FINAL REPORT

On Project 25-34
Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)

APPENDIX E
Multi-Lane Highways

Prepared for:
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Appendix E Multi-Lane Highways

E.1 Introduction

Based upon the extensive FHWA TNM modeling experience of team members and the review of data obtained from our literature search, a number of candidate modeling techniques for multi-lane highways were previously identified and presented in the Interim Technical Report.

Typical issues encountered in FHWA TNM modeling of roadway sections which contain more than one travel lane in each direction include:

- Modeling groups of lanes versus modeling each lane as its own roadway
- How much to overlap lanes
- How to represent shoulders and median areas
- How to represent edge of roadway section diffraction points
- Shielding of one roadway by another roadway, such as in a bifurcated roadway section
- Modeling super-elevated roadways
- It is envisioned that the FHWA TNM Version 3.0 will eventually be capable of modeling multi-lane highways via use of its multi-lane tool; however, this version is not yet available for use and its limitations and graphic functionality are still being evaluated. Therefore, evaluations using FHWA TNM Version 3.0 were not conducted.

In evaluating the modeling techniques related to multi-lane highways, the team focused on the bulleted items listed above, addressing traffic and noise measurements associated with locations with relatively non-complex topography. The evaluation and testing reinforced the team's knowledge that other factors such as pavement type, ground type, topography, noise barriers, etc. affect noise levels. The influences of these factors were determined to often be more significant than the variations of noise levels associated with the different techniques for modeling roadway lanes, shoulders, and median areas. While various pavement and ground types exist for the selected sites, no attempts were made as part of this task to address their variability factors in developing best modeling practices for multi-lane highways.

In selecting measurement and validation data related to multi-lane highways, the team focused on collecting information for receptors located on adjacent lands level with the highway, elevated with respect to the highway, and lower than the elevation of the highway. Sites without median barriers were also selected to eliminate this variable from the other variables examined. No data could be obtained for bifurcated highway projects without median barriers or outside Jersey barriers. Note that the topic of median barriers is addressed by the team in Chapter 5and Appendix D.

The techniques associated with FHWA TNM Version 2.5 were evaluated and tested using measurement data from the six selected projects described in paragraph E.2 of this appendix. Suggested best modeling practices related to modeling multi-lane highways were developed based upon this evaluation and testing.

E.2 Measurement Locations Evaluated

By far, the highest quality of measurement and validation data exists in recent studies conducted by the Volpe Center. From this data, the following three Volpe sites were selected for the evaluation of multi-lane highways:

- Volpe Site AZ3B – This site is located in Arizona and is part of Volpe's Arizona Quiet Pavement Program evaluation project. The site is relatively flat and the six-lane divided highway (three lanes in each direction) is relatively level. The shoulder was modeled by Volpe as a roadway with no traffic, referred to herein as a "dummy lane". In 2008, three sets of measurements were taken at three primary locations – 50 feet, 95 feet, and 246 feet from the center of the near lane. The reference (50 foot) microphone was positioned at five feet above the roadway while the microphone heights at the 95-foot and 246-foot locations were positioned at five feet above the ground. Travel lane widths were input as 12.1 feet. Lane by lane traffic data (volumes, speed, and composition) was recorded and one-third octave band measurements were obtained.

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 1 Volpe Site AZ3B in Arizona

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 2 Volpe Site AZ3B Setback measurements

- Volpe Site 01MA – In 2008, measurements were taken at this site, located adjacent to Route 24 in Massachusetts for use by Volpe in its FHWA TNM Validation Project. The site is relatively flat and the four-lane divided highway (two lanes in each direction) is relatively level. The paved shoulders were modeled as ten-foot wide roadways with no traffic. Measurements were taken at 5 feet and 15 feet above the ground at distances of 50, 100, and 200 feet from the center of the near lane. Travel lane widths were input as 12.1 feet. Lane-by-lane traffic data was recorded and one-third octave band measurements were obtained.

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 3 Volpe Site 01MA in Massachusetts

- Volpe Site 20PA - This site is located adjacent to Interstate 81 (I-81) west of Harrisburg, Pennsylvania and is part of Volpe's FHWA TNM Phase 2 Validation Project. In 2001, noise measurements were taken at four sites adjacent to the four-lane divided highway (two lanes in each direction) with a wide grass median. The sites were located at 90 feet, 200 feet, 400 feet, and 600 feet on generally level terrain, except for the 600-foot site which was approximately 14 feet higher than the others. Travel lane widths were input as 12.1 feet. Lane-by-lane traffic data was recorded and one-third octave band measurements were obtained.

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 4 Volpe Site 20PA in Pennsylvania

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 5 Volpe Site 20PA Setback measurements

- Volpe Site 19PA - This site is located adjacent to US Route 30 in Coatesville, Pennsylvania, and is part of Volpe's FHWA TNM Phase 2 Validation Project. In 2001, noise measurements were taken at seven sites adjacent to the four-lane divided highway (two lanes in each direction) with a grass median. The sites were located at 50 feet, 200 feet, 400 feet, 500 feet, and 700 feet along a center offset row of microphones. While the terrain at the reference (50') microphone was lower than the roadway, the other sites were located on terrain that generally rose in elevation with distance from the roadway. Two of the seven sites were located to the sides of the central offset line, with microphones set at 15 feet above the ground. Travel lane widths were input as 12.1 feet. Lane-by-lane traffic data was recorded and one-third octave band measurements were obtained.

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 6 Volpe Site 19PA in Pennsylvania

Source: J. Rochat, U.S. DOT Volpe Center Acoustics Facility

Figure 7 Volpe Site 19PA Setback measurements

In addition to the evaluation and testing of the high quality noise measurement and traffic data available from the above discussed Volpe studies, the team also evaluated and tested modeling techniques using four data sets from the following project, which used a simplified technique in modeling a multi-lane highway:

- U.S. Route 35 Noise Analysis Project, Dayton, OH – In 2005, EA conducted a variety of noise measurements for a section of US 35 as part of its preliminary noise evaluation for the Ohio Department of Transportation's (ODOT) proposed reconstruction and widening project. Numerous measurement sites were located along this four-lane highway (two lanes in each direction) at locations level with the highway and above and below the elevation of the highway. Lanes were grouped and represented by a single roadway in each direction, with the edge of shoulder diffraction edge defined by the outside edge of the modeled roadway closest to the measurement sites.

In addition to utilizing measurements taken at the above locations, the team considered measurements taken at an additional location adjacent to Interstate 95 in Philadelphia, PA in a limited evaluation of a multi-lane highway section where each roadway lane's profile was independently modeled. Receptors at this location were located approximately 50 and 100 feet from the highway and approximately 15 feet below roadway grade.

E.3 Evaluation of Modeling Techniques

Based on review of data collected by the team and input from team members and other noise specialists contacted, candidate modeling techniques were previously identified by the team. For evaluation and testing of each one of these techniques, the team utilized the measurement and traffic information from the bulleted projects described in paragraph E.2. This process resulted in the development of recommended best modeling practices to apply when modeling multi-lane highways using the FHWA TNM.

Receptors located at various distances from the highway were evaluated using each of the techniques discussed below. In its evaluation of each of these modeling techniques, the team utilized 67 individual measurements and related traffic information associated with the five bulleted projects listed in paragraph E.2. These measurements were taken at distances ranging from 50 feet to 700 feet from the center of the near traffic lane at points where the measurement site (microphone) ranged from approximately 20 feet below the elevation of the highway to near level with the highway to approximately 29 feet above the highway.

E.3.1 Description of Modeling Techniques

Candidate modeling techniques have been selected for basic FHWA TNM input elements related to roadways, shoulders, and diffraction edges, with consideration given to the bulleted factors listed in paragraph E.1. For all projects, the ground type for any area existing between the inside shoulders was defined by the default ground type designated in the project's FHWA TNM run. The three basic modeling techniques are defined as follow:

E.3.1.1 Dummy Lane (DL) Technique

This technique involves representing a shoulder in the FHWA TNM by entering it as a roadway with a defined width and elevation. The width of any designated outside dummy lane is typically set so as to also define the roadway section's diffraction point.

E.3.1.2 Ground Zone (GZ) Technique

This technique involves defining a shoulder in the FHWA TNM by representing the area of the shoulder with a ground zone. When representing a shoulder with a ground zone, the outside edge of the shoulder must be defined by a terrain line unless its elevation is the same as the adjacent topography and the elevation of that adjacent topography is correctly defined in the FHWA TNM..

E.3.1.3 Adjacent Lane Width (ALW) Technique

This technique involves defining a shoulder in the FHWA TNM by establishing the outside of the shoulder by designating an appropriate width for its adjacent roadway lane. This width can also be used to define the outside diffraction edge of the roadway section.

E.3.2 Application of techniques to projects

Various technique sub-categories are listed below, with the project identified where each sub-category was evaluated. The best-performing methodologies were identified and used to develop best modeling practices for multi-lane highways.

E.3.2.1 Modeling roadways

- Grouping lanes: All projects
  - 2-lane grouping: Volpe Sites 01MA, 19PA, and 20PA, and EA's US35 Site
  - 3-lane grouping: Volpe Site AZ3B, Volpe Site 01MA, EA's I-95 GIR Site (NB lanes)
  - 4-lane grouping: EA's I-95 GIR Site (SB lanes)
- Modeling each lane separately: All projects
  - Directional roadway's profile applied to each directional travel lane: All bulleted projects listed in paragraph E.2.
  - Different roadway profile applied to each travel lane to represent roadway super-elevation: EA's I-95 GIR Site
  - Lane overlaps of 0.1 foot, 1.0 foot, 5 feet, and 10 feet: All bulleted projects listed in paragraph E.2.

E.3.2.2 Modeling shoulders

- Modeled as separate roadways (dummy lanes) without traffic (DL): All projects
- Modeled as Ground Zone (GZ): All bulleted projects listed in paragraph 8.2.
- Incorporated in adjacent modeled roadway lane's width (ALW): All bulleted projects listed in paragraph E.2.

E.3.2.3 Establishing roadway section diffraction edges

- Based on edge of shoulder in dummy lane (DL) technique
- Incorporated in modeled roadway width in adjacent lane width (ALW) technique
- Using terrain lines in ground zone (GZ) technique

E.3.3 Comparison of modeling techniques for selected projects

Results of the comparison of the various modeling techniques are presented in Table 1. These differences were calculated from the noise level predictions for each technique. Related FHWA TNM data files are included on the CD-ROM on file at Environmental Acoustics. Table 1 includes the measured minus modeled noise levels for each of the three primary modeling techniques previously described – Dummy Lane (DL), Ground Zone (GZ), and Adjacent Lane Width (ALW). For each of these techniques, values are provided for four-lane overlap options plus a grouped lane option.

Table 1(Part 1) Measured minus modeled noise level comparisons

Project		Analysis Site Characteristics		Measured Minus Modeled L_{eq}(h) in dB(A): Using Dummy Travel Lanes to Represent Paved Shoulder Areas (DL) — Each Lane Modeled Separately					Paved Shoulders Defined by Ground Zone (GZ) — Each Lane Modeled Separately					Paved Shoulders Defined by Adjacent Lane Width (ALWAW) — Each Lane Modeled Separately				
I.D.	Location	Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping
3B AZ (955)	Arizona	50	5.0	-1.7	-1.7	-1.7	-1.8	-1.7	-1.8	-1.8	-1.8	-1.8	-1.8	-1.7	-1.7	-1.7	-1.8	-1.8
3B AZ (1010)	Arizona	50	5.0	-1.4	-1.4	-1.5	-1.6	-1.5	-1.5	-1.5	-1.6	-1.6	-1.6	-1.4	-1.4	-1.5	-1.5	-1.6
3B AZ (1040)	Arizona	50	5.0	-1.7	-1.7	-1.8	-1.9	-1.8	-1.8	-1.8	-1.9	-1.9	-1.8	-1.7	-1.7	-1.8	-1.8	-2.6
3B AZ (955)	Arizona	95	-0.9	0.6	0.6	0.6	-0.2	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	0.5	0.5	0.5	0.6	1.2
3B AZ (1010)	Arizona	95	-0.9	1.2	1.2	1.1	0.4	0.6	0.5	0.5	0.5	0.4	0.5	1.1	1.1	1.1	1.2	1.7
3B AZ (1040)	Arizona	95	-0.9	1.0	1.0	1.0	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.9	0.9	1.0	1.0	1.6
3B AZ (955)	Arizona	246	0.0	0.0	0.0	-0.1	-0.3	-0.7	-0.1	-0.1	-0.2	-0.3	-0.7	0.1	0.0	-0.1	-0.2	-0.7
3B AZ (1010)	Arizona	246	0.0	0.3	0.3	0.2	0.0	-0.4	0.2	0.2	0.1	0.0	-0.4	0.4	0.3	0.2	0.1	-0.5
3B AZ (1040)	Arizona	246	0.0	0.4	0.4	0.3	0.3	-0.2	0.4	0.4	0.3	0.3	-0.3	0.5	0.5	0.4	0.4	-0.4
19PA (1140)	Coatesville, PA	50	5.0	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
19PA (1500)	Coatesville, PA	50	5.0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.8
19PA (1540)	Coatesville, PA	50	5.0	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
19PA (1140)	Coatesville, PA	200	14.7	0.7	0.7	0.6	0.5	0.4	0.5	0.5	0.5	0.4	0.1	0.4	0.3	0.3	0.2	0.1
19PA (1500)	Coatesville, PA	200	14.7	0.3	0.3	0.2	0.0	0.0	0.2	0.2	0.0	-0.1	-0.3	0.0	0.0	-0.1	-0.2	-0.4
19PA (1540)	Coatesville, PA	200	14.7	1.7	1.7	1.6	1.4	1.4	1.6	1.6	1.5	1.4	1.1	1.4	1.4	1.3	1.3	1.1
19PA (1140)	Coatesville, PA	200	24.7	0.9	0.9	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.6	0.8	0.8	0.7	0.8	0.7
19PA (1500)	Coatesville, PA	200	24.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.3
19PA (1540)	Coatesville, PA	200	24.7	1.4	1.4	1.2	1.2	1.2	1.3	1.3	1.2	1.2	1.1	1.3	1.3	1.2	1.2	1.2
19PA (1140)	Coatesville, PA	400	20.6	0.0	-0.1	-0.1	-0.3	-0.4	-0.3	-0.3	-0.4	-0.4	-0.6	-0.4	-0.4	-0.5	-0.6	-0.7
19PA (1500)	Coatesville, PA	400	20.6	-0.1	-0.1	-0.2	-0.4	-0.4	-0.3	-0.3	-0.5	-0.6	-0.6	-0.4	-0.4	-0.5	-0.7	-0.7
19PA (1540)	Coatesville, PA	400	20.6	1.3	1.3	1.2	1.1	1.1	1.1	1.1	1.0	0.9	0.8	1.1	1.1	1.0	0.8	0.8
19PA (1140)	Coatesville, PA	500	24.6	-0.3	-0.4	-0.5	-0.7	-0.8	-0.6	-0.6	-0.7	-0.8	-1.0	-0.7	-0.7	-0.8	-1.0	-0.9
19PA (1500)	Coatesville, PA	500	24.6	0.2	0.1	0.0	-0.2	-0.1	0.0	-0.1	-0.2	-0.4	-0.4	-0.1	-0.1	-0.2	-0.5	-0.4
19PA (1540)	Coatesville, PA	500	24.6	1.8	1.7	1.6	1.4	1.5	1.5	1.5	1.5	1.4	1.3	1.6	1.6	1.5	1.3	1.3
19PA (1140)	Coatesville, PA	700	28.4	-2.7	-2.8	-2.9	-3.0	-3.0	-2.9	-2.9	-3.0	-3.1	-3.3	-2.9	-2.9	-3.0	-3.1	-3.0
19PA (1500)	Coatesville, PA	700	28.4	-1.0	-1.0	-1.2	-1.3	-1.2	-1.2	-1.2	-1.3	-1.5	-1.6	-1.1	-1.1	-1.2	-1.4	-1.5
19PA (1540)	Coatesville, PA	700	28.4	0.4	0.4	0.3	0.2	0.2	0.3	0.2	0.1	0.0	-0.1	0.4	0.4	0.3	0.1	0.2
US35 (M18a)	Dayton, OH	61	9.0	0.6	0.5	0.3	0.4	0.0	1.2	1.1	0.8	0.3	-0.2	0.2	0.2	0.0	-0.2	-0.5
US35 (M18b)	Dayton, OH	61	9.0	3.2	3.2	3.0	3.1	2.6	3.9	3.8	3.5	3.0	2.4	2.9	2.8	2.6	2.4	0.2
US35 (M9)	Dayton, OH	165	-20.0	0.4	0.5	0.6	0.7	0.4	0.6	0.6	0.6	0.5	0.7	0.2	0.2	0.4	0.5	0.0
US35 (M1)	Dayton, OH	175	20.0	1.6	1.5	1.3	1.0	1.8	1.1	1.1	1.0	0.9	0.5	1.7	1.7	1.4	1.1	0.5

KEY
- Within 1 dB
- >1 to 2 dB
- >2 to 3 dB
- Greater than 3 dB
- Best Performing

Table 1(Part 2) Measured minus modeled noise level comparisons

Project		Analysis Site Characteristics		Measured Minus Modeled L_{eq}(h) in dB(A)														
				Using Dummy Travel Lanes to Represent Paved Shoulder Areas (DL)					Paved Shoulders Defined by Ground Zone (GZ)					Paved Shoulders Defined by Adjacent Lane Width (ALWAW)				
				Each Lane Modeled Separately					Each Lane Modeled Separately					Each Lane Modeled Separately				
I.D.	Location	Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping	0.1' Lane Overlap	1' Lane Overlap	5' Lane Overlap	10' Lane Overlap	2 or 3 Lane Grouping
20PA (1200)	Harrisburg, PA	90	6.0	0.2	0.1	-0.4	-1.0	-0.8	0.0	-0.1	-0.3	-0.5	1.3	-0.8	-0.8	-1.0	-1.0	-1.1
20PA (1250)	Harrisburg, PA	90	6.0	-0.4	-0.5	-1.0	-1.5	-1.4	-0.4	-0.5	-0.7	-1.0	-1.1	-1.2	-1.3	-1.5	-1.6	-1.6
20PA (855)	Harrisburg, PA	90	6.0	0.5	0.4	0.0	-0.4	-0.3	0.7	0.7	0.4	0.1	1.8	-0.2	-0.2	-0.5	-0.6	-0.7
20PA (855)	Harrisburg, PA	90	16.0	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.3	0.5	0.8	0.5	0.5	0.5	0.5	0.5
20PA (1200)	Harrisburg, PA	90	16.0	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.1	0.5	0.2	0.2	0.2	0.2	0.2
20PA (1250)	Harrisburg, PA	90	16.0	0.0	0.0	0.0	-0.1	0.0	0.1	0.0	-0.1	-0.1	-0.3	0.0	0.0	0.0	0.0	0.0
20PA (855)	Harrisburg, PA	200	7.0	-2.9	-3.0	-3.3	-3.6	-3.7	-2.8	-2.9	-3.1	-3.2	-2.7	-3.3	-3.3	-3.6	-3.8	-4.4
20PA (1200)	Harrisburg, PA	200	7.0	-3.2	-3.3	-3.7	-4.0	-4.2	-3.5	-3.5	-3.7	-3.8	-3.2	-3.9	-4.0	-4.2	-4.4	-4.9
20PA (1250)	Harrisburg, PA	200	7.0	-3.8	-3.8	-4.2	-4.5	-4.7	-3.9	-3.9	-4.1	-4.2	-4.7	-4.3	-4.4	-4.6	-4.9	-5.4
20PA (855)	Harrisburg, PA	200	17.0	0.6	0.5	0.3	0.2	0.2	0.9	0.8	0.4	0.3	1.4	0.2	0.2	0.2	0.2	0.3
20PA (1200)	Harrisburg, PA	200	17.0	0.2	0.1	-0.2	-0.2	-0.2	0.4	-0.3	0.0	-0.1	0.9	-0.3	-0.3	-0.3	-0.3	-0.2
20PA (1250)	Harrisburg, PA	200	17.0	-0.4	-0.5	-0.7	-0.8	-0.8	-0.2	-0.3	-0.6	-0.7	-0.5	-0.8	-0.8	-0.8	-0.8	-0.8
20PA (855)	Harrisburg, PA	400	7.0	-3.8	-3.9	-4.0	-4.3	-4.3	-3.6	-3.7	-3.8	-4.0	-3.4	-4.2	-4.3	-4.4	-4.5	-4.6
20PA (1200)	Harrisburg, PA	400	7.0	-4.3	-4.4	-4.6	-4.9	-4.9	-4.4	-4.4	-4.5	-4.6	-4.0	-4.9	-4.9	-5.0	-5.1	-5.2
20PA (1250)	Harrisburg, PA	400	7.0	-3.7	-3.8	-4.0	-4.2	-4.3	-3.7	-3.7	-3.9	-4.0	-4.2	-4.2	-4.3	-4.3	-4.4	-4.6
20PA (855)	Harrisburg, PA	400	17.0	-1.6	-1.7	-1.9	-2.1	-1.8	-1.2	-1.3	-1.6	-1.7	-0.8	-2.0	-2.1	-2.2	-2.4	-2.2
20PA (1200)	Harrisburg, PA	400	17.0	-2.2	-2.3	-2.6	-2.8	-2.6	-2.2	-2.2	-2.5	-2.6	-1.5	-2.9	-2.9	-3.0	-3.1	-3.0
20PA (1250)	Harrisburg, PA	400	17.0	-2.8	-2.8	-3.1	-3.3	-3.1	-2.5	-2.6	-2.9	-3.0	-3.1	-3.3	-3.3	-3.4	-3.5	-3.4
20PA (855)	Harrisburg, PA	600	19.0	-1.1	-1.3	-1.6	-1.9	-1.6	-1.4	-1.4	-1.5	-1.6	-1.5	-1.4	-1.5	-1.8	-2.1	-2.9
20PA (1200)	Harrisburg, PA	600	19.0	-1.9	-2.0	-2.3	-2.6	-2.5	-2.2	-2.2	-2.3	-2.4	-2.3	-2.3	-2.4	-2.7	-3.0	-3.8
20PA (1250)	Harrisburg, PA	600	19.0	-2.2	-2.3	-2.5	-2.8	-2.7	-2.4	-2.5	-2.6	-2.7	-3.1	-2.5	-2.6	-2.8	-3.2	-4.0
20PA (855)	Harrisburg, PA	600	29.0	-2.1	-2.1	-2.4	-2.6	-2.4	-1.7	-1.7	-1.9	-2.1	-1.7	-2.4	-2.5	-2.8	-3.0	-3.3
20PA (1200)	Harrisburg, PA	600	29.0	-2.8	-2.9	-3.1	-3.4	-3.3	-2.8	-2.9	-3.0	-3.1	-2.6	-3.4	-3.5	-3.8	-4.0	-4.2
20PA (1250)	Harrisburg, PA	600	29.0	-3.2	-3.2	-3.4	-3.7	-3.6	-3.0	-3.0	-3.2	-3.3	-4.0	-3.6	-3.7	-4.0	-4.2	-4.4
01MA (1315)	Massachusetts	50	5.0	-3.1	-3.2	-3.6	-3.8	-3.7	-2.9	-3.0	-3.5	-3.8	-3.7	-3.5	-3.6	-3.9	-3.9	-3.7
01MA (1515)	Massachusetts	50	5.0	-2.1	-2.1	-2.4	-2.5	-2.3	-1.9	-2.0	-2.3	-2.5	-2.3	-2.3	-2.4	-2.5	-2.5	-2.3
01MA (1315)	Massachusetts	50	15.0	-2.0	-2.0	-2.0	-2.1	-1.8	-2.0	-2.0	-2.1	-2.1	-2.0	-2.0	-2.0	-2.1	-2.2	-1.9
01MA (1515)	Massachusetts	50	15.0	-0.9	-0.9	-0.9	-1.0	-0.6	-1.0	-1.0	-1.0	-1.0	-0.9	-0.9	-1.0	-1.0	-1.1	-0.8
01MA (1315)	Massachusetts	100	5.0	-3.7	-3.9	-4.6	-5.4	-5.5	-3.8	-3.9	-4.6	-5.4	-5.4	-4.9	-5.0	-5.3	-5.9	-6.1
01MA (1515)	Massachusetts	100	5.0	-3.0	-3.2	-4.0	-4.8	-4.9	-3.7	-3.8	-4.2	-4.8	-4.8	-4.3	-4.3	-4.6	-5.1	-5.2
01MA (1315)	Massachusetts	100	15.0	-2.2	-2.2	-2.2	-2.2	-2.1	-2.2	-2.2	-2.2	-2.2	-2.1	-2.3	-2.3	-2.2	-2.2	-2.1
01MA (1515)	Massachusetts	100	15.0	-1.7	-1.7	-1.7	-1.7	-1.6	-1.7	-1.7	-1.7	-1.7	-1.6	-1.7	-1.7	-1.7	-1.7	-1.6
01MA (1315)	Massachusetts	200	5.0	-2.2	-2.4	-3.2	-4.3	-4.0	-2.8	-2.9	-3.5	-4.3	-4.6	-3.4	-3.5	-4.3	-5.3	-5.9
01MA (1515)	Massachusetts	200	5.0	-1.3	-1.5	-2.3	-3.6	-3.7	-2.6	-2.7	-3.1	-3.6	-4.4	-2.8	-2.9	-3.7	-4.6	-5.2
01MA (1315)	Massachusetts	200	15.0	-1.8	-2.0	-2.9	-3.2	-3.1	-1.8	-1.9	-2.8	-3.2	-3.0	-2.5	-2.6	-3.1	-3.2	-3.1
01MA (1515)	Massachusetts	200	15.0	-1.2	-1.4	-2.3	-2.4	-2.3	-1.4	-1.5	-2.2	-2.4	-2.3	-1.8	-1.9	-2.4	-2.5	-2.4

KEY	
	Within 1 dB
	>1 to 2 dB
	>2 to 3 dB
	Greater than 3 dB
	Best Performing

In applying the various modeling techniques to the bulleted projects listed in paragraph E.2, several conclusions became evident. These conclusions are listed and discussed below and relate to the evaluation of these specific projects.

1. While there were a few "outlying" values, the vast majority of analysis sites showed little variation between the techniques in terms of the difference between measured and modeled values. This is documented in Table 2, which also shows that the average measured versus modeled absolute differences for each technique were approximately 0.5 to 0.6 dB.
2. Table 3 shows the measured minus modeled noise level variation of the four evaluated lane overlap options. This information indicates that with the exception of a few "outlying" values, the vast majority of analysis sites showed little variation between the techniques in terms of the difference between measured and modeled values. Even including the outlying values, the average measured versus modeled absolute differences for all techniques was approximately 0.7 dB. Evaluation of the data appeared to indicate that the differences between values at sites located significantly lower than the elevation of the highway showed greater differences between techniques when modeling grouped roadway lanes than when modeling individual lanes. However, sufficient receptors did not exist in the selected projects to verify this possibility.
3. Table 4 tabulates the "best performances" of the evaluated modeling techniques in terms of their modeled values matching the measurement values. The data in this table give some indications that it may be best to keep lane overlap distances in the 0.1 to 1.0 foot range and that using the Dummy Lane technique may be the best in terms of best performances. The Ground Zone technique employing grouped lanes resulted in a similar number of best performances. Most of these GZ best performances were associated with sites that were elevated with respect to the roadway. These observations, while pointing to some trends, are not sufficient in themselves to formulate a best modeling practice.
4. The uncertainties inferred in item 3 above are due to a variety of factors associated with the measurement sites evaluated.
    a. Some sites, such as the Arizona site (3BAZ) and the Massachusetts site (01MA) had quieter pavements than the average pavement used in the FHWA TNM evaluation runs. This was recognized by Volpe and discussed in the 2010 FHWA Report titled *Ground and Pavement Effects using FHWA's Traffic Noise Model® 2.5*. Also discussed in the FHWA report were the influences of differing ground types. In the calculation of noise level differences reported herein (in our report), adjustments were made to the Arizona and Massachusetts project data in an attempt to account for pavement and ground types. This was more successful for the Arizona project than for the Massachusetts project, probably since the adjacent ground type in Arizona appeared to be easily defined. Regardless, in its evaluations, the team was more focused on the comparison of the relative differences in modeling techniques (which technique more closely replicated the measured data) than in the absolute difference between measured and modeled noise levels.

    b. All Volpe sites had excellent lane-by-lane traffic data and controlled simultaneous noise measurements taken during 5-minute time periods. This data was extrapolated to a one-hour period for modeling purposes. Noise measurements taken by EA for the Dayton, Ohio (US 35) and Philadelphia (I-95 GIR) projects were conducted in a more traditional project-related noise study manner with 20-minute long measurement periods and simultaneous traffic data collected for each roadway direction, but for all lanes combined. While speeds were sometimes checked by electronic devices, they were more often estimated by traveling car methods. As such, variations in traffic data collection and noise measurement procedures are factors influencing measured minus modeled noise levels.

c. Evaluation of data indicated that shadow zones associated with vehicle to source noise paths are a function of specific geometrics of each site and that lines of sight can, in certain situations, be influenced by a minor shift in vehicle positions. Differences in predicted values are more likely to occur in grouped lanes versus individual lane comparisons.

For the selected bulleted projects described in paragraph E.2, the factors discussed above have the potential for creating more of a variation between measured and modeled values than do the different multi-lane modeling techniques evaluated. This potential, plus the fact that only a few insights into the development of a best modeling practice could be gleaned from the evaluation of the selected sites, prompted the team to consider a generic site where most of the above factors could be normalized and where differences associated with the analysis techniques could be better determined.

Table 2 (Part 1) Range of measured minus modeled L_{eq} variation of modeling analysis techniques

Project		Analysis Site Characteristics		Measured Minus Modeled L_{eq}(h) in dB(A)								
				Using Dummy Travel Lanes to Represent Paved Shoulder Areas (DL)			Paved Shoulders Defined by Ground Zone (GZ)			Paved Shoulders Defined by Adjacent Lane Width (ALW)		
				Variation of Absolute Values Between Lane Treatment Methods			Variation of Absolute Values Between Lane Treatment Methods			Variation of Absolute Values Between Lane Treatment Methods		
I.D.	Location	Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	Least	Greatest	Range of Absolute Differences	Least	Greatest	Range of Absolute Differences	Least	Greatest	Range of Absolute Differences
3B AZ (955)	Arizona	50	5.0	-1.7	-1.8	0.1	-1.8	-1.8	0.0	-1.7	-1.8	0.1
3B AZ (1010)	Arizona	50	5.0	-1.4	-1.6	0.2	-1.5	-1.6	0.1	-1.4	-1.6	0.2
3B AZ (1040)	Arizona	50	5.0	-1.7	-1.9	0.2	-1.8	-1.9	0.1	-1.7	-2.6	0.9
3B AZ (955)	Arizona	95	-0.9	0.0	0.6	0.6	-0.1	-0.2	0.1	0.5	1.2	0.7
3B AZ (1010)	Arizona	95	-0.9	0.4	1.2	0.8	0.4	0.5	0.1	1.1	1.7	0.6
3B AZ (1040)	Arizona	95	-0.9	0.4	1.0	0.6	0.3	0.4	0.1	0.9	1.6	0.7
3B AZ (955)	Arizona	246	0.0	0.0	-0.7	0.7	-0.1	-0.7	0.6	0.0	-0.7	0.7
3B AZ (1010)	Arizona	246	0.0	0.0	-0.4	0.4	0.0	-0.4	0.4	0.1	-0.5	0.4
3B AZ (1040)	Arizona	246	0.0	-0.2	0.4	0.2	0.3	0.4	0.1	0.4	0.5	0.1
19PA (1140)	Coatesville, PA	50	5.0	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.2	0.1
19PA (1500)	Coatesville, PA	50	5.0	-0.3	-0.3	0.0	-0.3	-0.4	0.1	-0.3	-0.8	0.5
19PA (1540)	Coatesville, PA	50	5.0	0.5	0.6	0.1	0.5	0.5	0.0	0.5	0.6	0.1
19PA (1140)	Coatesville, PA	200	14.7	0.4	0.7	0.3	0.1	0.5	0.4	0.1	0.4	0.3
19PA (1500)	Coatesville, PA	200	14.7	0.0	0.3	0.3	0.0	0.3	0.3	0.0	-0.4	0.4
19PA (1540)	Coatesville, PA	200	14.7	1.4	1.7	0.3	1.1	1.6	0.5	1.1	1.4	0.3
19PA (1140)	Coatesville, PA	200	24.7	0.7	0.9	0.2	0.6	0.8	0.2	0.7	0.8	0.1
19PA (1500)	Coatesville, PA	200	24.7	0.5	0.6	0.1	0.4	0.5	0.1	0.3	0.5	0.2
19PA (1540)	Coatesville, PA	200	24.7	1.2	1.4	0.2	1.1	1.3	0.2	1.2	1.3	0.1
19PA (1140)	Coatesville, PA	400	20.6	-0.1	-0.4	0.3	-0.3	-0.6	0.3	-0.4	-0.7	0.3
19PA (1500)	Coatesville, PA	400	20.6	-0.1	-0.4	0.3	-0.3	-0.6	0.3	-0.4	-0.7	0.3
19PA (1540)	Coatesville, PA	400	20.6	1.1	1.3	0.2	0.8	1.1	0.3	0.8	1.1	0.3
19PA (1140)	Coatesville, PA	500	24.6	-0.4	-0.8	0.4	-0.6	-1.0	0.4	-0.7	-1.0	0.3
19PA (1500)	Coatesville, PA	500	24.6	0.0	0.2	0.2	0.0	-0.4	0.4	-0.1	-0.5	0.4
19PA (1540)	Coatesville, PA	500	24.6	1.4	1.8	0.4	1.2	1.5	0.3	1.3	1.6	0.3
19PA (1140)	Coatesville, PA	700	28.4	-2.7	-3.0	0.3	-2.9	-3.3	0.4	-2.9	-3.1	0.2
19PA (1500)	Coatesville, PA	700	28.4	-1.0	-1.3	0.3	-1.2	-1.6	0.4	-1.1	-1.5	0.4
19PA (1540)	Coatesville, PA	700	28.4	0.2	0.4	0.2	0.0	0.3	0.3	0.1	0.4	0.3
US35 (M18a)	Dayton, OH	61	9.0	0.0	0.6	0.6	-0.3	1.2	0.9	0.0	-0.5	0.5
US35 (M18b)	Dayton, OH	61	9.0	3.0	3.2	0.2	2.4	3.9	1.5	0.2	2.9	2.7
US35 (M9)	Dayton, OH	165	-20.0	0.4	0.7	0.3	0.5	0.7	0.2	0.0	0.5	0.5
US35 (M1)	Dayton, OH	175	20.0	1.0	1.8	0.8	0.5	1.1	0.6	0.5	1.7	1.2

Table 2 (Part 2) Range of measured minus modeled L_{eq} variation of modeling analysis techniques

Project		Analysis Site Characteristics		Measured Minus Modeled $L_{eq}(h)$ in dB(A)								
				Using Dummy Travel Lanes to Represent Paved Shoulder Areas (DL)			Paved Shoulders Defined by Ground Zone (GZ)			Paved Shoulders Defined by Adjacent Lane Width (ALW)		
				Variation of Absolute Values Between Lane Treatment Methods			Variation of Absolute Values Between Lane Treatment Methods			Variation of Absolute Values Between Lane Treatment Methods		
I.D.	Location	Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	Least	Greatest	Range of Absolute Differences	Least	Greatest	Range of Absolute Differences	Least	Greatest	Range of Absolute Differences
20PA (1200)	Harrisburg, PA	90	6.0	0.1	-1.0	0.9	0.0	1.3	1.3	-0.8	-1.1	0.3
20PA (1250)	Harrisburg, PA	90	6.0	-0.4	-1.5	1.1	-0.4	-1.1	0.7	-1.2	-1.6	0.4
20PA (855)	Harrisburg, PA	90	6.0	0.0	0.5	0.5	0.1	1.8	1.7	-0.2	-0.7	0.5
20PA (855)	Harrisburg, PA	90	16.0	0.5	0.6	0.1	0.5	0.8	0.3	0.5	0.5	0.0
20PA (1200)	Harrisburg, PA	90	16.0	0.2	0.2	0.0	0.1	0.5	0.4	0.2	0.2	0.0
20PA (1250)	Harrisburg, PA	90	16.0	0.0	-0.1	0.1	0.0	-0.3	0.3	0.0	0.0	0.0
20PA (855)	Harrisburg, PA	200	7.0	-2.9	-3.7	0.8	-2.7	-3.2	0.5	-3.3	-4.4	1.1
20PA (1200)	Harrisburg, PA	200	7.0	-3.2	-4.2	1.0	-3.2	-3.8	0.6	-3.9	-4.9	1.0
20PA (1250)	Harrisburg, PA	200	7.0	-3.8	-4.7	0.9	-3.9	-4.7	0.8	-4.3	-5.4	1.1
20PA (855)	Harrisburg, PA	200	17.0	0.2	0.5	0.3	0.3	1.4	1.1	0.2	0.3	0.1
20PA (1200)	Harrisburg, PA	200	17.0	-0.1	-0.2	0.1	0.0	0.9	0.9	-0.2	-0.3	0.1
20PA (1250)	Harrisburg, PA	200	17.0	-0.4	-0.8	0.4	-0.2	-0.7	0.5	-0.8	-0.8	0.0
20PA (855)	Harrisburg, PA	400	7.0	-3.8	-4.3	0.5	-3.4	-4.0	0.6	-4.2	-4.6	0.4
20PA (1200)	Harrisburg, PA	400	7.0	-4.3	-4.9	0.6	-4.0	-4.6	0.6	-4.9	-5.2	0.3
20PA (1250)	Harrisburg, PA	400	7.0	-3.7	-4.3	0.6	-3.7	-4.2	0.5	-4.2	-4.6	0.4
20PA (855)	Harrisburg, PA	400	17.0	-1.6	-2.1	0.5	-0.8	-1.7	0.9	-2.0	-2.4	0.4
20PA (1200)	Harrisburg, PA	400	17.0	-2.2	-2.8	0.6	-1.5	-2.6	1.1	-2.9	-3.1	0.2
20PA (1250)	Harrisburg, PA	400	17.0	-2.8	-3.3	0.5	-2.5	-3.1	0.6	-3.3	-3.5	0.2
20PA (855)	Harrisburg, PA	600	19.0	-1.2	-1.9	0.7	-1.4	-1.6	0.2	-1.4	-2.9	1.5
20PA (1200)	Harrisburg, PA	600	19.0	-1.9	-2.6	0.7	-2.2	-2.4	0.2	-2.3	-3.8	1.5
20PA (1250)	Harrisburg, PA	600	19.0	-2.2	-2.8	0.6	-2.5	-3.1	0.6	-2.5	-4.0	1.5
20PA (855)	Harrisburg, PA	600	29.0	-2.1	-2.6	0.5	-1.7	-2.1	0.4	-2.4	-3.3	0.9
20PA (1200)	Harrisburg, PA	600	29.0	-2.8	-3.4	0.6	2.6	-3.1	0.5	-3.4	-4.2	0.8
20PA (1250)	Harrisburg, PA	600	29.0	-3.2	-3.7	0.5	-3.0	-4.0	1.0	-3.6	-4.4	0.8
01MA (1315)	Massachusetts	50	5.0	-3.2	-3.8	0.6	-2.9	-3.8	0.9	-3.5	-3.9	0.4
01MA (1515)	Massachusetts	50	5.0	-2.1	-2.5	0.4	-1.9	-2.5	0.6	-2.3	-2.5	0.2
01MA (1315)	Massachusetts	50	15.0	-1.8	-2.1	0.3	-2.0	-2.1	0.1	-1.9	-2.2	0.3
01MA (1515)	Massachusetts	50	15.0	-0.6	-1.0	0.4	-0.9	-1.0	0.1	-0.8	-1.1	0.3
01MA (1315)	Massachusetts	100	5.0	-3.7	-5.5	1.8	-3.8	-5.4	1.6	-4.9	-6.1	1.2
01MA (1515)	Massachusetts	100	5.0	-3.0	-4.9	1.9	-3.7	-4.8	1.1	-4.3	-5.2	0.9
01MA (1315)	Massachusetts	100	15.0	-2.1	-2.2	0.1	-2.1	-2.2	0.1	-2.1	-2.3	0.2
01MA (1515)	Massachusetts	100	15.0	-1.6	-1.7	0.1	-1.6	-1.7	0.1	-1.6	-1.7	0.1
01MA (1315)	Massachusetts	200	5.0	-2.2	-4.3	2.1	-2.8	-4.6	1.8	-3.4	-5.9	2.5
01MA (1515)	Massachusetts	200	5.0	-1.3	-3.7	2.4	-2.6	-4.4	1.8	2.8	-5.2	2.4
01MA (1315)	Massachusetts	200	15.0	-1.8	-3.2	1.4	-1.8	-3.2	1.4	-2.5	-3.2	0.7
01MA (1515)	Massachusetts	200	15.0	-1.2	-2.4	1.2	-1.4	-2.4	1.0	-1.8	-2.5	0.7
				AVERAGE OF ALL TABLE 8.2 VARIATION RANGES>>>>		0.5	AVERAGE OF ALL TABLE 8.2 VARIATION RANGES>>>>		0.5	AVERAGE OF ALL TABLE 8.2 VARIATION RANGES>>>>		0.6

Table 3 (Part 1) Range of measured minus modeled L_{eq} variation of individual lane treatments

Analysis Site Characteristics		Measured Minus Modeled Noise Levels All Individual Lane Techniques (Excludes Grouping)		
Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	Least	Greatest	Range of Absolute Differences
50	5.0	-1.7	-1.8	0.1
50	5.0	-1.4	-1.5	0.1
50	5.0	-1.7	-1.9	0.2
95	-0.9	-0.1	-0.6	0.5
95	-0.9	0.4	1.2	0.8
95	-0.9	0.3	1.0	0.7
246	0.0	0.0	-0.3	0.3
246	0.0	0.0	0.3	0.3
246	0.0	0.3	0.5	0.2
50	5.0	0.1	0.2	0.1
50	5.0	-0.3	-0.4	0.1
50	5.0	0.5	0.5	0.0
200	14.7	0.2	0.7	0.5
200	14.7	0.0	0.3	0.3
200	14.7	1.3	1.7	0.4
200	24.7	0.7	0.9	0.2
200	24.7	0.4	0.6	0.2
200	24.7	1.2	1.4	0.2
400	20.6	0.0	-0.6	0.6
400	20.6	-0.1	-0.7	0.6
400	20.6	0.8	1.3	0.5
500	24.6	-0.4	-1.0	0.6
500	24.6	0.0	-0.5	0.5
500	24.6	1.3	1.8	0.5
700	28.4	-2.7	-3.1	0.4
700	28.4	-1.0	-1.5	0.5
700	28.4	0.0	0.4	0.4
61	9.0	0.0	1.2	1.2
61	9.0	2.4	3.9	1.5
165	-20.0	0.2	0.6	0.4
175	20.0	0.9	1.7	0.8

Table 3 (Part 2) Range of measured minus modeled L_{eq} variation of individual lane treatments

Analysis Site Characteristics		Measured Minus Modeled Noise Levels All Individual Lane Techniques (Excludes Grouping)		
Analysis Point Distance from Center of Near Lane	Height of Receptor Above Elevation of Roadway	Least	Greatest	Range of Absolute Differences
90	6.0	0.0	-1.0	1.0
90	6.0	-0.4	-1.6	1.2
90	6.0	0.0	0.7	0.7
90	16.0	0.5	0.6	0.1
90	16.0	0.1	0.2	0.1
90	16.0	0.0	-0.1	0.1
200	7.0	-2.8	-3.8	1.0
200	7.0	-3.2	-4.4	1.2
200	7.0	-3.8	-4.9	1.1
200	17.0	0.2	0.9	0.7
200	17.0	0.0	0.4	0.4
200	17.0	-0.2	-0.8	0.6
400	7.0	-3.6	-4.5	0.9
400	7.0	-4.3	-5.1	0.8
400	7.0	-3.7	-4.4	0.7
400	17.0	-1.2	-2.4	1.2
400	17.0	-2.2	-3.1	0.9
400	17.0	-2.5	-3.5	1.0
600	19.0	-1.2	-2.1	0.9
600	19.0	-1.9	-3.0	1.1
600	19.0	-2.2	-3.2	1.0
600	29.0	-1.7	-3.0	1.3
600	29.0	-2.8	-4.0	1.2
600	29.0	-3.0	-4.2	1.2
50	5.0	-2.9	-3.9	1.0
50	5.0	-1.9	-2.5	0.6
50	15.0	-2.0	-2.2	0.2
50	15.0	-0.9	-1.1	0.2
100	5.0	-3.7	-5.9	2.2
100	5.0	-3.0	-5.1	2.1
100	15.0	-2.2	-2.3	0.1
100	15.0	-1.7	-1.7	0.0
200	5.0	-2.2	-5.3	3.1
200	5.0	-1.3	-4.6	3.3
200	15.0	-1.8	-3.2	1.4
200	15.0	-1.4	-2.5	1.1
		AVERAGE OF ALL TABLE 8.3 VARIATION RANGES>>>>		0.7

Table 4 Comparative performance of noise modeling techniques

Technique	Number of Best Performances by Technique					
	Totals	Individual Lane Overlap Distances				Grouped Lanes
		0.1'	1'	5'	10'	
Dummy Lane (DL)	56	22	11	7	6	10
Ground Zone (GZ)	56	17	7	6	7	19
Adjacent Lane Width (ALW)	40	9	10	6	6	9
TOTALS	152	48	28	19	19	38

E.3.4 Comparison of modeling techniques for a generic project

The noise analysis of any highway project must deal with a variety of factors that are related to the highway geometry, vehicle traffic characteristics, and characteristics of the adjacent study area. The noise model validation that is an integral part of any highway noise analysis helps assure that the collective accounting for all project-specific variables results in a model that adequately predicts both existing and future noise levels. In the construction of a project-validated model, the specific effect of any individual input factor is not usually evident. This was true in the team's evaluation of the selected projects. For that reason, a generic project was developed and analyzed in an attempt to isolate the relative influences and difference between the multi-lane modeling techniques.

The generic project considered a 4,000-foot long four-lane divided highway with a level grade and an elevation of 0, containing 10-foot wide paved inside and outside shoulders and a paved median. The default ground type was set as pavement and the area adjacent to the highway was modeled as lawn, using ground zones within the FHWA TNM. Directional traffic in each direction was assumed to be 2,000 autos, 200 medium trucks, and 200 heavy trucks, all travelling at a speed of 60 miles per hour. For individual lane evaluations, traffic was divided evenly between lanes. Receptors were placed at setback distances of 50, 100, 200, 300, 400, and 500 feet from the center of the near lane at heights of 5 and 15 feet above the assumed ground level at each receptor location. To account for receptors both above and below the elevation of the highway, the ground was assumed to be level and was modeled under two scenarios - ground at an elevation of 0 feet and ground at an elevation of minus 20 feet. This resulted in receptors located at each setback distance at the following positions related to the highway: minus 15 feet, minus 5 feet, plus 5 feet, and plus 15 feet. Figures 8 and 9 show screenshots of the FHWA plan and skew sections representing the generic four-lane project.

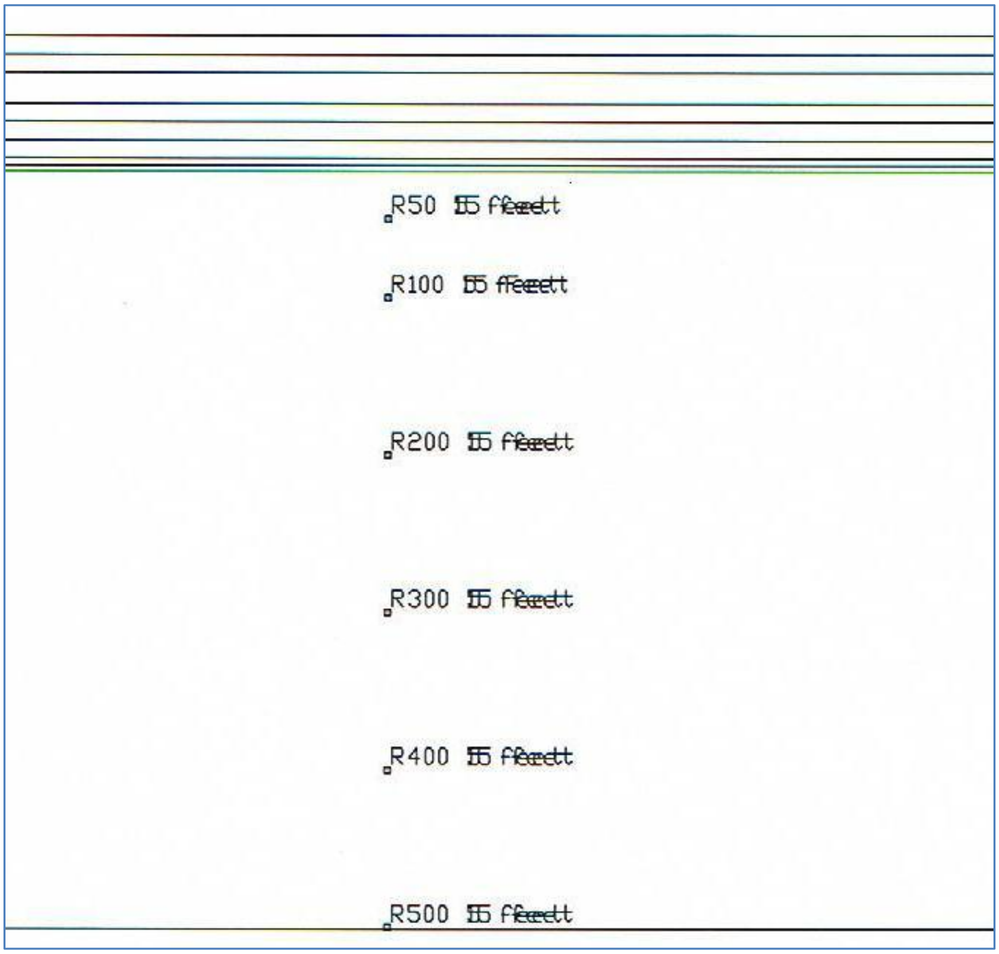

Figure 8 FHWA TNM plan view of generic four-lane project showing setback receptors

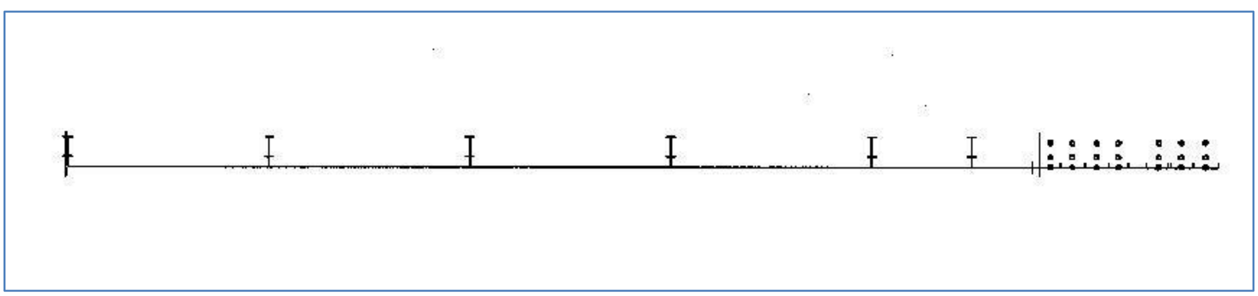

Figure 9 FHWA TNM skew section of generic four-lane project showing above-roadway receptors

Table 5 displays the results of the evaluation of all primary modeling techniques (Dummy Lane, Adjacent Lane Width, and Ground Zone) for all of the generic project's receptors. For each of these primary techniques, grouped lanes were modeled and compared to the use of individual lanes with 0.1 foot overlaps.

Table 5 Evaluation of four-lane generic project

Relationship of Receptor to Roadway	Site I.D.	Distance from Center of Near Travel Lane	Height of Receptor Above Ground	Height of Receptor Above Roadway	Shoulders Represented by Dummy Lanes with No Traffic (DL)			Edge of Outside Shoulder Defined by Width of Outside Travel Lane (ALW)			Outside Shoulders Modeled as Pavement Ground Zones (GZ)		
					0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes	Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes	Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes
Receptors Above Roadway	R50	50	5	5	78.4	78.3	-0.1	78.4	78.3	-0.1	78.4	78.3	-0.1
	R100	100	5	5	75.5	75.5	0.0	75.5	75.5	0.0	75.5	75.5	0.0
	R200	200	5	5	71.6	71.7	0.1	71.6	71.7	0.1	71.6	71.7	0.1
	R300	300	5	5	68.5	68.5	0.0	68.5	68.5	0.0	68.5	68.5	0.0
	R400	400	5	5	66.4	66.3	-0.1	66.4	66.3	-0.1	66.4	66.3	-0.1
	R500	500	5	5	64.7	64.7	0.0	64.7	64.7	0.0	64.7	64.7	0.0
	R50	50	15	15	78.5	78.5	0.0	78.5	78.5	0.0	78.5	78.5	0.0
	R100	100	15	15	75.8	75.8	0.0	75.8	75.8	0.0	75.8	75.8	0.0
	R200	200	15	15	72.5	72.5	0.0	72.5	72.5	0.0	72.5	72.5	0.0
	R300	300	15	15	70.4	70.4	0.0	70.4	70.4	0.0	70.4	70.4	0.0
	R400	400	15	15	68.7	68.8	0.1	68.7	68.8	0.1	68.7	68.8	0.1
	R500	500	15	15	67.0	67.4	0.4	67.0	67.4	0.4	67.0	67.4	0.4
Receptors Below Roadway	R50	50	5	-15	69.4	69.9	0.5	69.5	70.1	0.6	69.4	69.9	0.5
	R100	100	5	-15	69.4	69.3	-0.1	69.4	69.5	0.1	69.3	69.2	-0.1
	R200	200	5	-15	67.4	67.4	0.0	67.5	67.5	0.0	67.3	67.2	-0.1
	R300	300	5	-15	65.2	65.2	0.0	65.3	65.4	0.1	65.1	65.1	0.0
	R400	400	5	-15	63.0	63.0	0.0	63.2	63.2	0.0	62.8	62.8	0.0
	R500	500	5	-15	61.0	61.0	0.0	61.2	61.2	0.0	60.8	60.8	0.0
	R50	50	15	-5	74.2	74.5	0.3	74.3	74.5	0.2	74.5	74.6	0.1
	R100	100	15	-5	72.7	72.7	0.0	72.6	72.6	0.0	72.7	72.7	0.0
	R200	200	15	-5	69.5	69.5	0.0	69.6	69.6	0.0	69.5	69.4	-0.1
	R300	300	15	-5	68.7	67.8	-0.9	68.8	67.9	-0.9	68.7	67.7	-1.0
	R400	400	15	-5	67.3	68.0	0.7	67.4	68.0	0.6	67.3	67.9	0.6
	R500	500	15	-5	66.3	66.7	0.4	66.4	66.8	0.4	66.4	66.6	0.2
						Average Differences >>>	0.1		Average Differences >>>	0.1		Average Differences >>>	0.0

The evaluation results contained in Table 5 illustrate the insignificant difference between individual and grouped lane modeling techniques. This confirmed the general findings from the evaluation of the selected projects previously discussed. This finding was further validated by evaluation of the I-95 GIR project in Philadelphia. That project has super-elevated roadway lanes, but showed no significant differences between the individual lane and grouped lane modeling techniques. However, Table 5 indicates several trends that appear to be evident. The greatest variations occurred at locations lower than the highway and resulted in individual lane values higher than grouped lane values at 300 feet and lower than grouped lane values at 400 feet for each of the primary modeling techniques. This indicated that for below grade receptors, lines of sight play an important part in modeling. These results led the team to evaluate a wider eight-lane divided highway generic project and to add additional receptors at greater distances below the highway grade. Therefore, in addition to the locations described above, the team modeled receptors located 25 feet and 35 feet below the highway grade at all setback distances. Since the evaluation of techniques for the four-lane generic highway showed similar results for all three primary modeling techniques, only the Dummy Lane technique was modeled for the eight-lane generic highway project. Results of the eight-lane generic highway project evaluation are shown in Table 6.

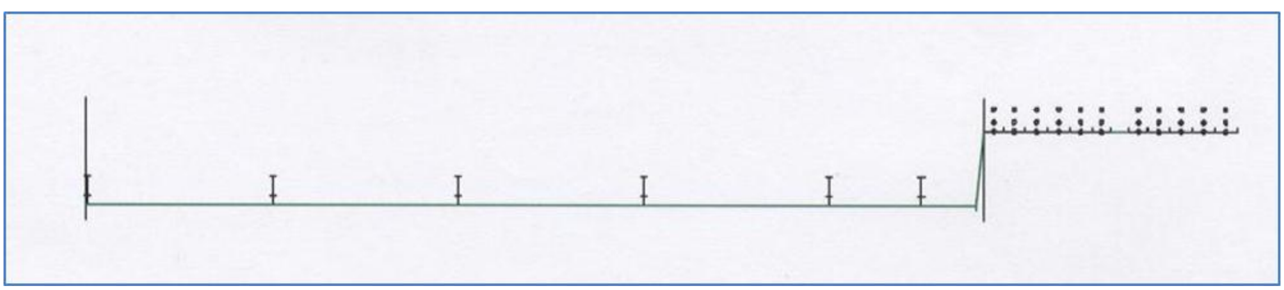

Figure 10 FHWA TNM skew section of generic eight-lane project showing lowest receptors

Table 6 Evaluation of eight-lane generic project

Relationship of Receptor to Roadway	Ground Elevation	Site I.D.	Distance from Center of Near Travel Lane	Height of Receptor Above Ground	Height of Receptor Above Roadway	Shoulders Represented by Dummy Lanes with No Traffic (DL)		
						Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes
Receptors Above Roadway	0	R50	50	5	5	77.5	77.3	-0.2
	0	R100	100	5	5	74.9	74.8	-0.1
	0	R200	200	5	5	71.4	71.7	0.3
	0	R300	300	5	5	68.9	69.1	0.2
	0	R400	400	5	5	66.7	66.7	0.0
	0	R500	500	5	5	64.9	64.9	0.0
	0	R50	50	15	15	77.7	77.6	-0.1
	0	R100	100	15	15	75.4	75.1	-0.3
	0	R200	200	15	15	72.1	72.1	0.0
	0	R300	300	15	15	70.1	70.1	0.0
	0	R400	400	15	15	68.4	68.5	0.1
	0	R500	500	15	15	66.9	67.1	0.2
Receptors Below Roadway	-20	R50	50	5	-15	67.5	65.9	-1.6
	-20	R100	100	5	-15	68.1	67.7	-0.4
	-20	R200	200	5	-15	66.6	66.5	-0.1
	-20	R300	300	5	-15	64.5	64.4	-0.1
	-20	R400	400	5	-15	62.5	62.5	0.0
	-20	R500	500	5	-15	60.6	60.6	0.0
	-20	R50	50	15	-5	72.6	72.5	-0.1
	-20	R100	100	15	-5	71.2	71.0	-0.2
	-20	R200	200	15	-5	69.3	69.3	0.0
	-20	R300	300	15	-5	68.0	67.4	-0.6
	-20	R400	400	15	-5	66.6	66.1	-0.5
	-20	R500	500	15	-5	65.5	65.0	-0.5
	-40	R50	50	5	-35	61.9	60.8	-1.1
	-40	R100	100	5	-35	64.9	62.8	-2.1
	-40	R200	200	5	-35	64.8	64.4	-0.4
	-40	R300	300	5	-35	64.0	63.9	-0.1
	-40	R400	400	5	-35	63.1	63.0	-0.1
	-40	R500	500	5	-35	61.7	61.7	0.0
	-40	R50	50	15	-25	65.9	62.5	-3.4
	-40	R100	100	15	-25	67.1	66.6	-0.5
	-40	R200	200	15	-25	66.3	66.5	0.2
	-40	R300	300	15	-25	65.7	65.7	0.0
	-40	R400	400	15	-25	64.8	64.7	-0.1
	-40	R500	500	15	-25	63.9	63.9	0.0
						Average Differences >>>		-0.5

The highlighted data in Table 6 demonstrates the grouped lane technique's under-prediction of noise levels (relative to the individual lane technique) at receptors located close to and significantly lower than the highway. This illustrates the important of modeling individual lanes in areas where certain lanes may be shielded and others may be exposed, or where certain vehicles in certain lanes are shielded and some are not. While this situation most often exists in locations close and below the grade of the highway, it could also exist at other locations that may be shielded or partially shielded by either manmade (structures, barriers, etc.) or natural (undulating terrain, natural berms, etc.) features.

To gather additional data related the causes of the grouped lane under-prediction of noise levels for the eight-lane generic project, the FHWA TNM was run individually for autos, medium trucks, and heavy trucks. Results of these runs are shown in Tables 7, 8, and 9. Review of these tables shows the predominance of the heavy truck noise component, indicating that truck stack noise is a major component and a factor that must be considered in modeling roadway travel lanes in multi-lane highway situations.

Table 7 Evaluation of eight-lane generic project (autos only)

Relationship of Receptor to Roadway	Ground Elevation	Site I.D.	Distance from Center of Near Travel Lane	Height of Receptor Above Ground	Height of Receptor Above Roadway	Shoulders Represented by Dummy Lanes with No Traffic (DL)		
						Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes
Receptors Above Roadway	0	R50	50	5	5	73.8	74.0	0.2
	0	R100	100	5	5	71.5	71.4	-0.1
	0	R200	200	5	5	67.9	68.3	0.4
	0	R300	300	5	5	65.3	65.5	0.2
	0	R400	400	5	5	63.1	63.0	-0.1
	0	R500	500	5	5	61.3	61.2	-0.1
	0	R50	50	15	15	73.9	74.2	0.3
	0	R100	100	15	15	71.8	71.7	-0.1
	0	R200	200	15	15	68.7	68.7	0.0
	0	R300	300	15	15	66.6	66.6	0.0
	0	R400	400	15	15	64.8	64.9	0.1
	0	R500	500	15	15	63.2	63.4	0.2
Receptors Below Roadway	-20	R50	50	5	-15	61.9	61.1	-0.8
	-20	R100	100	5	-15	63.2	62.3	-0.9
	-20	R200	200	5	-15	61.9	61.8	-0.1
	-20	R300	300	5	-15	59.9	59.8	-0.1
	-20	R400	400	5	-15	57.8	57.8	0.0
	-20	R500	500	5	-15	55.7	55.6	-0.1
	-20	R50	50	15	-5	67.9	67.6	-0.3
	-20	R100	100	15	-5	66.8	66.7	-0.1
	-20	R200	200	15	-5	65.5	65.5	0.0
	-20	R300	300	15	-5	64.2	63.5	-0.7
	-20	R400	400	15	-5	62.8	62.3	-0.5
	-20	R500	500	15	-5	61.8	61.2	-0.6
	-40	R50	50	5	-35	57.1	56.3	-0.8
	-40	R100	100	5	-35	58.6	57.8	-0.8
	-40	R200	200	5	-35	59.6	58.8	-0.8
	-40	R300	300	5	-35	59.4	59.5	0.1
	-40	R400	400	5	-35	58.4	58.3	-0.1
	-40	R500	500	5	-35	57.1	57.0	-0.1
	-40	R50	50	15	-25	58.6	57.8	-0.8
	-40	R100	100	15	-25	61.4	59.5	-1.9
	-40	R200	200	15	-25	61.5	62.0	0.5
	-40	R300	300	15	-25	61.2	61.2	0.0
	-40	R400	400	15	-25	60.4	60.4	0.0
	-40	R500	500	15	-25	59.6	59.5	-0.1
							Average Differences >>>	-0.4

Table 8 Evaluation of eight-lane generic project (medium trucks only)

Relationship of Receptor to Roadway	Ground Elevation	Site I.D.	Distance from Center of Near Travel Lane	Height of Receptor Above Ground	Height of Receptor Above Roadway	Shoulders Represented by Dummy Lanes with No Traffic (DL)		
						Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes
Receptors Above Roadway	0	R50	50	5	5	70.3	70.1	-0.2
	0	R100	100	5	5	67.5	67.5	0.0
	0	R200	200	5	5	63.9	64.2	0.3
	0	R300	300	5	5	61.3	61.5	0.2
	0	R400	400	5	5	59.2	59.1	-0.1
	0	R500	500	5	5	57.4	57.3	-0.1
	0	R50	50	15	15	70.2	70.5	0.3
	0	R100	100	15	15	67.9	67.8	-0.1
	0	R200	200	15	15	64.9	64.9	0.0
	0	R300	300	15	15	62.7	62.7	0.0
	0	R400	400	15	15	60.9	61.0	0.1
	0	R500	500	15	15	59.4	59.6	0.2
Receptors Below Roadway	-20	R50	50	5	-15	59.3	58.5	-0.8
	-20	R100	100	5	-15	59.9	59.1	-0.8
	-20	R200	200	5	-15	58.0	57.9	-0.1
	-20	R300	300	5	-15	55.9	55.7	-0.2
	-20	R400	400	5	-15	53.9	54.0	0.1
	-20	R500	500	5	-15	51.9	51.9	0.0
	-20	R50	50	15	-5	65.2	65.1	-0.1
	-20	R100	100	15	-5	63.9	63.6	-0.3
	-20	R200	200	15	-5	62.6	62.6	0.0
	-20	R300	300	15	-5	60.7	60.1	-0.6
	-20	R400	400	15	-5	58.9	58.4	-0.5
	-20	R500	500	15	-5	57.7	57.0	-0.7
	-40	R50	50	5	-35	54.6	53.8	-0.8
	-40	R100	100	5	-35	56.0	55.2	-0.8
	-40	R200	200	5	-35	56.4	55.6	-0.8
	-40	R300	300	5	-35	55.6	55.7	0.1
	-40	R400	400	5	-35	54.4	54.3	-0.1
	-40	R500	500	5	-35	53.0	52.9	-0.1
	-40	R50	50	15	-25	56.3	55.5	-0.8
	-40	R100	100	15	-25	59.0	57.0	-2.0
	-40	R200	200	15	-25	59.0	59.4	0.4
	-40	R300	300	15	-25	58.3	58.3	0.0
	-40	R400	400	15	-25	57.4	57.4	0.0
	-40	R500	500	15	-25	56.4	56.4	0.0
						Average Differences >>>		-0.4

Table 9 Evaluation of eight-lane generic project (heavy trucks only)

Site I.D.	Distance from Center of Near Travel Lane	Height of Receptor Above Ground	Height of Receptor Above Roadway	Shoulders Represented by Dummy Lanes with No Traffic (DL)		
				Individual Lanes with 0.1 foot Lane Overlaps	Grouped Travel Lanes	Grouped minus Individual Lanes
R50	50	5	5	72.9	72.7	-0.2
R100	100	5	5	70.4	70.3	-0.1
R200	200	5	5	67.2	67.4	0.2
R300	300	5	5	64.7	64.9	0.2
R400	400	5	5	62.7	62.6	-0.1
R500	500	5	5	60.9	60.8	-0.1
R50	50	15	15	73.2	73.1	-0.1
R100	100	15	15	70.6	70.6	0.0
R200	200	15	15	67.6	67.6	0.0
R300	300	15	15	65.7	65.7	0.0
R400	400	15	15	64.2	64.3	0.1
R500	500	15	15	62.9	63.0	0.1
R50	50	5	-15	65.1	62.7	-2.4
R100	100	5	-15	65.4	65.3	-0.1
R200	200	5	-15	63.7	63.7	0.0
R300	300	5	-15	61.7	61.6	-0.1
R400	400	5	-15	59.8	59.7	-0.1
R500	500	5	-15	58.0	58.0	0.0
R50	50	15	-5	69.5	69.4	-0.1
R100	100	15	-5	67.7	67.6	-0.1
R200	200	15	-5	65.0	65.0	0.0
R300	300	15	-5	63.9	63.4	-0.5
R400	400	15	-5	62.6	62.3	-0.3
R500	500	15	-5	61.7	61.3	-0.4
R50	50	5	-35	58.8	57.3	-1.5
R100	100	5	-35	63.0	59.9	-3.1
R200	200	5	-35	62.3	62.2	-0.1
R300	300	5	-35	61.2	60.8	-0.4
R400	400	5	-35	60.3	60.3	0.0
R500	500	5	-35	58.9	58.9	0.0
R50	50	15	-25	64.4	59.1	-5.3
R100	100	15	-25	64.6	65.1	0.5
R200	200	15	-25	63.1	63.1	0.0
R300	300	15	-25	62.4	62.3	-0.1
R400	400	15	-25	61.3	61.2	-0.1
R500	500	15	-25	60.4	60.4	0.0
				Average Differences >>>		-0.6

E.4 Determination of Best Modeling Practices

Based on the evaluation of the analysis techniques reported herein, the team has compiled a list of suggestions related to the modeling of multi-lane highway projects. This list represents the team's best managing practices. The following two suggestions are deemed to be most important:

1. Model each travel lane separately when receptors are located below the elevation of the highway.

2. Regardless of the receptor's relationship to the highway, model each travel lane separately when there are any intervening manmade or natural features that block the line of sight between any receptor and any travel lane. Consider roadway super-elevation and all perpendicular and flanking noise paths in making such determinations. If in doubt, model individual lanes.

The following modeling techniques are suggested by the team based upon the evaluations reported herein:

1. Set FHWA TNM default ground type to "Pavement" to minimize any possible effects created by inadvertently leaving gaps between roadways when modeling complex roadways with features such as ramp gores, curved roadway sections, and super-elevated roadways. Model median areas between paved shoulders and surfaces outside of the roadway section by use of the appropriate FHWA TNM ground zone(s).
2. Provide travel lane overlap distances in the 0.1 to 1.0 foot range
3. Use the Dummy Lane technique to model shoulders, especially outside shoulders. It presents less potential for illegal intercepts within FHWA TNM and does not require the addition of a contour line that is required with the Ground Zone technique. It also allows for a smaller lane overlap than that resulting from use of the Adjacent Lane Width technique and is more compatible with modeling super-elevated roadway sections.
4. When modeling super-elevated roadways, model the profile elevations associated with each roadway lane if such data is available at the time of modeling.

E.5 Conclusions

Suggested best modeling practices were developed for modeling multi-lane highways. The team developed two modeling practice suggestions related to travel lane modeling that it considers to be the most important and provided several other suggestions for improving modeling practices.