70.7	0.0	67.6	67.6	0.0	59.2	59.3	-0.1	55.1	55.2	-0.1	69.3	69.3	0.0	65.9	65.8	0.1
600ft-5ft	5	69.7	69.7	0.0	66.6	66.6	0.0	58.2	58.2	0.0	54.1	54.1	0.0	68.5	68.5	0.0	65.1	65.1	0.0
700ft-5ft	5	68.9	68.9	0.0	65.7	65.7	0.0	57.3	57.4	-0.1	53.2	53.2	0.0	67.9	67.8	0.1	64.4	64.4	0.0
800ft-5ft	5	68.0	68.0	0.0	64.9	64.9	0.0	56.6	56.7	-0.1	52.5	52.5	0.0	67.4	67.3	0.1	64.0	64.0	0.0
900ft-5ft	5	67.3	67.3	0.0	64.2	64.2	0.0	55.9	56.0	-0.1	51.8	51.8	0.0	66.8	66.7	0.1	63.4	63.3	0.1
1000ft-5ft	5	66.7	66.7	0.0	63.5	63.5	0.0	55.2	55.3	-0.1	51.1	51.1	0.0	66.2	66.1	0.1	62.8	62.7	0.1
AVERAGE				**0.0**			**0.0**			**-0.1**			**0.0**			**0.1**			**0.1**
MINIMUM				**-0.1**			**0.0**			**-0.1**			**-0.1**			**0.0**			**0.0**
MAXIMUM				**0.2**			**0.1**			**0.0**			**0.0**			**0.9**			**0.6**
STANDARD DEVIATION				**0.1**			**0.0**			**0.0**			**0.1**			**0.3**			**0.2**
50ft-15ft	15	80.1	80.0	0.1	77.1	77.1	0.0	77.6	77.9	-0.3	74.0	74.0	0.0	76.5	76.5	0.0	72.7	72.6	0.1
100ft-15ft	15	77.6	77.5	0.1	74.6	74.6	0.0	71.3	71.3	0.0	67.3	67.2	0.1	75.1	75.1	0.0	71.7	71.6	0.1
200ft-15ft	15	74.5	74.6	-0.1	71.7	71.6	0.1	64.7	64.8	-0.1	60.7	60.8	-0.1	72.2	72.1	0.1	68.8	68.7	0.1
300ft-15ft	15	72.6	72.5	0.1	69.7	69.7	0.0	62.3	62.3	0.0	58.2	58.3	-0.1	71.3	71.1	0.2	68.0	67.9	0.1
400ft-15ft	15	71.2	71.1	0.1	68.3	68.3	0.0	60.5	60.5	0.0	56.5	56.5	0.0	69.9	69.7	0.2	66.7	66.6	0.1
500ft-15ft	15	70.0	70.0	0.0	67.0	67.1	-0.1	59.2	59.2	0.0	55.1	55.1	0.0	69.1	69.1	0.0	66.0	66.0	0.0
600ft-15ft	15	69.0	69.0	0.0	66.0	66.0	0.0	58.1	58.1	0.0	53.9	54.0	-0.1	68.2	68.2	0.0	65.1	65.1	0.0
700ft-15ft	15	68.1	68.2	-0.1	65.2	65.2	0.0	57.1	57.2	-0.1	53.0	53.0	0.0	67.5	67.4	0.1	64.4	64.4	0.0
800ft-15ft	15	67.4	67.4	0.0	64.4	64.4	0.0	56.4	56.4	0.0	52.3	52.3	0.0	66.8	66.8	0.0	63.7	63.7	0.0
900ft-15ft	15	66.7	66.7	0.0	63.6	63.6	0.0	55.6	55.7	-0.1	51.5	51.5	0.0	66.2	66.2	0.0	63.1	63.1	0.0
1000ft-15ft	15	66.1	66.1	0.0	62.9	62.9	0.0	55.0	55.0	0.0	50.8	50.8	0.0	65.7	65.7	0.0	62.6	62.6	0.0
AVERAGE				**0.0**			**0.0**			**-0.1**			**0.0**			**0.1**			**0.0**
MINIMUM				**-0.1**			**-0.1**			**-0.3**			**-0.1**			**0.0**			**0.0**
MAXIMUM				**0.1**			**0.1**			**0.0**			**0.1**			**0.2**			**0.1**
STANDARD DEVIATION				**0.1**			**0.0**			**0.1**			**0.1**			**0.1**			**0.1**

		Soft Ground Cases																	
		4-Lane At-Grade						4-Lane Depressed Rd						4-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff	Hi Trk %	Hi Trk % Uni	Diff	Typ Trk %	Typ Trk % Uni	Diff
50ft-5ft	5	79.5	79.2	0.3	76.6	76.4	0.2	70.8	70.9	-0.1	66.2	66.2	0.0	72.3	71.5	0.8	67.1	66.6	0.5
100ft-5ft	5	75.3	75.2	0.1	72.3	72.2	0.1	62.3	62.4	-0.1	58.3	58.3	0.0	71.3	71.2	0.1	67.3	67.2	0.1
200ft-5ft	5	70.1	70.4	-0.3	66.7	66.8	-0.1	57.2	57.3	-0.1	53.2	53.3	-0.1	69.3	69.3	0.0	65.5	65.5	0.0
300ft-5ft	5	67.3	67.6	-0.3	63.7	63.8	-0.1	54.5	54.6	-0.1	50.7	50.7	0.0	67.1	67.1	0.0	63.3	63.3	0.0
400ft-5ft	5	65.7	65.9	-0.2	62.2	62.3	-0.1	52.8	52.9	-0.1	49.0	49.0	0.0	65.0	65.0	0.0	61.1	61.1	0.0
500ft-5ft	5	64.3	64.3	0.0	60.7	60.7	0.0	51.5	51.6	-0.1	47.7	47.8	-0.1	63.1	63.1	0.0	59.0	59.0	0.0
600ft-5ft	5	62.4	62.4	0.0	58.7	58.7	0.0	50.4	50.5	-0.1	46.7	46.7	0.0	61.4	61.4	0.0	57.1	57.1	0.0
700ft-5ft	5	60.6	60.5	0.1	56.8	56.7	0.1	49.4	49.5	-0.1	45.7	45.8	-0.1	59.8	59.8	0.0	55.4	55.4	0.0
800ft-5ft	5	59.1	59.0	0.1	55.2	55.1	0.1	48.6	48.7	-0.1	45.0	45.0	0.0	58.3	58.3	0.0	53.7	53.7	0.0
900ft-5ft	5	57.7	57.6	0.1	53.8	53.8	0.0	48.0	48.0	0.0	44.3	44.3	0.0	57.0	57.1	-0.1	52.4	52.5	-0.1
1000ft-5ft	5	56.5	56.4	0.1	52.6	52.5	0.1	47.3	47.4	-0.1	43.7	43.7	0.0	55.9	56.0	-0.1	51.4	51.4	0.0
AVERAGE				**0.0**			**0.0**			**-0.1**			**0.0**			**0.1**			**0.0**
MINIMUM				**-0.3**			**-0.1**			**-0.1**			**-0.1**			**-0.1**			**-0.1**
MAXIMUM				**0.3**			**0.2**			**0.0**			**0.0**			**0.8**			**0.5**
STANDARD DEVIATION				**0.2**			**0.1**			**0.0**			**0.0**			**0.3**			**0.2**
50ft-15ft	15	79.7	79.6	0.1	76.7	76.7	0.0	77.1	77.2	-0.1	73.4	73.4	0.0	75.5	75.5	0.0	71.9	71.9	0.0
100ft-15ft	15	77.1	77.0	0.1	74.2	74.2	0.0	69.3	69.3	0.0	65.2	65.2	0.0	73.9	73.8	0.1	70.3	70.3	0.0
200ft-15ft	15	73.1	73.2	-0.1	70.3	70.2	0.1	60.4	60.4	0.0	56.2	56.2	0.0	71.1	71.1	0.0	67.8	67.8	0.0
300ft-15ft	15	70.6	70.7	-0.1	67.6	67.5	0.1	56.5	56.5	0.0	52.4	52.5	-0.1	69.6	69.5	0.1	66.3	66.2	0.1
400ft-15ft	15	68.7	68.8	-0.1	65.5	65.5	0.0	54.0	54.1	-0.1	50.1	50.1	0.0	67.9	68.1	-0.2	64.7	64.8	-0.1
500ft-15ft	15	66.6	66.7	-0.1	63.1	63.1	0.0	52.3	52.3	0.0	48.4	48.4	0.0	67.0	67.3	-0.3	63.8	64.0	-0.2
600ft-15ft	15	64.9	65.0	-0.1	61.2	61.2	0.0	50.9	50.9	0.0	47.1	47.1	0.0	65.6	65.9	-0.3	62.3	62.5	-0.2
700ft-15ft	15	63.5	63.6	-0.1	59.6	59.6	0.0	49.8	49.8	0.0	46.0	46.0	0.0	64.5	64.6	-0.1	61.0	61.2	-0.2
800ft-15ft	15	62.2	62.4	-0.2	58.2	58.3	-0.1	48.8	48.9	-0.1	45.1	45.2	-0.1	63.3	63.4	-0.1	59.8	59.9	-0.1
900ft-15ft	15	61.3	61.5	-0.2	57.3	57.4	-0.1	48.0	48.1	-0.1	44.4	44.4	0.0	62.3	62.4	-0.1	58.7	58.8	-0.1
1000ft-15ft	15	60.5	60.7	-0.2	56.5	56.6	-0.1	47.3	47.4	-0.1	43.7	43.7	0.0	61.3	61.4	-0.1	57.6	57.7	-0.1
AVERAGE				**-0.1**			**0.0**			**0.0**			**0.0**			**-0.1**			**-0.1**
MINIMUM				**-0.2**			**-0.1**			**-0.1**			**-0.1**			**-0.3**			**-0.2**
MAXIMUM				**0.1**			**0.1**			**0.0**			**0.0**			**0.1**			**0.1**
STANDARD DEVIATION				**0.1**			**0.1**			**0.1**			**0.0**			**0.1**			**0.1**

		Hard Ground Cases																	
		8-Lane At-Grade						8-Lane Depressed Rd						8-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff
50ft-5ft	5	82.4	82.2	0.2	79.5	79.4	0.1	76.7	77.0	-0.3	73.5	73.4	0.1	74.7	73.5	1.2	69.9	68.9	1.0
100ft-5ft	5	80.0	80.0	0.0	77.3	77.2	0.1	71.5	71.6	-0.1	67.8	67.7	0.1	74.8	74.4	0.4	70.4	70.1	0.3
200ft-5ft	5	77.4	77.4	0.0	74.6	74.7	-0.1	67.4	67.6	-0.2	63.8	63.9	-0.1	74.2	74.1	0.1	70.3	70.3	0.0
300ft-5ft	5	75.8	75.7	0.1	72.9	72.9	0.0	65.4	65.6	-0.2	61.7	61.8	-0.1	73.2	73.1	0.1	69.5	69.4	0.1
400ft-5ft	5	74.4	74.4	0.0	71.4	71.5	-0.1	63.9	64.0	-0.1	60.1	60.2	-0.1	72.6	72.5	0.1	69.2	69.2	0.0
500ft-5ft	5	73.4	73.3	0.1	70.3	70.3	0.0	62.6	62.8	-0.2	58.8	58.9	-0.1	71.9	71.8	0.1	68.5	68.5	0.0
600ft-5ft	5	72.4	72.4	0.0	69.3	69.3	0.0	61.6	61.8	-0.2	57.8	57.8	0.0	71.1	71.1	0.0	67.8	67.7	0.1
700ft-5ft	5	71.6	71.5	0.1	68.4	68.4	0.0	60.8	60.9	-0.1	56.9	57.0	-0.1	70.4	70.4	0.0	67.1	67.1	0.0
800ft-5ft	5	70.8	70.8	0.0	67.7	67.7	0.0	60.1	60.2	-0.1	56.2	56.3	-0.1	70.0	69.9	0.1	66.6	66.6	0.0
900ft-5ft	5	70.1	70.1	0.0	67.0	67.0	0.0	59.4	59.5	-0.1	55.5	55.5	0.0	69.3	69.3	0.0	66.0	65.9	0.1
1000ft-5ft	5	69.4	69.4	0.0	66.3	66.3	0.0	58.7	58.9	-0.2	54.8	54.9	-0.1	68.7	68.7	0.0	65.4	65.4	0.0
AVERAGE				0.0			0.0			-0.2			0.0			0.2			0.1
MINIMUM				0.0			-0.1			-0.3			-0.1			0.0			0.0
MAXIMUM				0.2			0.1			-0.1			0.1			1.2			1.0
STANDARD DEVIATION				0.1			0.1			0.1			0.1			0.4			0.3
50ft-15ft	15	82.2	82.0	0.2	79.2	79.1	0.1	80.2	80.7	-0.5	77.1	77.5	-0.4	78.3	77.7	0.6	74.3	73.8	0.5
100ft-15ft	15	79.8	79.7	0.1	76.9	76.8	0.1	75.7	75.8	-0.1	72.8	72.6	0.2	76.9	76.7	0.2	73.1	73.0	0.1
200ft-15ft	15	77.0	76.9	0.1	74.1	74.1	0.0	69.8	69.6	0.2	65.3	65.2	0.1	74.7	74.5	0.2	71.4	71.3	0.1
300ft-15ft	15	75.1	75.1	0.0	72.3	72.3	0.0	65.8	66.0	-0.2	62.1	62.1	0.0	73.5	73.3	0.2	70.3	70.2	0.1
400ft-15ft	15	73.8	73.7	0.1	70.9	70.9	0.0	64.0	64.2	-0.2	60.2	60.3	-0.1	72.2	72.0	0.2	69.1	68.9	0.2
500ft-15ft	15	72.6	72.6	0.0	69.8	69.8	0.0	62.7	62.8	-0.1	58.8	58.9	-0.1	71.6	71.3	0.3	68.5	68.3	0.2
600ft-15ft	15	71.7	71.7	0.0	68.8	68.8	0.0	61.5	61.7	-0.2	57.7	57.8	-0.1	70.8	70.6	0.2	67.6	67.5	0.1
700ft-15ft	15	70.9	70.8	0.1	67.9	67.9	0.0	60.6	60.8	-0.2	56.7	56.8	-0.1	70.1	70.1	0.0	67.1	67.0	0.1
800ft-15ft	15	70.1	70.1	0.0	67.2	67.1	0.1	59.9	60.0	-0.1	56.0	56.1	-0.1	69.5	69.5	0.0	66.5	66.4	0.1
900ft-15ft	15	69.4	69.4	0.0	66.4	66.4	0.0	59.1	59.3	-0.2	55.2	55.3	-0.1	69.0	69.0	0.0	65.9	65.9	0.0
1000ft-15ft	15	68.8	68.8	0.0	65.7	65.7	0.0	58.4	58.6	-0.2	54.5	54.6	-0.1	68.4	68.4	0.0	65.4	65.3	0.1
AVERAGE				0.1			0.0			-0.2			-0.1			0.2			0.1
MINIMUM				0.0			0.0			-0.5			-0.4			0.0			0.0
MAXIMUM				0.2			0.1			0.2			0.2			0.6			0.5
STANDARD DEVIATION				0.1			0.0			0.2			0.1			0.2			0.1

		Soft Ground Cases																	
		8-Lane At-Grade						8-Lane Depressed Rd						8-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	i Trk % Un	Diff	Typ Trk %	p Trk % U	Diff	Hi Trk %	i Trk % Un	Diff	Typ Trk %	p Trk % U	Diff	Hi Trk %	i Trk % Un	Diff	Typ Trk %	p Trk % U	Diff
50ft-5ft	5	81.7	81.2	0.5	78.9	78.5	0.4	75.2	75.4	-0.2	71.9	72.0	-0.1	73.3	72.2	1.1	68.6	67.7	0.9
100ft-5ft	5	78.3	78.1	0.2	75.4	75.2	0.2	67.0	66.8	0.2	62.8	62.5	0.3	73.2	72.8	0.4	69.1	68.8	0.3
200ft-5ft	5	74.2	74.3	-0.1	71.3	71.3	0.0	60.4	60.6	-0.2	56.7	56.8	-0.1	71.3	71.2	0.1	67.5	67.4	0.1
300ft-5ft	5	70.9	71.5	-0.6	67.9	68.3	-0.4	57.7	57.9	-0.2	54.1	54.2	-0.1	69.2	69.2	0.0	65.5	65.4	0.1
400ft-5ft	5	68.7	69.2	-0.5	65.7	66.0	-0.3	56.1	56.3	-0.2	52.5	52.6	-0.1	67.2	67.2	0.0	63.4	63.3	0.1
500ft-5ft	5	67.3	67.7	-0.40	64.2	64.5	-0.3	54.8	55.0	-0.2	51.2	51.3	-0.1	65.4	65.3	0.1	61.4	61.4	0.0
600ft-5ft	5	66.2	66.4	-0.2	63.1	63.3	-0.2	53.7	53.9	-0.2	50.2	50.3	-0.1	63.7	63.7	0.0	59.6	59.5	0.1
700ft-5ft	5	65.1	65.2	-0.1	62.0	62.0	0.0	52.8	53.0	-0.2	49.2	49.3	-0.1	62.2	62.2	0.0	57.9	57.9	0.0
800ft-5ft	5	64.1	63.9	0.2	60.9	60.8	0.1	52.0	52.2	-0.2	48.5	48.6	-0.1	60.7	60.8	-0.1	56.3	56.4	-0.1
900ft-5ft	5	62.8	62.6	0.2	59.6	59.4	0.2	51.4	51.6	-0.2	47.8	47.9	-0.1	59.5	59.6	-0.1	55.1	55.2	-0.1
1000ft-5ft	5	61.5	61.3	0.2	58.2	58.1	0.1	50.8	51.0	-0.2	47.2	47.3	-0.1	58.5	58.5	0.0	54.1	54.1	0.0
AVERAGE				-0.1			0.0			-0.2			-0.1			0.1			0.1
MINIMUM				-0.6			-0.4			-0.2			-0.1			-0.1			-0.1
MAXIMUM				0.5			0.4			0.2			0.3			1.1			0.9
STANDARD DEVIATION				0.3			0.3			0.1			0.1			0.3			0.3
50ft-15ft	15	81.7	81.6	0.1	78.9	78.8	0.1	79.4	80.2	-0.8	76.7	77.1	-0.4	77.3	76.9	0.4	73.5	73.2	0.3
100ft-15ft	15	79.2	79.1	0.1	76.5	76.4	0.1	75.0	74.9	0.1	72.2	71.9	0.3	75.8	75.5	0.3	72.2	72.1	0.1
200ft-15ft	15	76.0	75.9	0.1	73.2	73.0	0.2	66.8	66.4	0.4	61.7	61.5	0.2	73.6	73.4	0.2	70.5	70.3	0.2
300ft-15ft	15	73.8	73.7	0.1	70.8	70.8	0.0	60.4	60.5	-0.1	56.6	56.6	0.0	71.9	71.8	0.1	68.8	68.6	0.2
400ft-15ft	15	72.2	72.0	0.2	69.0	69.0	0.0	57.8	57.9	-0.1	54.1	54.1	0.0	70.4	70.5	-0.1	67.3	67.3	0.0
500ft-15ft	15	70.5	70.5	0.0	67.3	67.3	0.0	56.0	56.1	-0.1	52.3	52.3	0.0	69.7	69.6	0.1	66.5	66.5	0.0
600ft-15ft	15	69.1	69.1	0.0	65.9	65.9	0.0	54.5	54.7	-0.2	50.9	50.9	0.0	68.4	68.4	0.0	65.2	65.2	0.0
700ft-15ft	15	67.8	67.9	-0.1	64.5	64.6	-0.1	53.3	53.5	-0.2	49.7	49.8	-0.1	67.4	67.7	-0.3	64.3	64.5	-0.2
800ft-15ft	15	66.5	66.7	-0.2	63.2	63.3	-0.1	52.4	52.5	-0.1	48.8	48.9	-0.1	66.3	66.5	-0.2	63.2	63.2	0.0
900ft-15ft	15	65.3	65.6	-0.3	62.0	62.2	-0.2	51.6	51.8	-0.2	48.0	48.1	-0.1	65.3	65.8	-0.5	62.2	62.5	-0.3
1000ft-15ft	15	64.1	64.6	-0.5	60.8	61.1	-0.3	50.9	51.1	-0.2	47.4	47.4	0.0	64.3	64.9	-0.6	61.1	61.5	-0.4
AVERAGE				0.0			0.0			-0.1			0.0			-0.1			0.0
MINIMUM				-0.5			-0.3			-0.8			-0.4			-0.6			-0.4
MAXIMUM				0.2			0.2			0.4			0.3			0.4			0.3
STANDARD DEVIATION				0.2			0.1			0.3			0.2			0.3			0.2

		Hard Ground Cases																	
		12-Lane At-Grade						12-Lane Depressed Rd						12-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff
50ft-5ft	5	83.5	83.3	0.2	80.5	80.5	0.0	79.6	79.2	0.4	75.9	75.7	0.2	73.6	74.2	-0.6	69.2	69.6	-0.4
100ft-5ft	5	81.5	81.3	0.2	78.5	78.5	0.0	74.6	74.2	0.4	70.3	70.1	0.2	75.8	75.4	0.4	71.0	71.0	0.0
200ft-5ft	5	79.2	78.9	0.3	76.1	76.0	0.1	70.2	69.9	0.3	66.3	66.1	0.2	75.5	75.1	0.4	71.4	71.2	0.2
300ft-5ft	5	77.6	77.3	0.3	74.4	74.3	0.1	68.3	67.9	0.4	64.3	64.1	0.2	75.0	74.7	0.3	71.1	70.9	0.2
400ft-5ft	5	76.3	76.0	0.3	73.1	73.0	0.1	66.8	66.4	0.4	62.7	62.5	0.2	74.3	73.9	0.4	70.4	70.3	0.1
500ft-5ft	5	75.3	74.9	0.4	72.0	71.9	0.1	65.6	65.2	0.4	61.4	61.3	0.1	73.7	73.3	0.4	70.0	69.9	0.1
600ft-5ft	5	74.3	74.0	0.3	71.0	70.9	0.1	64.5	64.2	0.3	60.4	60.2	0.2	73.0	72.7	0.3	69.4	69.3	0.1
700ft-5ft	5	73.5	73.2	0.3	70.2	70.0	0.2	63.7	63.4	0.3	59.6	59.4	0.2	72.4	72.0	0.4	68.7	68.6	0.1
800ft-5ft	5	72.8	72.4	0.4	69.4	69.3	0.1	63.0	62.6	0.4	58.8	58.7	0.1	71.8	71.5	0.3	68.2	68.1	0.1
900ft-5ft	5	72.1	71.8	0.3	68.7	68.6	0.1	62.3	61.9	0.4	58.1	57.9	0.2	71.2	70.9	0.3	67.6	67.5	0.1
1000ft-5ft	5	71.5	71.1	0.4	68.1	67.9	0.2	61.6	61.3	0.3	57.4	57.2	0.2	70.6	70.3	0.3	67.1	66.9	0.2
AVERAGE				**0.3**			**0.1**			**0.4**			**0.2**			**0.3**			**0.1**
MINIMUM				**0.2**			**0.0**			**0.3**			**0.1**			**-0.6**			**-0.4**
MAXIMUM				**0.4**			**0.2**			**0.4**			**0.2**			**0.4**			**0.2**
STANDARD DEVIATION				**0.1**			**0.1**			**0.1**			**0.0**			**0.3**			**0.2**
50ft-15ft	15	83.4	83.1	0.3	80.2	80.2	0.0	82.7	82.1	0.6	79.2	78.9	0.3	79.0	78.7	0.3	74.6	74.7	-0.1
100ft-15ft	15	81.2	80.9	0.3	78.1	78.1	0.0	78.0	77.7	0.3	74.4	74.3	0.1	78.2	77.9	0.3	74.2	74.2	0.0
200ft-15ft	15	78.6	78.4	0.2	75.6	75.4	0.2	72.4	72.0	0.4	68.0	67.8	0.2	76.3	76.0	0.3	72.8	72.7	0.1
300ft-15ft	15	77.0	76.6	0.4	73.9	73.7	0.2	69.6	69.1	0.5	65.2	64.9	0.3	75.0	74.7	0.3	71.6	71.6	0.0
400ft-15ft	15	75.6	75.3	0.3	72.6	72.5	0.1	67.0	66.6	0.4	62.9	62.7	0.2	73.8	73.5	0.3	70.4	70.4	0.0
500ft-15ft	15	74.6	74.2	0.4	71.4	71.3	0.1	65.6	65.2	0.4	61.5	61.4	0.1	73.1	72.8	0.3	69.8	69.7	0.1
600ft-15ft	15	73.7	73.3	0.4	70.5	70.4	0.1	64.5	64.1	0.4	60.4	60.2	0.2	72.4	72.1	0.3	69.1	69.0	0.1
700ft-15ft	15	72.8	72.5	0.3	69.6	69.5	0.1	63.6	63.3	0.3	59.5	59.3	0.2	71.9	71.6	0.3	68.6	68.5	0.1
800ft-15ft	15	72.1	71.8	0.3	68.9	68.7	0.2	62.8	62.5	0.3	58.7	58.5	0.2	71.4	71.0	0.4	68.1	67.9	0.2
900ft-15ft	15	71.5	71.1	0.4	68.2	68.0	0.2	62.1	61.7	0.4	57.9	57.7	0.2	70.9	70.6	0.3	67.6	67.5	0.1
1000ft-15ft	15	70.8	70.5	0.3	67.5	67.4	0.1	61.4	61.0	0.4	57.2	57.0	0.2	70.4	70.1	0.3	67.1	66.9	0.2
AVERAGE				**0.3**			**0.1**			**0.4**			**0.2**			**0.3**			**0.1**
MINIMUM				**0.2**			**0.0**			**0.3**			**0.1**			**0.3**			**-0.1**
MAXIMUM				**0.4**			**0.2**			**0.6**			**0.3**			**0.4**			**0.2**
STANDARD DEVIATION				**0.1**			**0.1**			**0.1**			**0.1**			**0.0**			**0.1**

		Soft Ground Cases																	
		12-Lane At-Grade						12-Lane Depressed Rd						12-Lane Elevated Rd					
TNM ID	Height	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff	Hi Trk %	Hi Trk % Un	Diff	Typ Trk %	Typ Trk % U	Diff
50ft-5ft	5	82.8	82.4	0.4	79.8	79.7	0.1	78.5	78.1	0.4	74.8	74.7	0.1	72.4	72.9	-0.5	68.1	68.4	-0.3
100ft-5ft	5	80.2	79.6	0.6	77.1	76.8	0.3	70.7	70.2	0.5	65.7	65.4	0.3	74.2	73.8	0.4	69.7	69.6	0.1
200ft-5ft	5	76.9	76.3	0.6	73.7	73.3	0.4	63.1	62.8	0.3	59.1	58.9	0.2	72.6	72.3	0.3	68.6	68.4	0.2
300ft-5ft	5	74.3	73.9	0.4	71.0	70.8	0.2	60.5	60.1	0.4	56.5	56.3	0.2	70.8	70.5	0.3	66.8	66.6	0.2
400ft-5ft	5	72.0	71.9	0.1	68.8	68.7	0.1	58.9	58.5	0.4	54.9	54.7	0.2	69.0	68.6	0.4	64.8	64.7	0.1
500ft-5ft	5	70.3	70.1	0.2	67.0	67.0	0.0	57.7	57.3	0.40	53.7	53.5	0.2	67.3	66.9	0.40	63.0	62.8	0.2
600ft-5ft	5	68.9	68.6	0.3	65.6	65.5	0.1	56.6	56.2	0.4	52.6	52.5	0.1	65.7	65.3	0.4	61.3	61.1	0.2
700ft-5ft	5	67.8	67.5	0.3	64.5	64.4	0.1	55.6	55.3	0.3	51.7	51.5	0.2	64.2	63.8	0.4	59.7	59.5	0.2
800ft-5ft	5	66.8	66.5	0.3	63.6	63.4	0.2	54.9	54.5	0.4	50.9	50.8	0.1	62.9	62.5	0.4	58.3	58.0	0.3
900ft-5ft	5	65.9	65.5	0.4	62.6	62.5	0.1	54.2	53.9	0.3	50.3	50.2	0.1	61.7	61.3	0.4	57.1	56.9	0.2
1000ft-5ft	5	65.0	64.6	0.4	61.7	61.5	0.2	53.7	53.3	0.4	49.7	49.6	0.1	60.7	60.2	0.5	56.1	55.9	0.2
AVERAGE				0.4			0.2			0.4			0.2			0.3			0.1
MINIMUM				0.1			0.0			0.3			0.1			-0.5			-0.3
MAXIMUM				0.6			0.4			0.5			0.3			0.5			0.3
STANDARD DEVIATION				0.2			0.1			0.1			0.1			0.3			0.2
50ft-15ft	15	83.0	82.7	0.3	80.0	79.9	0.1	82.2	81.6	0.6	79.0	78.6	0.4	78.2	77.9	0.3	74.0	74.0	0.0
100ft-15ft	15	80.7	80.4	0.3	77.7	77.6	0.1	77.3	76.9	0.4	73.9	73.7	0.2	77.1	76.9	0.2	73.4	73.4	0.0
200ft-15ft	15	77.9	77.4	0.5	74.8	74.7	0.1	69.4	69.1	0.3	64.5	64.4	0.1	75.2	74.8	0.4	71.8	71.7	0.1
300ft-15ft	15	75.9	75.4	0.5	72.8	72.5	0.3	65.7	65.1	0.6	60.5	60.2	0.3	73.7	73.4	0.3	70.4	70.3	0.1
400ft-15ft	15	74.4	73.8	0.6	71.1	70.8	0.3	61.0	60.6	0.4	56.9	56.7	0.2	72.4	72.1	0.3	69.0	68.9	0.1
500ft-15ft	15	73.0	72.4	0.6	69.7	69.3	0.4	59.1	58.7	0.4	55.0	54.8	0.2	71.5	71.1	0.4	68.1	68.0	0.1
600ft-15ft	15	71.8	71.2	0.6	68.4	68.0	0.4	57.6	57.2	0.4	53.6	53.4	0.2	70.4	70.0	0.4	67.0	66.8	0.2
700ft-15ft	15	70.7	70.1	0.6	67.2	66.8	0.4	56.3	56.0	0.3	52.3	52.2	0.1	69.8	69.2	0.6	66.3	66.0	0.3
800ft-15ft	15	69.6	69.0	0.6	66.1	65.7	0.4	55.4	55.0	0.4	51.4	51.2	0.2	68.7	68.1	0.6	65.1	64.8	0.3
900ft-15ft	15	68.5	68.0	0.5	65.0	64.7	0.3	54.6	54.2	0.4	50.6	50.5	0.1	68.1	67.4	0.7	64.4	64.1	0.3
1000ft-15ft	15	67.5	67.1	0.4	64.0	63.8	0.2	53.9	53.5	0.4	49.9	49.8	0.1	67.1	66.4	0.7	63.4	63.0	0.4
AVERAGE				0.5			0.3			0.4			0.2			0.4			0.2
MINIMUM				0.3			0.1			0.3			0.1			0.2			0.0
MAXIMUM				0.6			0.4			0.6			0.4			0.7			0.4
STANDARD DEVIATION				0.1			0.1			0.1			0.1			0.2			0.1

Appendix E. Sample QA Plan

The QA Plan in this appendix presents some concepts that organizations may wish to consider when drafting a QA Plan. Note that this sample QA Plan is provided solely as an example and that the language appearing in it is not mandated by the FHWA. For instance, although some state SHAs may wish to do so, the FHWA is not mandating the amount of experience for different levels of staff who may work on a highway noise study. The sample QA Plan is based on one organization's approach to QA.

Sample Quality Assurance Plan

- The objectives of the Quality Assurance (QA) Plan are to improve the quality of noise models and noise analysis reports prepared by this organization. Adherence and commitment to the policies and procedures outlined herein help ensure, to the degree practicable, that:
    - Noise models are accurate and developed in a consistent, traceable, and repeatable manner.
    - Noise analysis reports meet all applicable regulatory requirements and present the results of the noise study in a clear and concise manner.
- All members of the highway noise team shall understand and commit to the policies and objectives of the QA Plan.
- The QA Plan will be reviewed and updated, as necessary, on a periodic basis, or in conjunction with planned revisions to the SHA Noise Abatement Policy developed under 23 CFR 772.
- Each highway noise study will be overseen and reviewed by a Principal Investigator (PI) or Principal in Charge (PIC) who has specialized experience in highway noise analysis. The PI typically has 20 or more years of experience, has demonstrated exceptional technical ability, and has shown the ability to find creative and appropriate solutions to complex technical problems. The PI often serves as the Project Manager (PM) on the largest or most complex highway noise projects. On smaller or less complex projects, the PM often has 5 or more years of experience in highway noise analysis. In such cases, a PI will always serve in an oversight and review capacity for the PM.
- The PI will review each study proposal for the completeness and reasonableness of the proposed staffing, scope of work, schedule, and cost budget.
- At the beginning of the study, the PI and/or PM will review all mapping and traffic data provided for the noise analysis to ensure that the data are sufficient. For example, mapping must be extensive enough to include all potentially impacted land uses, and traffic data must be sufficient to allow computation of the loudest hour of the day, as required by the FHWA.
- On the larger projects, which require a number of staff members working simultaneously, regular project team meetings shall be held by the PM to ensure accuracy and consistency among all of the team members.
- Before conducting highway noise measurements, all staff members shall be trained in all aspects of measurement by experienced senior staff, or through approved training courses and/or programs.
- During noise measurement surveys for roadway improvement projects, traffic classification counts shall be conducted simultaneously with noise measurements of the existing facility whenever possible. These traffic counts will then be used as input to the noise prediction model to compute noise levels from the existing facility at the measurement locations. Comparison of the measured noise levels to the computed levels will serve to validate the noise model or to assist in refining modeling assumptions that relate to sound propagation.

- Before performing any noise modeling, all staff members shall be trained in all aspects of highway noise prediction and the details of the models by qualified senior staff, or through approved training courses.
- Upon completion of a TNM model for a highway project, the PM shall review the modeled geometry and traffic input with the analyst, and as needed, complete a TNM Object input checklist to document the review.
- For NEPA noise studies, the PI and/or PM shall review the predicted noise levels at each reported measurement and prediction location for each of the project alternatives to ensure consistency of predicted noise levels among multiple alternatives. Differences in predicted levels among alternatives shall be evaluated to determine the appropriateness of the observed differences. Where differences are greater or less than expected by the PI and/or PM, or where sound levels appear incorrect, the input data, calculation procedures, and modeling assumptions shall be reviewed and discussed. TNM-computed noise levels shall not be finalized until all reported noise levels are reviewed and approved by the PI and/or PM.
- Prior to finalizing the noise impact inventory, the PI and/or PM shall carefully review the inventory numbers by FHWA Activity Category and by alternative and the locations of the impacted properties. The review evaluates both the appropriateness of impact numbers along each alternative and the differences among alternatives. Where, in the judgment of the PI/PM, inventory numbers or impact locations appear to be inappropriate or inconsistent among alternatives, the approach, analysis, and assumptions shall be reviewed, and the impact inventory shall not be finalized until all reported numbers meet the approval of the PI/PM.
- The noise abatement (acoustical) design shall be conducted in accordance with the individual SHA's requirements pertaining to barrier feasibility and reasonableness. Prior to finalizing any noise abatement design, the PI and/or PM shall carefully review the details of each barrier concept including location, height, length, range of insertion loss predicted, number of homes protected, cost, and cost effectiveness. Based on professional judgment, the PI and/or PM may provide suggestions to modify the design to improve cost-effectiveness, provide additional protection, or limit cost. In the case of final barrier design studies, after barrier designs are finalized to the satisfaction of the PI/PM, they shall be submitted to the SHA for review prior to submitting a draft noise study report. Finally, modifications to the abatement designs shall be made as requested by the SHA, prior to submitting the final noise study report.
- All draft and final versions of noise study reports and noise abatement design reports shall be reviewed and approved by the PI and/or PM before submittal to the SHA.
- All checklists prepared for TNM object input and/or noise analysis reports should be submitted to the SHA as part of the project closeout process.

Appendix F. FDOT’s Checklist for TNM Objects

TRAFFIC NOISE MODEL (TNM) INPUT FILE CHECK LIST

Project Name and Limits:
County:
FPID Number:
FDOT District:
Analyst/Organization:

PROJECT ALTERNATIVE

- ☐ Existing Conditions (Year ____)
- ☐ No Build Conditions (Design Year ____)
- ☐ Build Alternative (Design Year ____) Location: ______________________________

TNM INPUT

File Name: __________________________

- ☐ Run Identification Correct
- ☐ Units in file - English or Metric
- ☐ Pavement type – Average & Default Ground Type – Lawn
- ☐ Traffic volumes & posted speeds match Noise Study Report & Approved Traffic Volumes
- ☐ Roadway and Ground Zones named correctly
- ☐ Receiver heights (5 ft), Criteria (66 dBA), and Substantial Increase (15 dBA)
- ☐ All noise sensitive areas/sites represented
- ☐ Tree Zone heights and locations correct
- ☐ Building Row heights and locations correct
- ☐ Terrain Line heights and limits correct
- ☐ Ground Zone designations and limits correct
- ☐ Roadway width, elevations, and directions correct
- ☐ Ground elevations at proposed barrier locations and receivers correct
- ☐ Input file includes all appropriate Roadways, Ground Zones, Existing barriers/berms, Tree Zones, Bridges, and Building Rows
- ☐ Cross section data along roadway verified using skew view in TNM
- ☐ TNM print outs checked for missing data and data consistent within each category

Name of Reviewer: __________________________

Date of Review: _____________________________

Figure F-1. Florida DOT's TNM Input File QC Checklist

Source: Florida Department of Transportation, "Traffic Noise Modeling and Analysis Practitioners Handbook: Appendix C," Environmental Management Office, May 5, 2015. Available at: http://www.dot.state.fl.us/emo/pubs/Traffic%20Noise%20Modeling%20and%20Analysis%20Practitioners%20Handbook.pdf

Appendix G. Sample Checklist for Noise Study Reports Supporting Environmental Documents

The sample checklist in this appendix is intended to be used during the preparation of a noise study report that contributes to and supports an environmental document under NEPA and/or applicable state environmental laws and regulations. Examples of such environmental documents include Environmental Assessments (EAs) and Environmental Impact Statements (EISs). The purpose of these studies is to evaluate potential noise impacts from the proposed project, and to determine if noise abatement to mitigate those impacts would be feasible and reasonable according to FHWA and SHA policy. Portions and/or conclusions from these reports are used in the body of the Affected Environment and Environmental Consequences sections of environmental documents such as EAs and EISs. The complete noise technical report is published as an appendix to the environmental document, and is reviewed by state and federal agencies and often by members of the public through online access or at public hearings.

Checklist for Noise Study Reports Supporting Environmental Documents

1. Executive Summary

- ☐ A synopsis of the project improvements, noise impact criteria, affected noise-sensitive land use, predicted noise impact by alternative, and potential noise abatement measures by alternative.

2. Introduction

- ☐ Project overview. Appropriate background, specific details of the proposed roadway improvements, existing year, design year.

- ☐ Study Area. Summary of noise-sensitive land uses in the study area and their locations. A map of the study area is useful in this section.

- ☐ Study Participants. Report authors and those who provided data for the study.

3. Noise Terminology and Criteria

- ☐ Regulations and Guidelines. FHWA and SHA regulations, guidance documents, full references and active links to documents.

- ☐ Noise Abatement Criteria. Definitions, Table of Activity Categories, criteria and descriptions, description of acoustical metrics including dBA and L_{eq}, "approach or exceed" discussion and the definition of one decibel as "approach," discussion of the "substantial increase" impact criterion and the SHA's definition of substantial increase in existing levels.

- ☐ State DOT Noise Abatement Guidelines. (Details of this discussion can go here or in Section 7.) Description of feasibility requirements including acoustical feasibility (minimum 5 dBA reduction) and constructability. Description of reasonableness requirements including cost-effectiveness criteria, noise reduction design goals, and consideration of property owner viewpoints. Differences between the cost-effectiveness evaluation approach for Activity Category B uses and that for Categories C and E.

4. Existing Noise Environment

- ☐ Existing Noise Monitoring. Narrative summary of noise monitoring program, including dates, times, locations, noise sources (traffic and otherwise), range of measured sound levels. Tables of pertinent information at each noise monitoring site, including location, time, measured L_{eq} (traffic only and total, if available), dominant noise sources. Graphic showing locations where noise monitoring was conducted. For long-term, 24-hour measurements, graphs of the measured hourly L_{eq}s and other metrics, as appropriate.

- ☐ Predicted Existing Noise Levels. Summary of the methods used to predict existing noise levels at all receptors evaluated for noise impact.

5. Predicted Noise Levels

- ☐ Noise Prediction Model. Discussion of the noise model used for noise predictions – TNM version number and general description of the modeling approach, level of detail, and the modeled elements.

- ☐ Noise Model Validation. Discussion of the noise model validation procedure, table comparing measured and predicted sound levels with counted traffic, showing difference to tenths of decibels. Potential reasons for substantial variations, explanations for differences greater than 3 decibels.

- ☐ Traffic Data for Noise Prediction. Description of traffic data sources, characteristics, how loudest traffic hour is determined. Refer to appendix that includes tables listing all traffic data used in noise modeling.

- ☐ Presentation of Results. Descriptions of predicted noise levels by alternative (including Existing and future No-build) in noise sensitive areas (Common Noise Environments). Table of noise levels for noise-sensitive receptors modeled in the FHWA TNM for each alternative. Large projects with hundreds of receptors may show sound-level ranges by Common Noise Environment (CNE) in the report body with an appendix that lists noise levels at all receptors. For each receptor, tables should provide site ID cross-referenced to graphic, site address or description, land use/category, applicable NAC, number of dwelling units or equivalent as well as the predicted L_{eq}(h) sound levels for each alternative. A scale graphic, preferably with an aerial photograph base, showing the entire project study area, CNE boundaries, line work depicting the proposed roadway improvements, receptor locations and site ID, and project limits as appropriate. As appropriate, receptor markers may be color-coded in the graphic to indicate noise impact status and also barrier benefit status.

6. Noise Impact Assessment

- ☐ Presentation of Noise Impact. Narrative and tabular summaries of the predicted noise impact of the project for all alternatives, grouped by CNE. Residential impact is assessed by number of dwelling units, recreational areas by the SHA's equivalent receptor units. Narrative discussion to include reasons for notable differences in predicted impact across alternatives in areas where they occur.

7. Noise Abatement Measures

- ☐ Alternative Mitigation Measures. Narrative discussion describing alternative abatement measures that were considered, including traffic management, alteration of horizontal or vertical alignment, and the use of buffer zones.

- ☐ Noise Barriers. If not presented in Section 3, discussion of all SHA Feasibility and Reasonableness requirements and criteria (See Section 3, 3rd bullet). Detailed narrative descriptions of all noise barriers evaluated, including those found to be not feasible, those found to be feasible but not reasonable, and those found to be both feasible and reasonable. Tables and narratives should list barrier location, CNE, applicable project alternative, barrier length, barrier height range, barrier surface area, total barrier cost, average noise reduction, number of receptors impacted, impacted and benefited, and total benefited, and the computed SHA cost-effectiveness metric. Graphics should be included to show the locations of all noise barriers that were evaluated for the study, including those found to be not feasible and/or reasonable. Different symbols should be used in the graphics to depict the results of the feasibility/reasonableness determinations, i.e., “Not Feasible”, “Feasible and Not Reasonable”, and “Feasible and Reasonable”.

8. Construction Noise

☐ Identification of potential highway construction noise impacts and abatement measures that could or will be used to mitigate the impacts.

9. Public Involvement

☐ Discussion of public hearings, meetings and survey/voting details and results, as appropriate.

10. Information for Local Government Officials

☐ <u>Noise-Compatible Land-Use Planning.</u> Narrative about communication with local officials about land-use planning adjacent to highways to minimize the potential impacts of highway noise. Provide links to FHWA-sponsored reports on noise-compatible land-use planning.

☐ <u>Noise Impact Zones in Undeveloped Land along the Study Corridor.</u> Discussion of and presentation of noise impact zones (distances to NAC contour) in any undeveloped land in the study area.

☐ <u>Federal Participation.</u> Discusses the limits of Federal-aid participation in Type II projects (noise abatement only, not part of a highway improvement project).

☐ <u>State DOT’s Noise Abatement Program.</u> Provides reference and link to SHA noise abatement program guidebook.

11. Appendices

☐ <u>Description of Noise Metrics.</u> Additional description of noise metrics may be included, as appropriate.

☐ <u>Traffic Data Used in Noise Modeling.</u> Tables including volumes and speeds by TNM vehicle type for all roadway links for all alternatives studied and presented.

☐ <u>TNM tables.</u> TNM results and input tables may be provided as appropriate. As-needed, submission of TNM electronic files may be more practical for larger noise studies.

☐ <u>Noise Measurement Program Details.</u> Additional information and data from the noise measurement program may be included, as appropriate. Such information may include field data sheets, photographs, noise monitor output, and field calibration records.

- ☐ Predicted Sound Levels. If not included in report body, predicted sound levels by alternative for each receptor with ID cross-referenced to graphic. For each receptor, tables should provide site ID, site address or description, land use/category, applicable NAC, number of dwelling units or recreational receptors represented, and the predicted project sound levels for each alternative.

- ☐ Feasibility/Reasonableness Worksheets. Worksheets for all barriers evaluated and presented in the report, as appropriate.

I have reviewed the report entitled____ and I have determined that it complies with the guidance and checklists in this document as well as with SHA policies and FHWA Regulations and Guidance.

____

Supervisor signature Date

Appendix H. Sample Checklist for Noise Abatement Design Reports

The sample checklist in this appendix is intended to be used for the preparation of a Noise Abatement Design Report, which provides the acoustical design details of the noise abatement measure under evaluation and documents the outcome of the feasibility/reasonableness determination. Such reports are used to assist in public involvement and to help survey public opinion on the noise abatement measures under consideration for their neighborhoods. The reports also are used by engineers to design the barriers and develop the plans and specifications for construction.

Customarily, one Noise Abatement Design Report is produced for each noise barrier under evaluation, unless two or more barriers are being evaluated together as part of a noise barrier system for one Common Noise Environment (CNE) with one cost-effectiveness metric. Some noise abatement design studies may consider only a single noise barrier for a single CNE, while other studies projects may consider multiple noise barriers for multiple CNEs. In the latter case, an overall noise barrier summary report also may be produced that includes all of the Noise Abatement Design Reports for each individual noise barrier, or noise barrier system, as well as a discussion of the public involvement process and other relevant information.

If an overall noise barrier summary report is produced for a highway project, it should include graphics to show the locations of all noise barriers that were evaluated for the study, including those found to be not feasible and/or not reasonable. Different symbols should be used in the graphics to depict the results of the feasibility/reasonableness determinations, i.e., “Not Feasible”, “Feasible and Not Reasonable”, and “Feasible and Reasonable”.

Checklist for Noise Abatement Design Reports

1. Title of Project and Barrier Number

2. Summary Table of Barrier Design Results

- ☐ Measured existing noise levels in study area
- ☐ Computed loudest-hour noise levels (no barrier)
- ☐ Number of dwelling units/receptors in study area exposed to noise impact
- ☐ Computed loudest-hour noise levels (with barrier)
- ☐ Number and percentage of impacted receptors receiving at least 5 dBA insertion loss, and whether the barrier is feasible
- ☐ Number and percentage of impacted receptors where noise reduction design goal is achieved
- ☐ Total number of benefited receptors
- ☐ Average barrier insertion loss for benefited receptors
- ☐ Total barrier length
- ☐ Barrier height range
- ☐ Total barrier surface area
- ☐ Total barrier cost and assumed unit cost
- ☐ Need for sound absorptive materials
- ☐ Computed SHA cost-effectiveness metric and whether the barrier is reasonable

3. Narrative Summary of Noise Barrier Characteristics and Benefits

- ☐ Study background and participants
- ☐ Noise measurements
- ☐ Noise modeling, including roadway sources, terrain, and shielding characteristics, any unique characteristics of the study area that presents modeling challenges
- ☐ Noise model validation details
- ☐ Traffic data source and loudest hour determination

- ☐ Characteristics of evaluated barrier (location, length, height, square feet, cost, need for sound absorptive material, etc.)

- ☐ Details of the barrier's feasibility and reasonableness determination, including:

    - Any analysis of barrier concepts associated with a mix of Activity Categories B, C, and/or D to be benefited by the same barrier, and the details of that analysis
    - Number of impacted dwelling units/recreational receptors
    - Number and percentage of impacted receptors receiving at least 5 dBA insertion loss and whether the barrier is feasible
    - Number and percentage of impacted receptors where noise reduction design goal is achieved and whether that reasonableness criterion is achieved
    - Total number of benefited receptors
    - Insertion loss range and average
    - Cost-effectiveness metric calculation compared to SHA criteria

4. Table of Loudest-hour Noise Levels

- ☐ Receptor number, location/address, Activity Category
- ☐ Number of dwelling units and/or recreational units represented by each receptor
- ☐ No-barrier L_{eq}
- ☐ With-barrier L_{eq}
- ☐ Barrier insertion loss

5. Table of Barrier Design Data and Sound Attenuation Line

- ☐ Barrier location referenced to roadway baseline station number
- ☐ Barrier X and Y coordinates
- ☐ Elevation of ground at barrier base
- ☐ Elevation of top of barrier
- ☐ Height of barrier above ground

6. Table of Receptor Locations

- ☐ Receptor number and location/address
- ☐ Receptor X, Y and Z coordinates

7. Table of Noise Measurement and Model Validation Results

- ☐ Site number and location/address
- ☐ Measured Total L_{eq} and Traffic-only L_{eq}, if different/available
- ☐ TNM-predicted noise levels using traffic counted during measurement program as input
- ☐ Site-by-site differences between measured and predicted sound levels, and average for all sites

8. Table of Traffic Data Used in Noise Analysis

- ☐ Roadways modeled
- ☐ Loudest-hour Auto, Medium Truck and Heavy Truck volumes and speeds

9. Graphics of Study Area, Barrier, Noise Receptors and Results

- ☐ Two similar graphics may be produced, different only in the labeling of receptors
- ☐ Both graphics should include:
    - o Base map of aerial photography if possible
    - o Noise measurement sites
    - o All receptor locations
    - o The location of the proposed noise barrier, with station labeling to match the barrier design table
    - o Elevation contours, if available
- ☐ In one graphic, the receptor labels should indicate receptor site numbers to match the tables
- ☐ In the second graphic, the receptor labels should indicate three sound-level values: no-barrier L_{eq}, with-barrier L_{eq}, and insertion loss. In this graphic, it is useful to color-code the receptor symbols for the following four categories: impacted and benefited, impacted and not benefited, not impacted but benefited, not impacted and not benefited.

10. Public Involvement

- ☐ Discussion of public meetings and survey/voting details and results, as appropriate.

I have reviewed the report entitled ____ and I have determined that it complies with the guidance and checklists in this document as well as with SHA policies and FHWA Regulations and Guidance.

____

Supervisor signature Date

Appendix I. VDOT's Noise Report Guidance and Accountability Checklist

The Virginia DOT's "Noise Report Guidance Accountability Checklist" and other resources are available for download at: http://www.virginiadot.org/projects/pr-noise-walls-about.asp.

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