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U.S. Department of Transportation
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TNM VERSION 2.5 ADDENDUM to Validation of FHWA's Traffic Noise Model® (TNM): Phase 1

U.S. Department of Transportation
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13. ABSTRACT (Maximum 200 words)

The Volpe Center Acoustics Facility (Volpe) in support of the Federal Highway Administration (FHWA) is conducting a multiple-phase study to assess the accuracy and make recommendations on the use of FHWA's Traffic Noise Model (TNM). The TNM Validation Study involves highway noise data collection and TNM modeling for the purpose of data comparison. In 2002, Volpe completed Phase 1 of the study. For this phase, over 100 hours of traffic noise data were collected at seventeen highway sites around the country. The seventeen sites included: open areas next to the highway with acoustically soft ground (e.g., lawn); open areas with acoustically hard ground (e.g., pavement or water); and areas next to the highway with an open area behind a single noise barrier. Results indicated that TNM Version 2.0 was, on average, over-predicting when measured sound level data were not calibrated using a reference microphone, i.e., when site bias was not accounted for. This issue of over-prediction initiated the development of TNM Version 2.5, which addresses the over-prediction and also has other acoustical improvements. This addendum to the Phase 1 report includes results generated with TNM Version 2.5, where the results show TNM's improved performance.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1			2			3		4		5
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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1. INTRODUCTION

This addendum to the Federal Highway Administration's Traffic Noise Model (TNM) Validation Phase 1 report [Rochat 2002] provides an evaluation of the performance of TNM Version 2.5 (TNM v2.5) [Lau 2004][Anderson 1998][Menge 1998]. (Results from the full Phase 1 report are based on TNM Version 2.0 (TNM v2.0).) This chapter reviews the objective and process of the TNM Validation Study, reviews the results for Phase 1 based on TNM v2.0, and describes the development of TNM v2.5. Later chapters show TNM v2.5-updated Phase 1 results and discuss TNM v2.5's performance.

1.1 Review of the TNM Validation Study

The Volpe Center Acoustics Facility (VCAF), in support of the Federal Highway Administration (FHWA), has been conducting a study to quantify and assess the accuracy of FHWA's Traffic Noise Model® (TNM) and make recommendations on its use. The TNM Validation Study involves highway noise data collection and TNM modeling for the purpose of data comparison. The number of sites required to do a comprehensive study reflects the incorporation of numerous TNM features, either isolated or grouped with other TNM features. This large task is more manageable divided into multiple phases; in this manner, interim results are available to TNM users.

Phase 1 of the TNM Validation Study, also supported by the California Department of Transportation (Caltrans), was completed in 2002. For this phase, over 100 hours of traffic noise data were collected at 17 highway sites around the country. The sites had characteristics of those most commonly modeled by TNM users and were relatively simplistic so as to isolate individual features of TNM. The 17 sites included: open areas next to the highway with acoustically soft ground [e.g., field grass (effective flow resistivity (F) . 150 cgs Rayls) or lawn (F . 300 cgs Rayls)]; open areas with acoustically hard ground [e.g., pavement or water (F . 20,000 cgs Rayls)]; and areas next to the highway with an open area behind a single noise barrier.

Instrumentation was deployed at each measurement site for capturing acoustical, meteorological, traffic, and site survey data. Acoustical data were captured at distances ranging from 50-1273 ft

(~15-390 m) from the roadway; please refer to Table 1 for more details by site type. TNM v2.0 was used to model each of the measurement sites, after which results were compared to the measured data. Please refer to the Phase 1 report [Rochat 2002] for details on field measurements and TNM modeling.

Table 1. Phase 1 Measurement Sites by Type.

Site Type		Number of Sites	Ranges of Microphone Distances d=dist from roadway bb=dist behind barrier
open area	acoustically soft ground	4	d = 50 to 800 ft (~15 to ~245 m)
	acoustically hard ground	4	d = 50 to 1273 ft (~15 to ~390 m)
noise barrier		9	bb = 50 to 300 ft (~15 to ~90 m)

The data sets were processed in two ways: 1) the TNM-predicted sound levels were calibrated to the measured sound levels using a reference microphone so as to make a direct comparison of measured sound propagation and TNM-predicted sound propagation; and 2) the TNM-predicted sound levels were not calibrated to the measured sound levels so as to add another level of comparison, comparing measurements and predictions with possibly slightly different sound source characteristics. The calibration for method (1) was accomplished by applying a calibration value (the difference between a site's measured sound levels at the reference microphone and the TNM-predicted sound levels at the same position) to the predicted sound levels at all other positions. This calibration process minimizes biases due to possible site-specific emission levels.

Since TNM currently calculates sound levels for a windless environment, the data were further processed in two other distinct ways according to the wind speed. The two processing methods were: 1) no data blocks were discarded due to wind conditions (this data set is referred to as the all-wind data); and 2) any data blocks that at any time achieved a "very windy" condition [winds exceeded ~11 mph (5 m/s)] were removed (this data set is referred to as the strong-wind-removed data).

For the final presentation, the data were compared in several ways. First, direct comparisons of TNM-predicted sound levels and measured sound levels were made, then the differences as a function of the following variables were calculated: distance from the roadway, height above the ground, wind speed, wind direction, and percentage of heavy trucks. Additional analysis was performed using alternate TNM runs in order to make recommendations on the use of TNM.

Results from the TNM v2.0 Phase 1 Validation Study will be reviewed in the next section.

1.2 Review of the TNM Version 2.0 Phase 1 Results

This review focuses on TNM v2.0's overall performance and the comparison of measured sound levels to TNM v2.0-predicted sound levels as a function of distance from the roadway/behind the barrier.

For all data comparisons with the calibrated data, TNM v2.0-predicted sound levels show good agreement with the measured sound levels for these types of sites: open area, acoustically soft ground sites [out to 800 ft (~245 m) from the roadway]; open area, acoustically hard ground sites [out to 300 ft (~90 m) from the roadway]; and noise barrier sites [out to 300 ft (~90 m) behind the barrier]. The only difference of concern arises for open area, acoustically hard ground sites at far distances. The uncalibrated data (where site bias has not been removed) show a general over-prediction (~2.6 dB) in the TNM v2.0-predicted sound levels. The qualitative descriptions of the results will be quantified when comparing to TNM v2.5 results in later chapters.

Based on the TNM v2.0 results, recommendations were made on the use of the model. Please refer to Chapter 4 in this document for TNM v2.5 updates to the recommendations.

1.3 TNM Version 2.5 Development

Due to the results from Phase 1 of the TNM Validation study, the FHWA supported the development of TNM v2.5. TNM v2.5 is the first version of the software with major improvements to the acoustics.

TNM v2.5 was developed to address the following issues: 1) the over-prediction found in the TNM v2.0 Phase 1 results; and 2) an anomaly related to diffraction points. Steps taken to address these issues include: 1) an improvement was made to the implementation of the vehicle emission level database in the TNM source code, where a more comprehensive methodology was applied in correcting the measured emission levels back to the source; and 2) a bug in the acoustics code was identified and corrected, where related diffraction algorithm parameters were improved.

The TNM v2.5 predictions are validated in this document, where results show TNM's improved performance.

2. TNM VERSION 2.5 INVESTIGATIONS

The TNM v2.5 investigations focus on directly comparing TNM-predicted sound levels to measured sound levels for both the uncalibrated (where site bias has not been removed) and calibrated data. In addition, the calibration values are examined, and the calibrated data is studied as a function of distance and height above the ground. The sections below further describe the investigations, focusing on comparative improvements relative to results computed using TNM v2.0.

2.1 Measured Data Parameters

The data processed for the TNM v2.0 investigations were used for comparative results presented in this addendum. As described below, some of the data from the previous investigations will not be presented here.

Where previous results considered data collected during all wind conditions and then refined the measured data to exclude data collected during strong wind conditions (strong-wind-removed data), TNM v2.5 investigations focus solely on the strong-wind-removed data [data collected during winds # ~11 mph (5 m/s)]. This refinement was made to increase the stability of the data (removing strong wind influences) and to eliminate any possible contamination at the microphone due to wind.

As was described in the TNM Validation Phase 1 report [Rochat 2002], 16 of the 17 measurement sites allowed for data to be collected during acceptable wind conditions. Therefore, results for the same 16 of the 17 sites will be presented in this addendum.

The measurement locations are listed by site in Appendix B in the Phase 1 report [Rochat 2002]. Most data were collected within 300 ft (~90 m) from the roadway or behind a barrier. Although there is limited data at farther distances (at some open soft and hard ground sites), data for all distances are analyzed and presented in this document.

2.2 TNM Prediction Parameters

TNM v2.5 was used for all calculations for the results presented in this addendum. Modeling and calculations were performed in the same manner as with the TNM v2.0 investigation; this includes modeling with "average" pavement, the current requirement for use of TNM. With one notable exception, there were no differences in how modeling was conducted using v2.0 as compared with v2.5.

Specifically, the 2.5 version of the software does behave differently than previous versions because of its acoustical improvements. As such, recommendations on its use have changed. The recommendation on how to model medians has changed from previous versions of TNM: if a median is a ground type *other than the default, it is to be modeled using a ground zone* that does *not overlap* or match edges with the adjacent roadways. The TNM Validation Phase 1 runs were updated to comply with this recommendation.

2.3 Comparing TNM-Predicted Data to Measured Data

As described in Section 1.1 of this report, for the TNM v2.0 investigations, the data are again processed in two ways, with and without calibrating each site's TNM-predicted sound levels to measured reference microphone sound levels to remove site bias.

The calibration was accomplished using the reference microphone at each site. For an open area site, the reference microphone was located at a distance of 50 ft (~15 m) (or as close to that as possible) from the center line of the near travel lane and 5 ft (1.5 m) above the roadway elevation. For a barrier site, it was approximately 5 ft (1.5 m) above the top of the barrier or off to the side of the barrier 5 ft (1.5 m) above the roadway elevation. For each site, The difference between the measured sound level at the reference microphone and the predicted sound level at the same position was calculated for each data block (for each 15 minutes for the final analysis). This calibration difference was then applied to the predicted sound levels at all other microphone locations at the study site.

3. TNM VERSION 2.5 PHASE 1 RESULTS

The results for the Version 2.5-updated TNM Validation Study Phase 1 are presented first for the uncalibrated data (Section 3.1). These are presented only as a direct comparison between the TNM-predicted sound levels and the measured sound levels. Following the uncalibrated results, the values used for data calibration will be presented (Section 3.2). Finally results for the calibrated data will be presented; in addition to the direct comparison, the data will also be shown as a function of distance and height (Section 3.3). The results are compared to those from the Phase 1 report [Rochat 2002], which were calculated using TNM v2.0 (TNM v2.1 results would be the same as those for TNM v2.0.)

3.1 Uncalibrated Results

The first investigation of the results was to directly compare the TNM-predicted sound levels to the measured sound levels for the uncalibrated data. A plot of the data is presented in Figure 1 (can be compared to Figure G.1 in the Phase 1 report [Rochat 2002]). Because none of the data for this comparison included calibrating the TNM-predicted data to the measured data, some site specific variables may have influenced the accuracy of the predicted sound levels.

The data in Figure 1 are plotted with the horizontal axis being the measured sound levels and the vertical axis being the TNM-predicted sound levels. Each 15-minute data block (15-min L_{Aeq}) is represented as an orange X, where the number of data points is stated in the lower right corner of the figure. A dashed blue line represents the linear fit and solid green lines show the 95 percent confidence band. A solid black diagonal line symbolizes perfect agreement between TNM-predicted data and measured data. Data points that fall above (to the left of) this line indicate over-prediction and points that fall below (to the right of) this line indicate under-prediction.

In addition to the graph in Figure 1, Table 2 gives numerical values corresponding to statistical elements of the graph. The values are stated for both TNM v2.5 and TNM v2.0 (where the TNM v2.0 results are extracted from Table 2 in the Phase 1 report [Rochat 2002]).

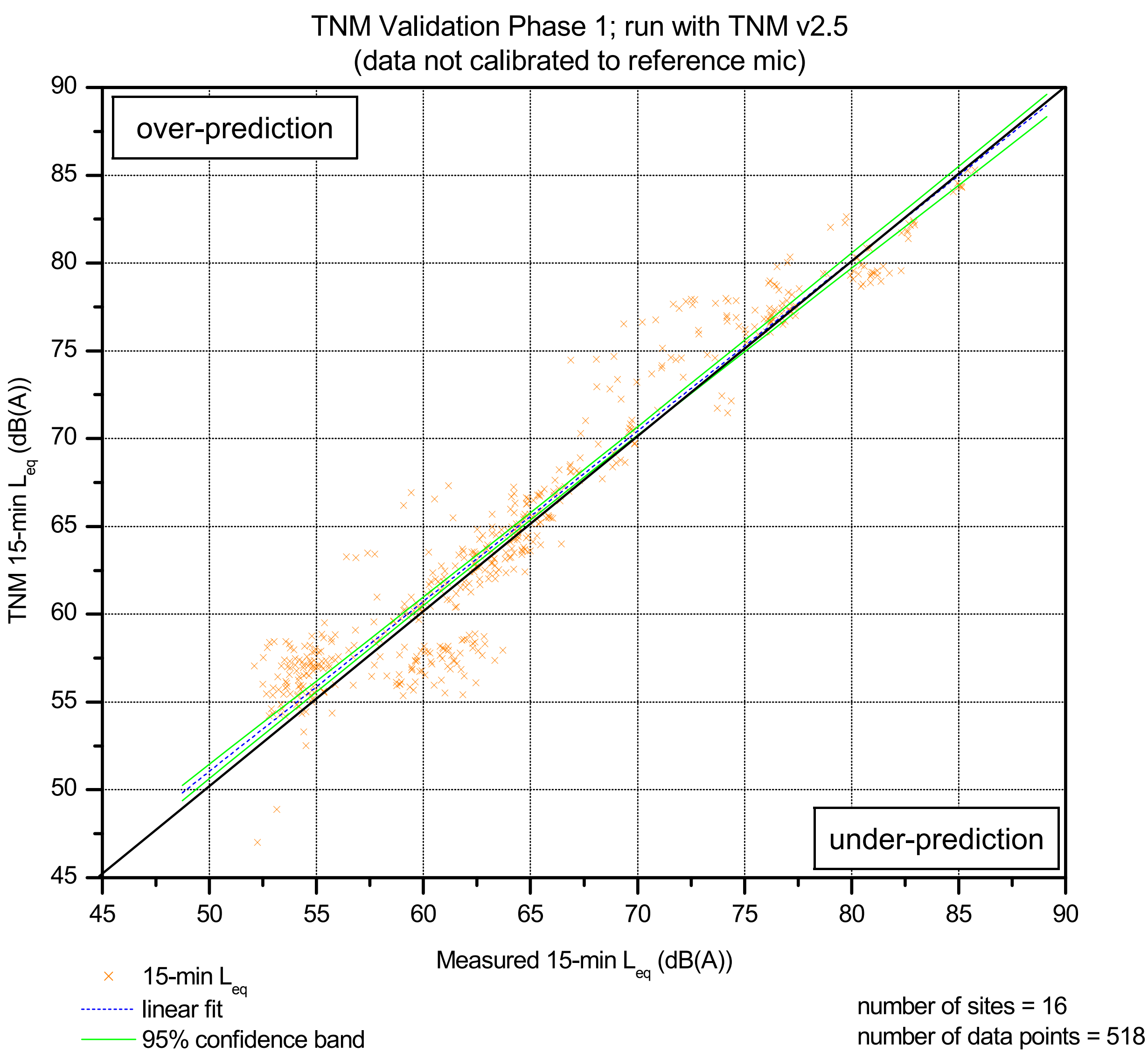

Figure 1. Direct Comparison of TNM and Measured Data; All Sites (not calibrated); Strong Wind Data Removed. (Note: Data for 16 of the 17 measurement sites are shown in this plot; no data points for Site 04CT remained after eliminating the strong wind data.)

In Table 2, the relation of the linear fit to the line of perfect agreement is examined along with the width of the 95 percent confidence band; values for five variables are stated across the columns. The first two variables concern the linear fit; values for both the average difference and the average of the absolute value of differences are stated. The average value represents the average difference, over the L_{Aeq} values represented, between the linear fit line and the perfect agreement line. The average difference indicates how well TNM is performing over a broad range of sound levels, combining the over- and under-predictions. The absolute value of differences indicates how well TNM is performing as a function of the amplitude of the over- and under-predictions. This second variable can also indicate the consistency of over- or under-predictions for a range of sound levels. The third, fourth, and fifth variables in the table are the average, maximum, and minimum values of the 95 percent confidence band width, respectively. If all three values are small, and the maximum and minimum values are similar, this indicates that an average of the data shows little variation in amplitude over a broad range of sound levels; as such, a similar data set (sound levels measured and predicted under the same conditions) would provide similar results.

Table 2. Direct Comparison of TNM-Predicted and Measured Data; Uncalibrated Data.

Sites	Differences of Linear Fit from Perfect Agreement (dB)				95% Confidence Band Width around Linear Fit (dB)					
	average difference		average of absolute value of differences		average		maximum		minimum	
	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**
all	2.6	**0.5**	2.6	**0.5**	0.8	**0.7**	1.4	**1.3**	0.4	**0.4**

Note: positive values indicate over-prediction; negative values indicate under-prediction.

Results indicate that TNM v2.5 is performing very well for the uncalibrated data (where site bias has not been removed). For TNM v2.5, the uncalibrated strong-wind-removed data for all sites show an average difference from perfect agreement being within half a decibel; for TNM v2.0, the over-prediction was 2.6 dB. The values corresponding to the 95 percent confidence band are very similar between the two versions of TNM, where TNM v2.5 is only slightly narrower. Due to the narrowness of the bands, both versions of the software show little variation in the data.

3.2 Data Calibration

After examining uncalibrated results, all data were calibrated to the reference microphone, as described in Section 2.3. Table 3 shows the average calibration values and ranges of calibration values for each measurement site for the strong-wind-removed data. All calibration values are shown for both TNM v2.0 and TNM v2.5. The TNM v2.0 values were extracted from Table 3 in the Phase 1 report [Rochat 2002]. (Site 04CT did not allow for data collection during acceptable wind conditions.)

Table 4 shows the average calibration values according to site type; the data are divided into three categories: open area, acoustically soft ground sites; open area, acoustically hard ground sites; and barrier, soft ground sites. Table 4 also shows two other categories: sites with the reference microphone in an open area; and sites with the reference microphone above the top of the barrier. All calibration values are shown for the strong-wind-removed data for both TNM v2.0 (extracted from Table 4 in the Phase 1 report [Rochat 2002]) and TNM v2.5.

Table 3. Data Calibration Values by Site.

Site ID	TNM v2.0		**TNM v2.5**	
	average calibration (dB)	calibration range (dB)	average calibration (dB)	calibration range (dB)
01MA	3.9	2.8 to 4.5	**3.2**	**2.3 to 4.1**
02MA	7.1	7.0 to 7.3	**3.8**	**3.4 to 4.1**
03MA	1.5	1.3 to 2.0	**0.9**	**0.7 to 1.3**
04CT	NA	NA	**NA**	**NA**
05CA	3.0	2.9 to 3.1	**0.1**	**0.0 to 0.1**
06CA	2.2	1.9 to 2.4	**0.0**	**-0.4 to 0.3**
08CA	2.0	0.4 to 2.5	**-1.1**	**-2.7 to -0.5**
09CA	1.2	0.6 to 1.6	**-1.8**	**-2.4 to -1.5**
10CA-berm	6.6	6.2 to 6.9	**5.6**	**5.2 to 6.0**
10CA-open	6.5	6.2 to 6.9	**5.6**	**5.2 to 6.0**
11CA	1.7	1.2 to 2.5	**-1.3**	**-1.8 to -0.6**
12CA	2.4	2.1 to 2.8	**-0.6**	**-0.8 to -0.1**
13CA	1.7	1.4 to 1.9	**-1.8**	**-2.0 to -1.5**
14CA	2.4	2.0 to 2.6	**-0.7**	**-1.3 to -0.4**
15CA	6.2	6.0 to 6.3	**2.8**	**2.6 to 3.0**
16MA	4.4	4.3 to 4.5	**2.8**	**2.7 to 2.8**
17CT	4.2	3.5 to 4.7	**0.6**	**0.2 to 1.0**

Table 4. Data Calibration Values by Site Type.

Site Type	TNM v2.0	**TNM v2.5**
	average calibration (dB)	average calibration (dB)
all	3.6	**1.1**
open area, soft ground	4.8	**3.4**
open area, hard ground	4.1	**1.1**
barrier, soft ground	2.7	**0.0**
ref mic in open	4.7	**2.6**
ref mic above barrier	2.1	**-0.8**

The average calibration values by site, as listed in Table 3, show improvement using TNM v2.5 as compared to TNM v2.0 for all except 2 sites. The averages of all the sites, as listed in Table 4, also show an improvement when using TNM v2.5; the average calibration value has dropped from 3.6 to 1.1 dB. When grouping into site types, it is seen (in Table 4) that each average calibration value has improved using TNM v2.5. As with TNM v2.0, average calibration values are lower for the barrier sites than the open area sites, with the open area, soft ground sites having the highest average calibration values (please see next paragraph). When grouping by reference microphone location, it is also seen that each average calibration value has improved using TNM v2.5. As with TNM v2.0, at sites where the reference microphone was placed above the top of a noise barrier, average calibrations values are lower than sites where the reference microphone was placed in the open.

The open area, soft ground sites are showing an average calibration value of 3.4 dB, which is a 1.4 dB improvement from TNM v2.0. The over-predictions seen at these sites are heavily influenced by Site 10CA; this site also affects the barrier site average value since Site 10CA had microphone lines in both an open area and behind a berm. As was explained in the Phase 1 report [Rochat 2002], Site 10CA was an unusual site with outlying results. Table 5 shows a comparison of how TNM v2.0 and TNM v2.5 are performing without including Site 10CA.

Table 5. Data Calibration Values by Site Type; not including Site 10CA.

Site Type	TNM v2.0	**TNM v2.5**
	average calibration (dB)	average calibration (dB)
all	3.1	**0.5**
open area, soft ground	4.2	**2.6**
open area, hard ground	4.1	**1.1**
barrier, soft ground	2.1	**-0.8**
ref mic in open	4.1	**1.8**
ref mic above barrier	2.1	**-0.8**

3.3 Calibrated Results

The results of the TNM Validation Study Phase 1 are now presented for the calibrated data. As with the uncalibrated data, the TNM-predicted sound levels are directly compared to the measured sound levels. In addition, data are presented in terms of distance from the roadway or barrier and height above the ground.

First, a direct comparison is made between the TNM-predicted sound levels and the measured sound levels, and a plot of the data for all the sites is presented in Figure 2 (can be compared to Figure G.2 in the Phase 1 report [Rochat 2002]). For details about the graph parameters, please refer to Section 3.1. In addition to presenting all the data from all the sites as a whole, the data are divided into the three categories mentioned in Section 3.2: open area, acoustically soft ground sites; open area, acoustically hard ground sites; and barrier, acoustically soft ground sites. Figures A.1-A.5 in Appendix A show plots for each site type, with additional categorization for soft and hard ground sites (separates site type into near and far distances from the roadway).

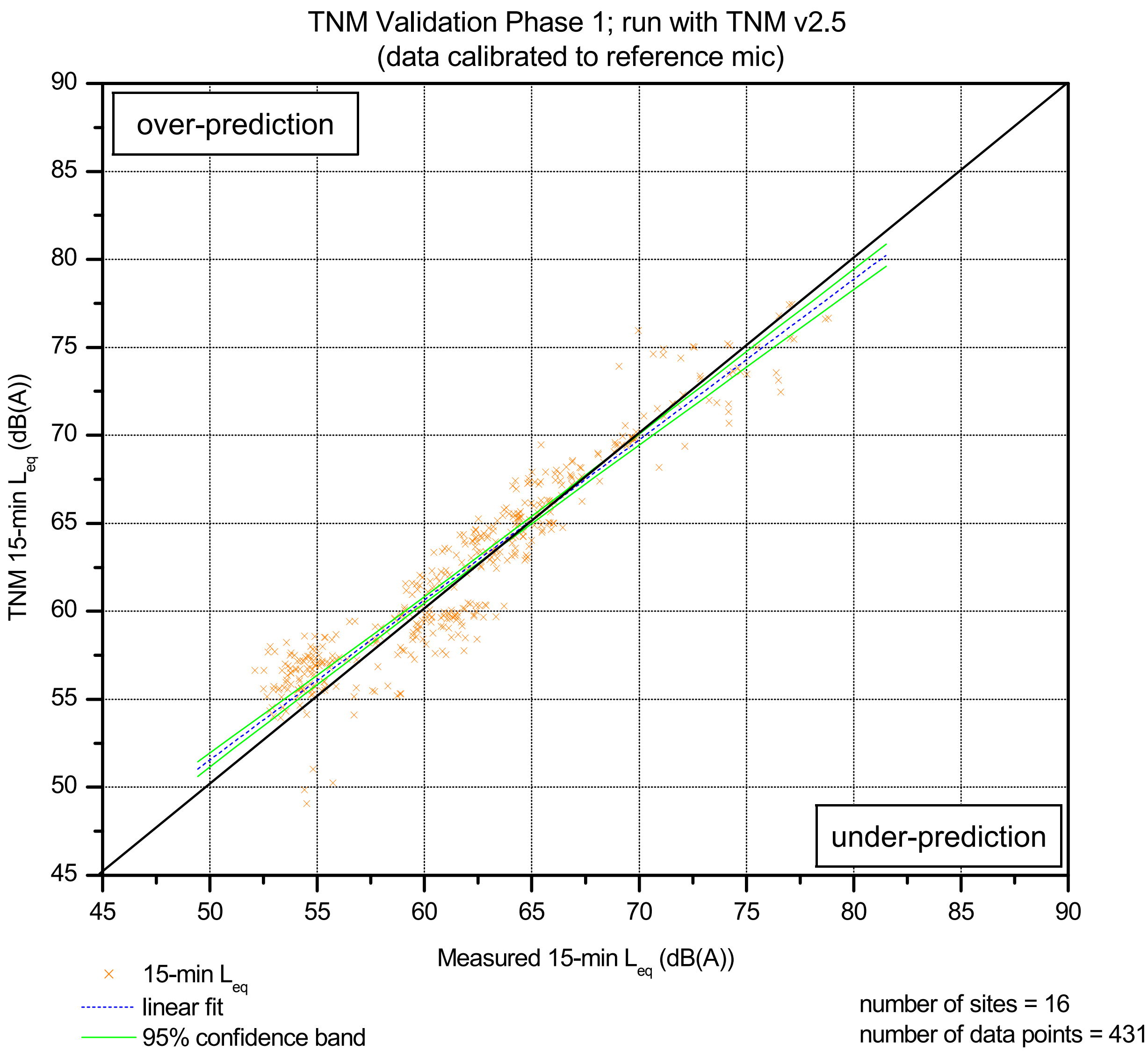

Figure 2. Direct Comparison of TNM and Measured Data; All Sites (calibrated); Strong Wind Data Removed. (Note: Data for reference locations not included (all would show perfect agreement due to the calibration; Data for 16 of the 17 measurement sites are shown in this plot; no data points for Site 04CT remained after eliminating the strong wind data.)

In addition to the graphs found here and in Appendix A, Table 6 gives numerical values corresponding to the statistical elements of the graphs. The values are stated for both TNM v2.5 and TNM v2.0 (where the TNM v2.0 are extracted from Table 10 in the Phase 1 report [Rochat 2002]). Please refer to Section 3.1 for discussion of entries in the table.

Table 6. Direct Comparison of TNM-Predicted and Measured Data; Calibrated Data.

Sites	Differences of Linear Fit from Perfect Agreement (dB)				95% Confidence Band Width around Linear Fit (dB)					
	average difference		average of absolute value of differences		average		maximum		minimum	
	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**	v2.0	**v2.5**
all	-0.4	**0.2**	0.8	**0.8**	0.6	**0.7**	1.2	**1.3**	0.3	**0.4**
open area, soft ground	0.1	**-1.5**	0.2	**1.6**	1.2	**1.4**	1.9	**2.3**	0.7	**0.8**
near distances	NA	**-0.9**	NA	**0.9**	NA	**1.4**	NA	**2.4**	NA	**0.8**
far distances	NA	**-4.3**	NA	**4.3**	NA	**1.9**	NA	**3.3**	NA	**1.3**
open area, hard ground	1.2	**1.1**	1.7	**1.6**	0.8	**0.8**	1.2	**1.3**	0.6	**0.6**
near distances	-0.4	**-0.4**	0.4	**0.9**	1.8	**1.6**	2.9	**2.6**	1.2	**1.1**
far distances	2.4	**2.2**	2.4	**2.2**	0.7	**0.9**	1.3	**1.6**	0.4	**0.5**
barrier, soft ground	-0.6	**0.6**	0.7	**0.6**	0.7	**0.7**	1.1	**1.1**	0.4	**0.4**

Note: positive values indicate over-prediction; negative values indicate under-prediction.
Additional note: NA appears in cells where values were not calculated for TNM v2.0.

Results indicate that TNM v2.5 is performing very well for the calibrated data for all the sites. For TNM v2.5, the calibrated strong-wind-removed data for all sites show an average difference from perfect agreement of 0.2 dB; for TNM v2.0, the difference was -0.4 dB. The values corresponding to the 95 percent confidence band are very similar between the two versions of TNM, where TNM v2.0 is only slightly narrower. Due to the narrowness of the bands, both versions of the software show little variation in the data.

In examining the performance by site type, TNM v2.5 is performing very well for open area, acoustically soft ground sites at near distances; open area, acoustically hard ground sites at near distances; and barrier sites. A slight degradation in model performance is observed at larger distances: for open area, acoustically soft ground sites [600 ft (~180 m) and beyond] and acoustically hard ground sites [900 ft (~275 m) and beyond]. At these distances, TNM appears to be under-predicting for soft ground and over-predicting for hard ground. Please see the discussion in the next chapter.

The second investigation of the calibrated data results examines the average differences as a function of the distance of the receiver from the roadway or noise barrier and height of the receiver above the ground. These differences are first computed for each site, then averaged over site type. Table 7 gives the values for the average difference in sound levels for each type of site (open area, soft ground; open area, hard ground; and barrier). The averages are given for ranges of distances from the highway or noise barrier; note that only some ranges of distances are covered for each type of site. The data are also divided by the two different heights [5 ft and 15 ft (~1.5 m and ~4.5 m)] above the ground, where averages over all distances are given in the right hand column. Unlike previous tables in this document, TNM v2.0 results are not shown here; please refer to Table 11 in the Phase 1 report [Rochat 2002] for comparison.

The results indicate that the average difference between the TNM-predicted sound levels and the measured data is generally smaller closer to the roadway. A slight degradation in model performance is observed at larger distances. Farther from the roadway, TNM is under-predicting for soft ground and over-predicting for hard ground. This supports what was seen with the direct comparison results (Table 6). Further discussion is presented in the next chapter.

Table 7. Average Differences (TNM minus Measured) as a Function of Distance and Height

Site Type	Mic Height (ft)	Average Differences in Sound Levels for Ranges of Distances from the Roadway						
		1-100 ft	101-200 ft	201-300 ft	301-500 ft	501-1000 ft	> 1000 ft	all distances
open area, soft ground	5	0.8	0.1	no data	-2.7	-5.7	no data	-1.5
	15	-1.1	-1.5	no data	-1.7	-3.4	no data	-1.7
open area, hard ground	5	0.6	1.0	no data	no data	0.7	3.9	1.3
	15	-1.5	-1.4	no data	no data	1.3	2.4	-0.5
barrier, soft ground	5	0.8	0.0	2.0	no data	no data	no data	0.7
	15	1.4	0.7	2.8	no data	no data	no data	1.2

Note: positive values indicate over-prediction; negative values indicate under-prediction.

4. DISCUSSION AND RECOMMENDATIONS

Discussion

Phase 1 of the TNM Validation Study [Rochat 2002] was conducted to assess the accuracy and make recommendations on the use of TNM. Based on this study, FHWA supported the development of TNM v2.5. For TNM v2.5, further investigations were conducted, with the same large set of measured data, to assess the accuracy and make recommendations on the use of this version of the model, where the results are presented in this document.

The investigations for TNM v2.5 focus on the uncalibrated data (where site bias is not accounted for), the data calibration values (differences between measured and predicted sound levels at the reference microphones), and the calibrated data, all with the strong wind data removed. In addition to examining the data set for all sites, the calibration values and the calibrated data are each examined by site type; also, the calibrated data are examined as a function of distance from the roadway/behind the barrier and height above the ground.

Results show that TNM v2.5 is performing extremely well for both the uncalibrated and calibrated data. As was stated in the Phase 1 report [Rochat 2002] regarding the uncalibrated data, "TNM [v2.0] is over-predicting in its vehicle emissions or there are site-specific biases in the measured vehicle emissions (or a combination of both)." Due to the improvements applied to the implementation of emission levels in TNM v2.5, the general over-prediction for the uncalibrated data is no longer an issue. Site biases can, however, still be a factor in the outcome of the predictions; pavement type, for example, can affect the sound levels.[1] Since the use of average pavement is generally required in TNM, that is how these sites were modeled; in general, when actual pavements are used to model the Phase 1 sites, improvements in the results are seen by site type and the overall data. To account for site biases, calibration should be considered; please refer to Section 6.2 in the Phase 1 report [Rochat 2002] for details.

[1] When more is learned about the effects of pavements and the longevity of those effects, it should be possible to implement them into TNM. Investigating pavement effects is planned for Phase 2 of the TNM Validation Study.

Results for TNM v2.5 also show that ground effects over long distances are overly exaggerated: too much absorption over the soft ground and too much reflection over the hard ground. Because of the limited data collected at far distances [600 ft (~180 m) and beyond for soft ground and 900 ft (~275 m) and beyond for hard ground], the stated results are based on 1 receiver location at each of 2 soft ground sites and 2 hard ground sites. Based on the results, two questions emerge: 1) have the proper ground types been chosen to model the Phase 1 sites?; and 2) are the purely theoretical reflections in TNM not properly capturing the true energy loss experienced in real outdoor situations?. The influence of meteorological effects (e.g., refraction and scattering) should also be considered as a factor for longer distances; these effects may have contributed to the resulting measured sound levels.

Preliminary investigations have pointed the issue to question (1) above. In selecting the ground types for modeling the Phase 1 sites, the types were chosen in keeping with conventional wisdom. For example, when terrain had a grassy surface other than manicured lawn, the type "field grass" was chosen. It has recently been discussed [Anderson 2002] that the common interpretation of "field grass" may be incorrect, and that a ground type with a higher effective flow resistivity value would be more appropriate in many cases. For this study, the authors feel that it is best to compare the TNM v2.0 and v2.5 results with the same ground types modeled. Preliminary investigations indicate that selecting a more appropriate ground type would further improve the results. More data needs to be collected/examined at far distances in order to fully understand and make recommendations on the use of ground types in TNM; this is planned for Phase 2 of the TNM Validation.

Recommendations

Some of the recommendations on the use of TNM have changed for Version 2.5. For the purpose of comparison, Table 8 lists the recommendations in the same order as Table 16 in the Phase 1 report [Rochat 2002]. Changes seen in the recommendations are attributable to fixing the diffraction anomaly mentioned in Section 1.3. For optimal results with TNM v2.5, the recommendations in Table 8 should be followed, along with guidance found on the TNM FAQs with Guidelines page on the TNM website (http://www.adc40.org/tnm).

Table 8. Recommendations on the Use of TNM Version 2.5.

Topic	Recommendation
Data Calibration	In order to remove site bias, TNM-predicted sound levels should be calibrated to sound levels measured at a site.
Ground Undulations	Substantial ground undulations [$ 5 ft (1.5 m)] should be modeled. *If a more detailed terrain analysis is required, smaller ground undulations can be included*.
Grass Medians	Medians [with widths $ 10 ft (~3 m)] *should be modeled using a ground zone for ground types other than the default*. The ground zone *should not overlap* or match edges with the roadways.
Ground Zones	Sites with mixed acoustically soft and hard ground *can be modeled with either ground type being the default; there are no longer restrictions for ground zones*.

5. REFERENCES

Anderson 1998 — Anderson, Grant S., Cynthia S.Y. Lee, Gregg G. Fleming, and Christopher W. Menge, *FHWA Traffic Noise Model, Version 1.0: User's Guide,* Report No.s FHWA-PD-96-009 and DOT-VNTSC-FHWA-98-1 (U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, 1998)

Anderson 2002 — Discussion with Grant S. Anderson regarding ground type descriptors and effective flow resistivity tables (2002)

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Menge 1998 — Menge, Christopher W., Christopher F. Rossano, Grant S. Anderson, and Christopher J. Bajdek, *FHWA Traffic Noise Model, Version 1.0: Technical Manual,* Report No.s FHWA-PD-96-010 and DOT-VNTSC-FHWA-98-2 (U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, 1998)
2004 update: TNM v2.5 Technical Manual update sheets, www.trafficnoisemodel.org

Rochat 2002 — Rochat, Judith L. and Gregg G. Fleming, *Validation of FHWA's Traffic Noise Model (TNM): Phase 1,* Report No.s FHWA-EP-02-031 and DOT-VNTSC-FHWA-02-01 (U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, 2002)

Appendix A:
Comparison of TNM v2.5-Predicted and Measured Sound Levels;
Strong Wind Data Removed

Data presented in this appendix include all processed data except where the wind speed exceeded ~11 mph (5 m/s).

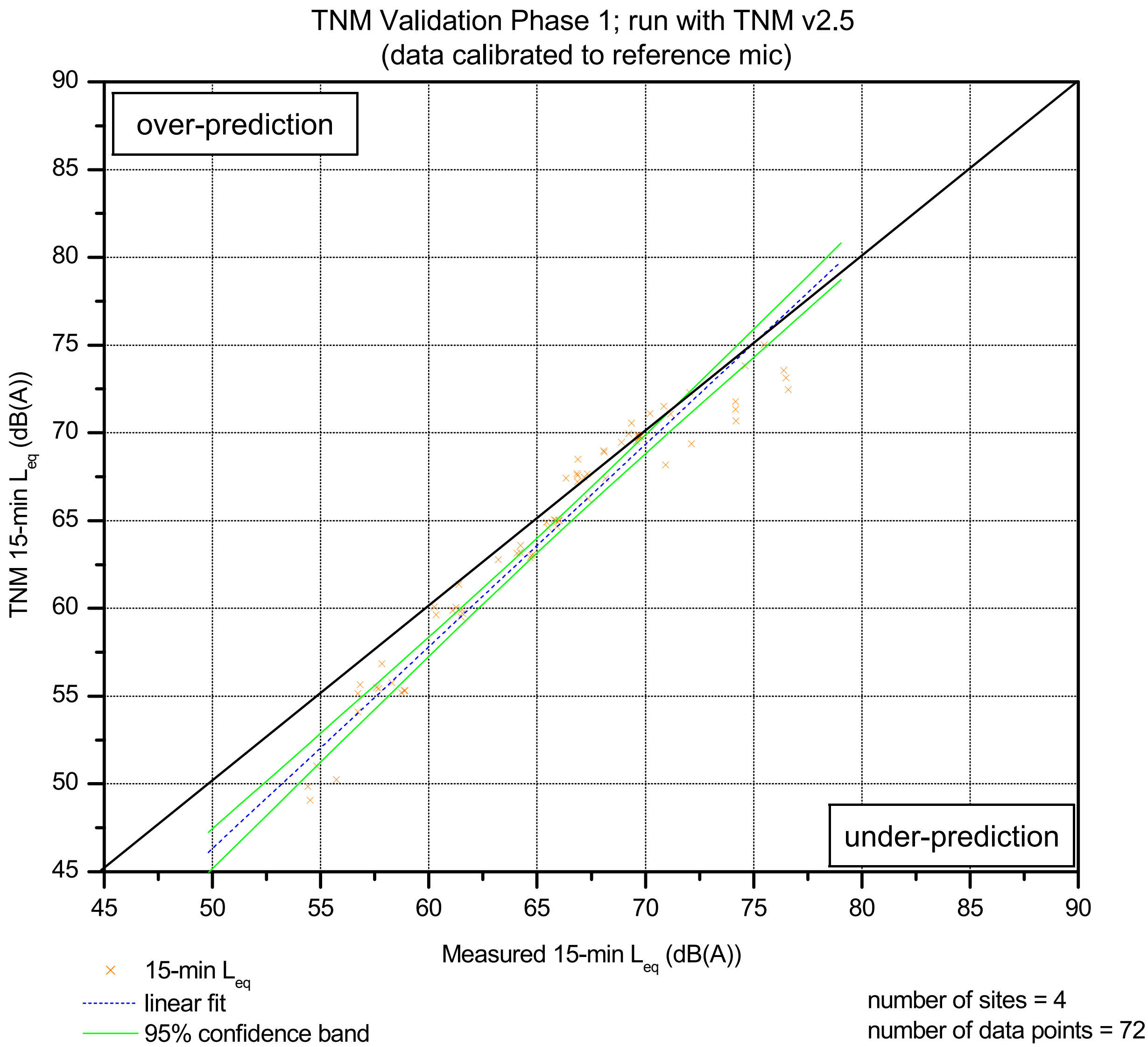
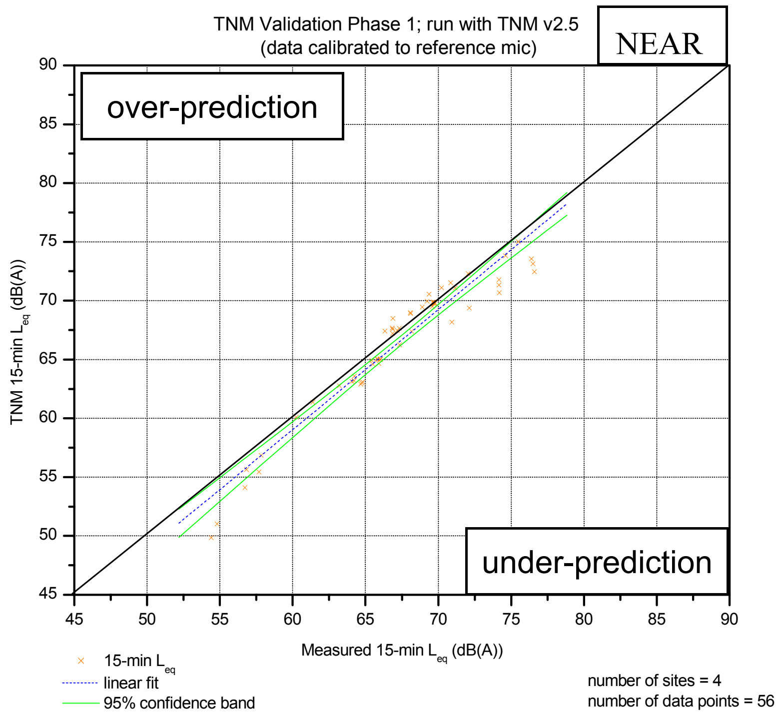


Figure A.1. Direct Comparison of TNM and Measured Data; Open Area, Soft Ground Sites; Strong Wind Data Removed.



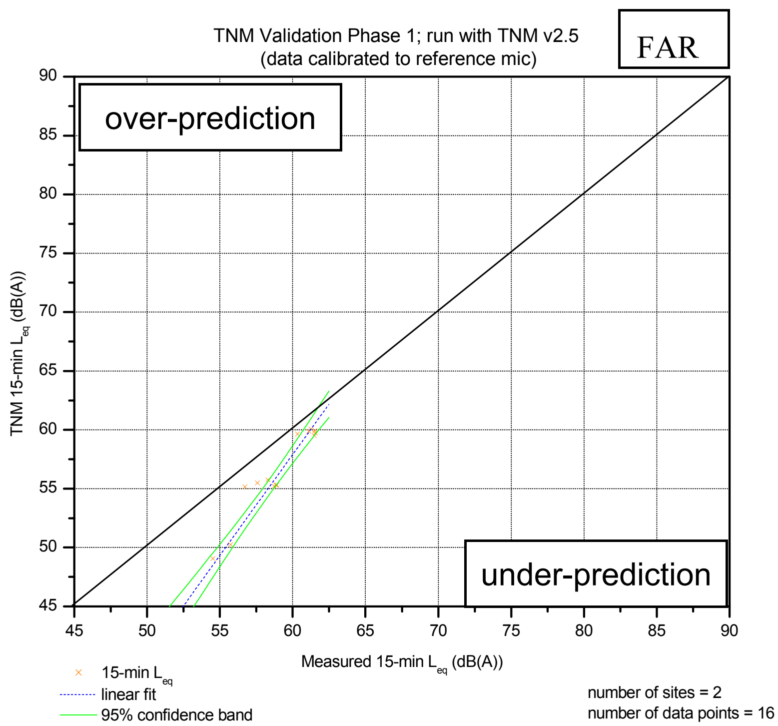


Figure A.2. Direct Comparison of TNM and Measured Data; Open Area, Soft Ground Sites; Separated into Near Roadway and Far from Roadway; Strong Wind Data Removed.

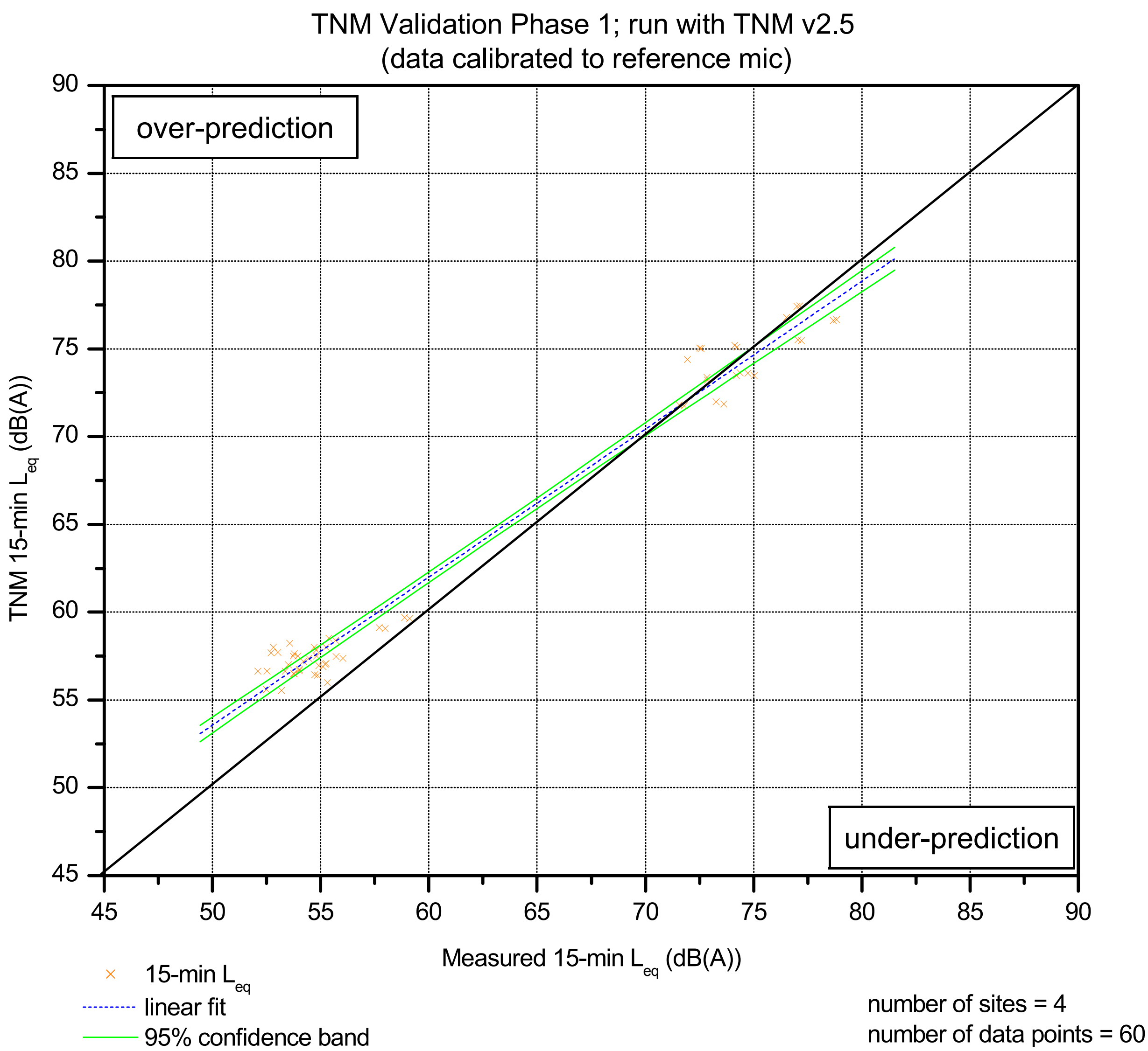
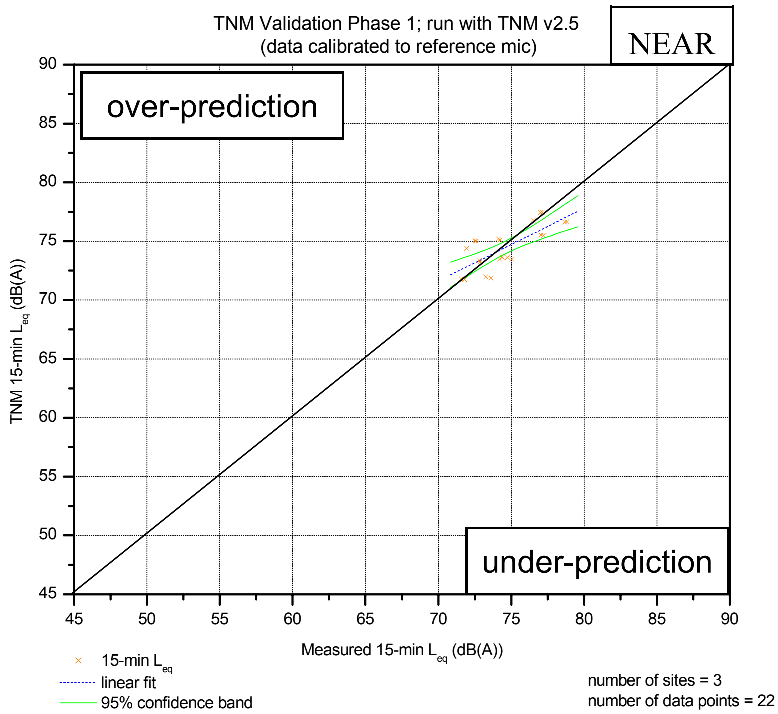


Figure A.3. Direct Comparison of TNM and Measured Data; Open Area, Hard Ground Sites; Strong Wind Data Removed.



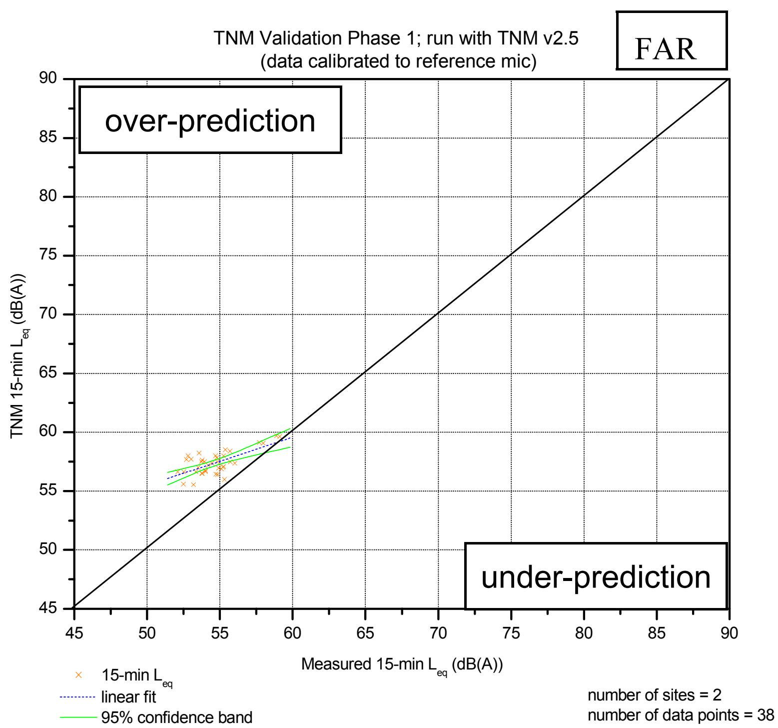


Figure A.4. Direct Comparison of TNM and Measured Data; Open Area, Hard Ground Sites; Separated into Near Roadway and Far from Roadway; Strong Wind Data Removed.

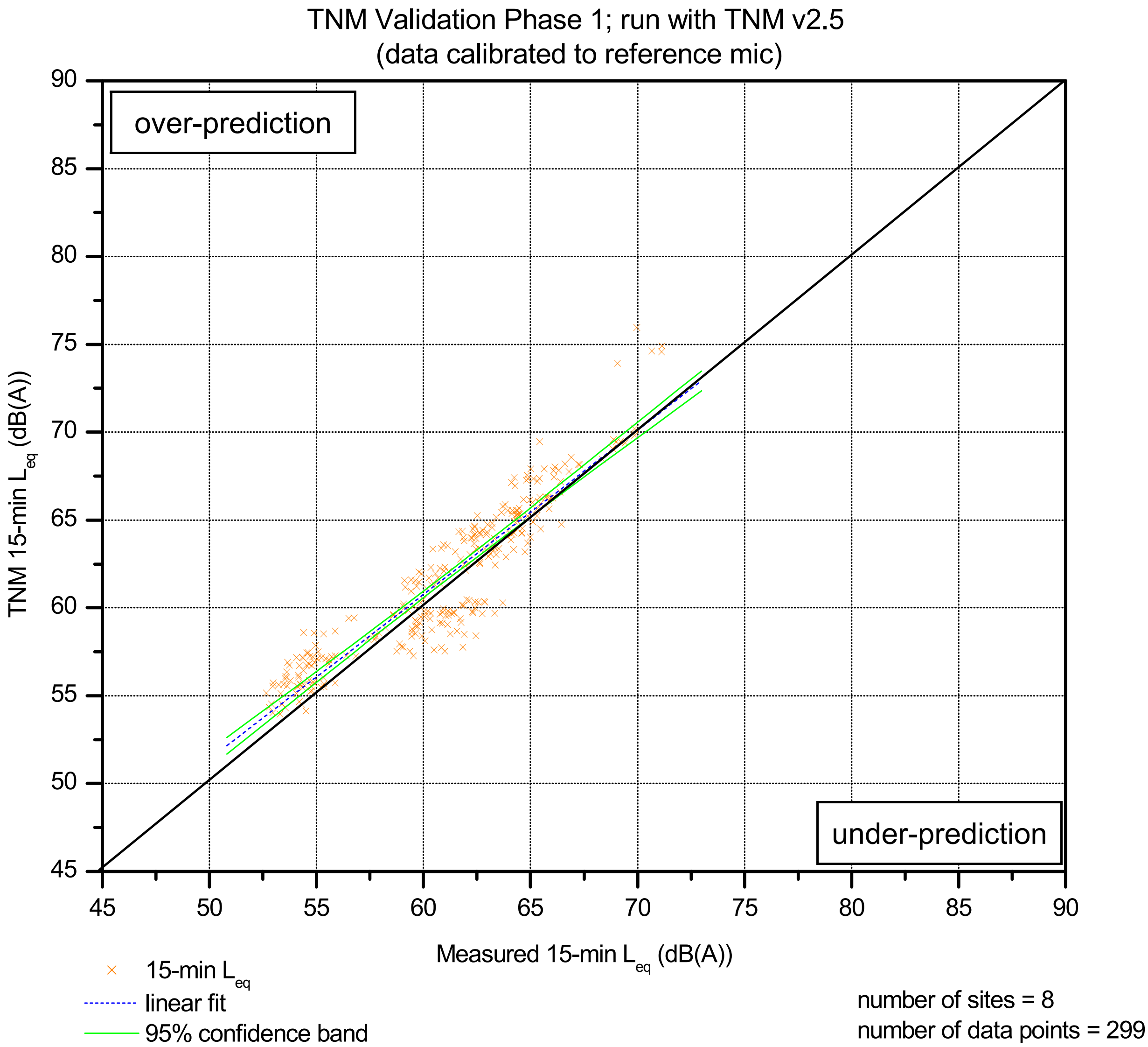


Figure A.5. Direct Comparison of TNM and Measured Data; Barrier, Soft Ground Sites; Strong Wind Data Removed.