inter•noise 2001

The Hague, Holland

The 2001 International Congress and Exhibition
on Noise Control Engineering
The Hague, The Netherlands, 2001 August 27-30

Observations of highway traffic noise measurements behind barriers and comparisons to FHWA's Traffic Noise Model

Judith L. Rochat
U.S. Department of Transportation, Volpe Center Acoustics Facility
55 Broadway, DTS-34, Cambridge, MA 02142, USA

Abstract

In 1998, the United States Federal Highway Administration (FHWA) released a new tool for highway traffic noise prediction and noise barrier design, the Traffic Noise Model® (TNM®). In order to assess the accuracy and make recommendations on the use of TNM for the FHWA, the Volpe Center Acoustics Facility is performing numerous roadside measurements, so far obtaining over 100 hours of traffic noise data from highways around the country. A majority of the measurement sites include noise barriers protecting homes, schools, or recreational parks in the area. These barriers are either berms or walls constructed of various materials with varying heights and configurations. For each site, acoustical, meteorological, and traffic data are collected simultaneously throughout the measurement period. Spectrum analyzers are used to collect 1/3-octave band A-weighted equivalent sound levels, and microphones are deployed at distances from 50 to 300 feet behind the barrier and at two heights above the ground, the number of microphones used being site dependent; a reference microphone is also deployed. Preliminary results indicate that these barriers are providing substantial noise reduction to the protected area, with attenuation over distance and height varying depending on the noise barrier configuration. Results also indicate that TNM is adequately modeling these typical sites; the calculated sound levels are mostly within 1.5 dB of the measured levels. Also, the effects of wind are seen to influence the accuracy of the model; since TNM does not account for wind, the model may be over- and under-predicting during different wind conditions.

1. Introduction

Since March 1998, the United States Federal Highway Administration's (FHWA) Traffic Noise Model® (TNM®) has been available for highway traffic noise analysis and barrier design [1]. Prior to release, the model was assessed for accuracy by comparing TNM computations to measurement data collected by various researchers and another model's results. The agreement between measured, other model-predicted, and TNM-predicted data was found to be quite good in most cases, the results of the comparisons published in the TNM Technical Manual [2]. Since the release, various States and consultants have performed independent, specific comparisons. Although all the above comparisons are useful, the measurements as a group do not represent a structured study performed with consistent data collection, reduction, and analysis techniques. Further, not all aspects of TNM computations have been investigated.

In order to better assess the accuracy and make recommendations on the use of TNM for the FHWA, the Volpe Center Acoustics Facility is performing an extensive validation study. The study involves highway noise data collection and TNM modeling for the purpose of data comparison, where the results will be published to serve as a reference for TNM. The first phase of the study is nearing completion; this phase incorporates measurement sites with acoustically soft and hard ground, with and without a noise barrier, and with various degrees of undulating terrain. At least one other phase will follow in order to incorporate more TNM features in the validation.

For Phase 1 of the TNM Validation, measurements were performed at 17 sites around the country, obtaining over 100 hours of highway traffic noise data. Of the 17 sites, 10 include noise barriers. Data collected at these sites give insight into how well the barriers are performing and, when compared to the TNM-predicted sound levels, help assess the accuracy of the model.

2. Measurement Sites

Measurement sites for Phase 1 of the TNM Validation were chosen for their relative simplicity (i.e. they contained no interfering diffractive or reflective objects other than those desired). A majority of the measurement sites include noise barriers protecting homes, schools, or recreational parks in the area. These barriers are either berms or walls constructed of various materials with varying heights and configurations.

There are three sites analyzed for presentation in the current paper:

The first site is identified as 12CA, located in San Ramon, California. This site contains a 12-ft concrete wall barrier that protects city-owned athletic fields. The ground slopes down slightly from the back of the barrier, where the flat mowed grass fields are in a plane approximately 6 ft below that of the roadway.

The second site is identified as 06CA, located in Wildomar, California. This site contains an earth berm / wall barrier combination. On the roadway side the 9-ft masonry block wall barrier sits atop ground that slopes up from the roadway to a height of 6 ft, thus forming a barrier that is effectively 15 ft. On the other side of the barrier the ground slopes down to an elevation 21 ft below the level of the roadway or 27 ft below the base of the wall barrier. The barrier protects a public elementary school whose flat mowed grass athletic fields abut the slope up to the barrier.

The third site is identified as 10CA, located in Mira Loma, California. This site contains a 16-ft earth berm covered with field grass; it was formed to protect a trailer park community. The berm extends beyond the community into an agricultural area. This flat plowed dirt area is in the same plane as the roadway.

3. Instrumentation

The primary instrumentation deployed at each site includes Bruel & Kjaer microphone systems, Larson Davis Laboratory spectrum analyzers, Sony DAT recorders, and Qualimetrics meteorological systems. The microphones are deployed at several distances behind the barrier and at two heights above the ground, the number of microphones used being site dependent; a reference microphone is also deployed either above the barrier or offset from the barrier. Table 1 summarizes the sensor locations; these sensors are arranged in a line perpendicular to the barrier, with the exception of location 1 for site 10CA. Also deployed are video cameras for traffic count and composition data; these are located on nearby highway overpasses. In addition to measurement day instrumentation, a differential global positioning system is deployed in advance to collect site terrain survey data.

	Microphones distance behind barrier; height				Meteorological Sensors distance behind barrier; height	
Site	location 1	location 2	location 3	location 4	location 1	location 2
12CA	0 ft; 4 ft*	50 ft; 5 ft and 15 ft	100 ft; 5 ft and 15 ft	200 ft; 5 ft and 15 ft	75 ft; 5 ft and 15 ft	150 ft; 5 ft and 15 ft
06CA	0 ft; 5 ft*	55 ft; 5 ft and 15 ft	100 ft; 5 ft and 15 ft	200 ft; 5 ft and 15 ft	75 ft; 5 ft and 15 ft	150 ft; 5 ft and 15 ft
10CA	50 ft; 5 ft (offset in open field next to berm)	70 ft; 5 ft and 15 ft	110 ft; 5 ft and 15 ft		90 ft; 5 ft and 15 ft	

Table 1: Sensor locations. Asterisk (*) indicates height above barrier; all other heights are above the ground.

4. Data

At each measurement site, up to six hours of data are collected. The data are then processed and analyzed then compared to TNM-predicted data. All data is collected and analyzed in accordance with ANSI standards [3] and FHWA's procedures [4].

4.1 Data collection and reduction

For each site, acoustical, meteorological, and traffic data are collected simultaneously throughout the measurement period. Spectrum analyzers are used to collect 5-second 1/3-octave band A-weighted equivalent sound levels (L_{Aeq}) at all microphone locations, some locations being processed at a later time by performing spectrum analysis of the DAT recordings offline. During all acoustical measurements, an incident noise log is maintained to record the start and stop times and identify any sound that may be intrusive to the highway traffic noise measurements. The meteorological data (including the wind speed, wind direction, temperature, and relative humidity) are collected every second. A visual record of all highway traffic is recorded continuously on 8 mm tape during the measurement period.

The acoustical and meteorological data are processed in 15-minute blocks. The processing results in 15-minute 1/3-octave band (and overall level) L_{Aeq}s and 15-minute averages of wind speed, wind direction, and relative humidity, as well as average wind speeds in the upwind and downwind directions according to the microphone line / roadway configuration. Each data block is analyzed for contamination using the incident noise log, where any contaminated data block is eliminated before final data analysis.

The highway traffic video recordings are processed manually and with an automated traffic detection system. For each traffic lane the vehicles are counted and categorized and speeds are recorded. The manual and automated results are averaged, where final results serve as traffic input to TNM. Also key terrain features are extracted from the site survey data and used as input for the object coordinates in TNM.

4.2 TNM-predicted data

Each measurement site is modeled according to the site survey data, other site features (barriers, etc.), meteorological data, and traffic data. Object input includes all barriers, roadways, receivers, terrain lines, and ground zones (field grass, pavement, etc.). Then, for each time block, the corresponding average temperature and relative humidity and the corresponding traffic data are applied. Each time block is run separately, ultimately providing 15-minute TNM-predicted 1/3-octave band (and overall level) L_{Aeq}s analogous to the processed measured data.

4.3 Data analysis

For the measured highway traffic noise data, the overall sound level at each microphone is extracted for each data block. This allows evaluating the noise barrier attenuation at each site, examining multiple distances behind the barriers.

In comparing the measured data and the TNM-predicted data, the TNM-predicted sound levels at the reference microphone are calibrated to those measured in the field for each site. This same calibration is then applied to all the other TNM-predicted sound levels for that site. The calibration process, as recommended in Reference 3, is performed to eliminate bias associated with the site-specific vehicle noise emission levels. Differences in the measured and predicted data are represented as delta values, or TNM-predicted levels minus measured levels, positive values indicating over-prediction and negative values indicating under-prediction.

5. Results

The analyzed data are here presented in two ways: the first investigating the measured overall L_{Aeq}s as a function of distance and height and the second comparing the measured and TNM-predicted data as a function of distance and height. The effects of wind are also discussed when comparing the data.

5.1 Noise barrier attenuation

Results indicate that the barriers at sites 12CA, 06CA, and 10CA are providing substantial noise reduction to the protected areas, with attenuation over distance and height varying depending on the noise barrier configuration. Please refer to Figure 1.

At site 12CA the sound level at the barrier location, assuming no influence from the barrier, is about 85 dB(A). At 50 ft behind the wall barrier, the traffic noise has been attenuated 19.0 dB at a height of 5 ft and 15.5 dB at a height of 15 ft. At greater distances behind the barrier, the attenuation is only 1 or 2 dB greater.

At site 06CA the sound level at the barrier location, assuming no influence from the barrier, is about 77 dB(A). At 65 ft behind the berm / wall combination barrier, the traffic noise has been attenuated 23.5 dB at a height of 5 ft and 22.2 dB at a height of 15 ft. At greater distances behind the barrier, the attenuation is either about the same and sometimes slightly less than the attenuation closer to the barrier.

At site 10CA the sound level 50 ft from the center of the near travel lane with no barrier, is about 72 dB(A). At 70 ft behind the berm, the traffic noise has been attenuated 15.1 dB at a height of 5 ft and 11.4 dB at a height of 15 ft. At greater distances behind the barrier, the attenuation is either about the same and sometimes slightly less than the attenuation closer to the barrier.

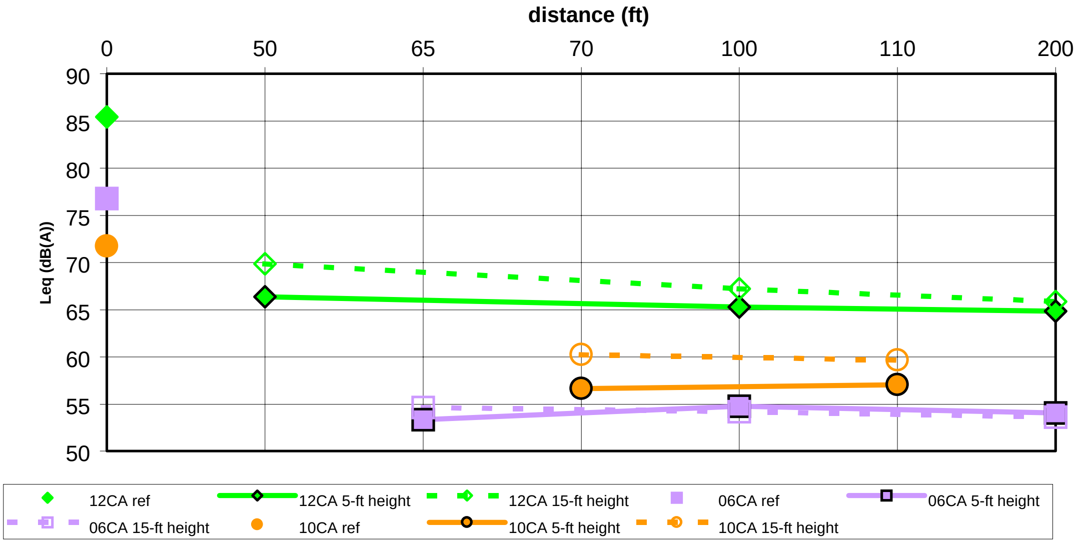

Figure 1: 15-minute average A-weighted equivalent sound levels (L_{Aeq}) as a function of distance behind barrier and height above ground for each site. Sites shown are 12CA: small decline from road plane to site, mowed lawn area, wall barrier; 06CA: steep decline from road plane to site, mowed lawn area, berm / wall barrier, and 10CA: flat, plowed dirt area, berm.

5.2 Comparison of TNM-predicted data to field data

Results indicate that TNM is adequately modeling sites 12CA, 06CA, and 10CA. Please refer to Figures 2 and 3 for the results. Here, the data represent the delta values, or calibrated TNM-predicted data minus measured data. The average delta values are indicated along with the standard deviation from those averages. The standard deviation is based on the data set for each microphone at each site, where each data set contains multiple 15-minute data blocks.

For the 5-ft high microphones (Figure 2), the average TNM-predicted sound levels are within 1.5 dB of the measured levels, except the 200-ft microphone for site 12CA, which is within about 2.5 dB. For the 15-ft high microphones (Figure 3), the average TNM-predicted sound levels are all within 1.5 dB of the measured levels.

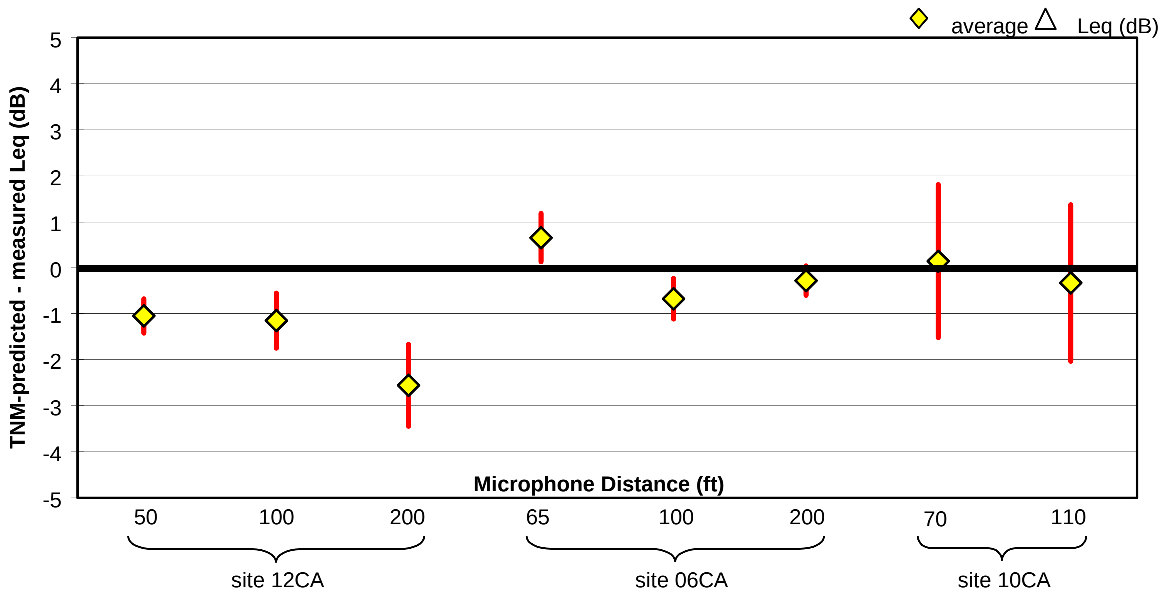

Figure 2: TNM-predicted and measured 15-minute sound levels compared; TNM-predicted data are calibrated to the reference microphones before subtracting the measured data. Shows standard deviations and averages as a function of distance behind barrier. Height above ground is 5 ft.

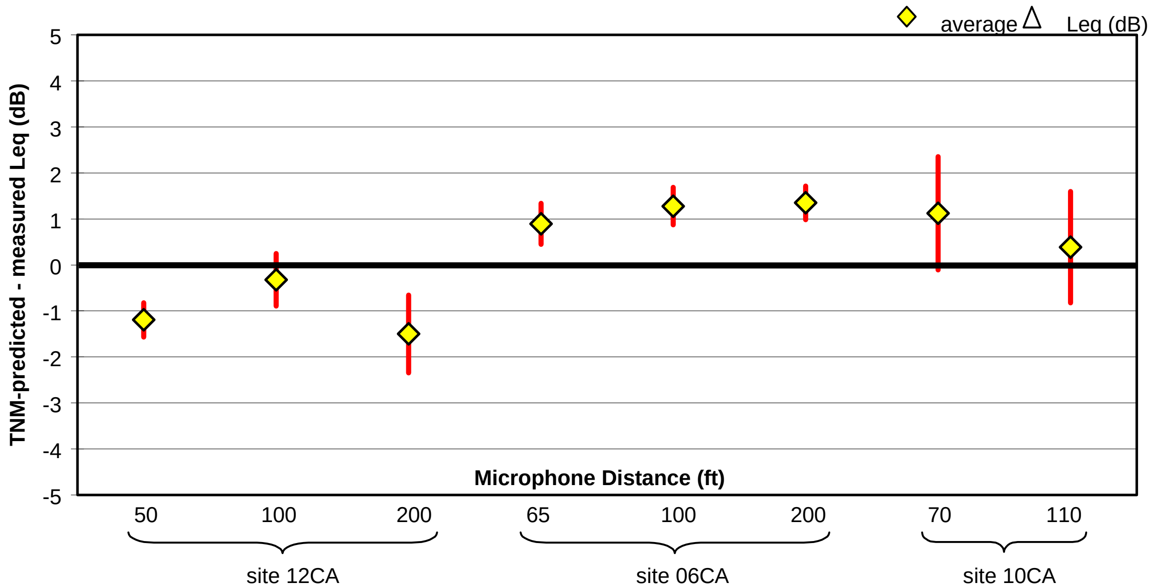

Figure 3: TNM-predicted and measured 15-minute sound levels compared; TNM-predicted data are calibrated to the reference microphones before subtracting the measured data. Shows standard deviations and averages as a function of distance behind barrier. Height above ground is 15 ft.

It can be seen that in some cases there is more variation in the data at a single location than in other cases. Also, it can be seen that in some cases TNM is over-predicting and in others it is under-predicting. For site 06CA there is little variation and mostly over-predicting, especially at the high microphones. For site 12CA there is slightly more variation than for site 06CA and under-predicting, especially at the high microphones. For site 10CA there is even more variation than for site 12CA and mostly over-predicting, especially at the high microphones. It is possible that these variations and prediction errors can be attributed to wind.

The current version of TNM does not account for wind in its sound level predictions. It is known that for upwind conditions (wind blowing in the direction from the microphone to the roadway), the received sound level decreases from that for calm wind conditions; for downwind conditions (wind is blowing in the direction from the roadway to the microphone) the received sound level increases [5]. Since the wind speed and direction are measured during all acoustical measurements, it is possible to identify the wind speed as well as upwind and downwind conditions at each measurement site.

At site 06CA the wind speeds ranged from approximately 0 to 6 mph, the stronger winds blowing in the upwind direction. At site 12CA the wind speeds ranged from approximately 1 to 8 mph, the stronger winds blowing in the downwind direction. At site 10CA the wind speeds ranged from approximately 1 to 11 mph, the stronger winds blowing in the upwind direction. This may explain the observations stated above such that: 1) the broadest range of wind speeds causes the most variation in the data (site 10CA) and 2) the upwind conditions cause over-prediction (sites 06CA and 10CA) and the downwind conditions cause under-prediction (site 12CA).

Conclusions

In a study to assess the accuracy of TNM, many hours of highway traffic noise data were collected at numerous sites (at multiple distances behind noise barriers and two heights above the ground). Three measurement sites chosen for analysis here give insight to how well their noise barriers are performing and also how well TNM is predicting the sound levels. The sound levels measured behind the noise barriers indicate that the barriers in combination with elevation changes from the roadway are providing substantial noise reduction, as much as 23.5 dB 65 ft behind the berm / wall combination barrier with the -21-ft elevation change from the roadway to the measurement field. When comparing the measured sound levels to those predicted using TNM, it is found that TNM-predicted levels are mostly within 1.5 dB of those measured in the field. For the sites analyzed here, the distances behind the barriers ranged from 50 ft to 200 ft. Only at one location (200 ft distance, 5-ft height) at one site is the average TNM-predicted sound level more than 1.5 dB different from the measured level (it is approximately 2.5 dB different). In addition, it is seen that effects of the wind may influence the accuracy of the model; since TNM does not account for wind, the model may be over-predicting in upwind conditions and under-predicting in downwind conditions.

Acknowledgements

The author would like to thank the Federal Highway Administration and the California Department of Transportation for their support of this work. The author also wishes to thank Dave Read (WT Chen), Cyndy Lee (Volpe Center), and Trevor May (Out of the Box Productions) for their essential participation and Gregg Fleming (Volpe Center) for his guidance. In addition, the help from Chris Roof, Amanda Rapoza, Brian Kim, Mike Lau, Matt Corbo, Khem Veasna, Clay Reherman, and Kevin Wright is greatly appreciated.

References

1. 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, 1998.
2. 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, 1998.
3. American National Standards Institute and the Acoustical Society of America Standards, "Methods for Determining the Insertion Loss of Outdoor Noise Barriers," ANSI S12.8-1998, Acoustical Society of America, New York, New York, 1998.
4. Lee, Cynthia S.Y. and Gregg G. Fleming, "Measurement of Highway-Related Noise," Report No.s FHWA-PD-96-046 and DOT-VNTSC-FHWA-96-5, U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, 1996.
5. Rochat, Judith L. and Gregg G. Fleming, "Acoustics and Your Environment: The Basics of Sound and Highway Traffic Noise (A Video Production)," Letter Report No. DTS-34-HW966-LR1, U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, 1999.