Comparison of Traffic Noise Model 2.5 with 2.1 and Measured Data

A. A. El-Aassar, R. L. Wayson, and J. M. MacDonald

Traffic Noise Model Version 2.5 (TNM 2.5) will soon be the official traffic noise model required by the FHWA for federally funded projects. TNM was updated from Version 2.1 to 2.5 to address two major issues: the overprediction found in the previous version of TNM and an anomaly related to diffraction points. This research focused on comparing the TNM 2.5 predicted results with TNM 2.1 predicted values and with measured data from 18 barrier locations in Florida. Matched pairs of predicted and measured differences between the data for TNM 2.5 and TNM 2.1 were evaluated and a direct comparison of the two models was made. This research demonstrated that the predicted results from TNM 2.5 had an average error for all 18 barrier locations of less than 1 dB. However, when each of the sites is evaluated individually, TNM 2.5 has a tendency to underpredict slightly at many of the evaluated barrier locations. Finally, TNM 2.5-predicted results tend to be about 3 dB(A) on average less than TNM 2.1 at a defined reference measurement position, which is relatively unaffected by ground effects or diffraction, and about 1 dB less at microphone positions behind evaluated barriers when compared with TNM 2.1.

This paper details the work of evaluating the newly released version of Traffic Noise Model Version 2.5 (TNM 2.5) (*1*). TNM 2.5 was revised to address two major issues: the overprediction found in TNM 2.1 (*2*) and correction of an anomaly in prediction related to diffraction points (*3*). TNM 2.5, TNM 2.1, and measured values were directly compared for 18 barrier locations where data had been previously taken and evaluated at multiple positions (*4*). This allowed an assessment of the change in TNM from the previous version and an evaluation of accuracy of TNM 2.5 when compared with quality-controlled, carefully collected measurement data.

Because TNM 2.5 may read input files created for TNM 2.1, the same input files were used during the execution of each model, allowing a direct comparison of the two models. In turn, the results of both versions were compared with measured data. All FHWA requirements for average pavement type, temperature, humidity, and so forth were followed. Predictive results were tabulated, allowing a direct comparison at each measurement position and each barrier location.

The data were collected as part of an in situ barrier insertion loss project sponsored by the Florida Department of Transportation, from January 1999 until May 2002 (*5*). A mobile noise laboratory was used to collect sound level data. The mobile laboratory allows use of a microphone array above [as high as 8.84 m (29 ft)] and behind [capable of 152.4-m (500-ft) distances] the barrier to measure existing sound levels. Measurements were conducted with careful regard to published procedures by FHWA (*6*), the American National Standards Institute (ANSI S12.8-1998), and the International Organization for Standardization [ISO 10847:1997(*F*)]. Microphone positions above and behind the barrier followed the indirect barrier insertion loss method (ANSI S12.8-1998). Detailed procedures were previously reported by Wayson et al. (*7*), and the interested reader is directed to that paper. Only those details necessary to understand the work are included in this paper.

Table 1 presents a description of each barrier location analyzed in the Florida project. The table includes the barrier locations in Florida, the primary roadway source, and the effective height of the barrier evaluated. The effective height is the height of the top of the wall relative to the receiver ground plane behind the wall. Any elevation increase due to berms or ground elevations is included in the effective height.

Sound levels were recorded at multiple microphone positions behind each barrier varying in distance behind the barrier and height above the ground plane. Typically, 12 measurement positions were used at each site, although more were used when possible. These positions included eight Ivies IE30A ⅓-octave band analyzers and four Metrosonic dB308 overall sound level analyzers (used to measure broadband A-weighted sound levels). Figure 1 presents a typical monitoring array of microphones used at each position. Distances beyond 30 m were difficult because existing homes prevented clear lines of sight over an extended angle to the barrier. The 12 typical microphone positions for all locations were the same except when power lines or other obstacles inhibited tower placement. In Figure 1, Positions 1 through 8 were measured using the ⅓-octave band analyzers and positions labeled A thru D were measured with the analyzers using the A-weighting scheme. Multiple heights and distances behind the barriers were achieved by using portable towers. It should be noted that microphone Positions 1 and 4 are the same as microphone Positions B and D. This was done intentionally for quality-control purposes. Moreover, microphone Positions 7 and 8 are always reference microphones and are always placed 1.5 m (4.92 ft) directly above the top of the noise barrier as prescribed in the ANSI standard method. Two microphones help to avoid Murphy's law and to ensure a good reference measurement was taken. Where possible, due to nearby obstructions, additional microphone positions were used.

RESULTS

This discussion is divided into three parts. Discussed first is a comparison between predicted results from TNM 2.5 and TNM 2.1 to measured data when compared with the reference measurement

Community Noise Laboratory, Civil and Environmental Engineering Department, University of Central Florida, Orlando, FL 32816-2450.

Transportation Research Record: Journal of the Transportation Research Board, No. 1941, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 149–154.

TABLE 1 Measurement Site Summary

Site	Major Source	Effective Wall Height
A. Jacksonville	I-95	18.5 ft. (5.6 m)
B. Jacksonville	I-295	13.5 ft. (4.1 m)
C. Daytona Beach	SR-5A	14.5 ft. (4.4 m)
E. Brandon	I-75	41.0 ft. (12.5 m)
F. Clearwater	SR-636	11.0 ft. (3.4 m)
G. St. Petersburg	SR-682	7.3 ft. (2.2 m)
H. Ft. Lauderdale	I-95	14.5 ft. (4.4 m)
I. Deerfield Beach	I-95	13.1 ft. (4.0 m)
J. Miami	I-195	18.0 ft. (5.5 m)
K. Tamiami	US-41	11.0 ft. (3.4 m)
L. Hialeah	SR-924	25.3 ft. (7.7 m)
M. Wildwood	SR-44	9.4 ft. (2.9 m)
N. Maitland	SR-414	11.6 ft. (3.5 m)
O. Ft. Lauderdale (Site H Repeat)	I-95	14.5 ft. (4.4 m)
P. Ft. Lauderdale	I-95	18.4 ft. (5.6 m)
Q. West Palm Beach	I-95	19.3 ft. (5.9 m)
R. Palm Harbor, Tampa	SR-586	7.7 ft. (2.3 m)
S. New Port Richey	SR-54	11.0 ft. (3.4 m)

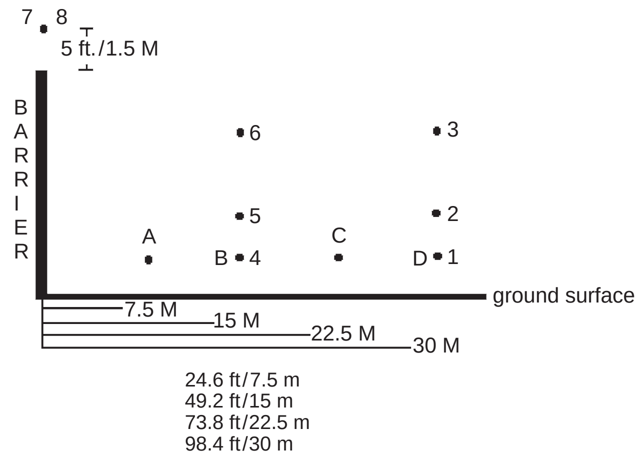

FIGURE 1 Microphone positions.

position. This allowed an evaluation of the direct sound wave from the highway with minimal ground or diffraction effects. The second discussion focuses on comparisons between the predicted and measured values for positions behind the barrier where diffractional effects are the major factor. Finally, the differences between predicted results from TNM 2.5 and TNM 2.1 are reviewed directly.

When the measured reference microphone levels are compared with the predictive results from TNM 2.1 and TNM 2.5, an improvement in the accuracy is generally shown for TNM 2.5. The values found are presented in Tables 2 and 3. Figure 2 graphically shows the predicted results to the measurements at the reference microphone position. There is less than a 0.5-dB difference between the results from TNM 2.5 and the measured data at barrier Locations B, C, H, M, N, and S. TNM 2.5 outperformed TNM 2.1 when compared with the measured data in most cases. When the results are further reviewed, an interesting trend appears. Figure 3 indicates the positive or negative error between the predicted when compared with the measured data at the reference microphone position. It can be concluded that TNM 2.1 has a tendency to overpredict, whereas

TABLE 2 Average Difference Between TNM 2.1 and Measured Data

Location	Ref.	1	2	3	4	5	6	A	C
A	1.6	–1.2	–0.7	–3.0		–2.4	–1.8	–2.5	–1.9
B	3.0	–1.0	–1.2	2.9	–1.0	–0.5	5.0	–2.1	–0.3
C	1.0	2.5	2.5	2.3	1.6	2.2		1.7	0.9
E	–0.3	–1.5	–1.1	–0.9	–1.7	–1.9	–0.8	0.9	–1.2
F	1.4	–0.6	2.6	0.3	0.1	2.5	1.6	0.7	–0.7
G	–2.1	–3.1	–1.5	0.6	–2.7	1.1		–3.5	–2.9
H	3.9	2.7	1.7	2.4	0.9	2.9	3.7	2.0	2.8
I	3.6	3.0	3.3	3.4	0.9	1.8	5.0	–1.1	1.2
J	0.3	–2.1	–0.5	–0.1	–3.0	–2.2	–2.3	–3.3	–2.5
K	1.5	–0.6	–0.3	3.1	2.0	2.3	4.0	0.6	–0.7
L	1.9	–0.4	1.7	–1.2	–0.9	–1.4	–1.4		–1.6
M	2.6	3.7	4.2	3.4	2.9	4.0	5.2	0.3	–0.9
N	1.9	–1.9	–0.8	0.5	–0.7	1.0		0.0	–1.9
O	3.6	2.8	2.0		1.6	1.8			
P	2.6	0.6	1.2		2.0	2.1	3.0	0.1	0.9
Q	4.4	4.5	4.5	4.1	5.1	4.5	4.0	4.4	3.4
R	4.3	2.5	5.5		4.4	7.3			–2.2
S	3.7	–1.7	–0.4	1.6	–0.6	1.7	5.4	–0.1	
Average	2.2	0.7	1.5	2.4	0.5	1.3	1.3	–0.1	–0.5
SD	1.7	2.3	2.5	2.9	2.3	2.2	2.0	2.1	1.8

Ref. = reference position.

TABLE 3 Average Difference Between TNM 2.5 and Measured Data

Location	Ref.	1	2	3	4	5	6	A	C
A	–1.6	–2.7	–2.1	–4.4		–3.9	–3.2	–4.0	–3.5
B	0.1	–2.2	–2.5	3.5	–2.4	–1.8	3.7	–3.5	–1.6
C	–0.5	2.4	2.0	1.7	1.3	1.7		0.9	0.9
E	–3.1	–3.0	–2.8	–2.3	–3.2	–3.5	–2.2	–0.4	–2.7
F	–1.5	0.0	4.2	–0.4	0.2	3.1	0.7	–0.1	–0.1
G	–3.9	–3.3	–1.9	0.6	–2.7	1.3		–3.7	–2.9
H	0.7	1.7	0.3	1.8	–0.6	1.1	3.7	0.3	1.4
I	0.5	4.3	3.1	2.5	0.5	0.8	4.8	–2.6	1.9
J	–2.5	0.8	1.8	1.0	–0.5	–0.2	1.2	–1.8	0.4
K	–1.5	–0.8	–0.9	2.3	1.0	1.6	2.4	–0.4	–1.7
L	–1.1	–2.6	–1.3	–2.8	–2.3	–3.0	–3.2		–3.0
M	–0.5	3.9	4.2	2.7	2.1	4.3	3.7	–0.7	–0.7
N	–0.8	–2.9	–0.7	0.4	–1.6	0.2		–1.0	–2.8
O	0.9	2.0	1.3		0.5	0.6			
P	–0.5	–0.4	0.3		1.0	0.8	1.6	–1.1	–0.3
Q	1.7	3.6	3.7	3.3	3.9	4.3	3.3	3.5	1.9
R	1.7	2.2	5.2		3.8	6.0			–2.6
S	0.2	–2.0	–0.8	1.1	–1.8	0.9	5.0	–1.5	
Average	–0.7	0.1	0.7	0.7	0.0	0.8	1.6	–1.1	–1.0
SD	1.5	2.6	2.5	2.3	2.1	2.7	2.9	1.9	1.9

Ref. = reference position.

TNM 2.5 tends to underpredict. Furthermore, as indicated in Figure 3, the overall error is significantly reduced in TNM 2.5 compared with TNM 2.1.

Prediction behind the barrier is also very important and was evaluated. The differences between predictions and measured data are presented in Tables 2 and 3. Table 4 presents an overall average of all locations by measurement position. On average, TNM 2.5 was more accurate at all but one position. This exception was at measurement Position 6, 6 m above the ground plane.

Two measurement positions behind the barrier were thought to be more important, Positions 1 and 4. These were the positions located at the typical modeling receiver height [1.5 m (5 ft) above the ground plane], at distances typical of first and second row homes. Additionally, duplicate measurements allowed more quality control at these positions. Figures 4 and 5 show these individual comparisons. Again, these results tend to indicate that TNM 2.5 is performing better than TNM 2.1 when comparing predicted results with measured data at Positions 1 and 4.

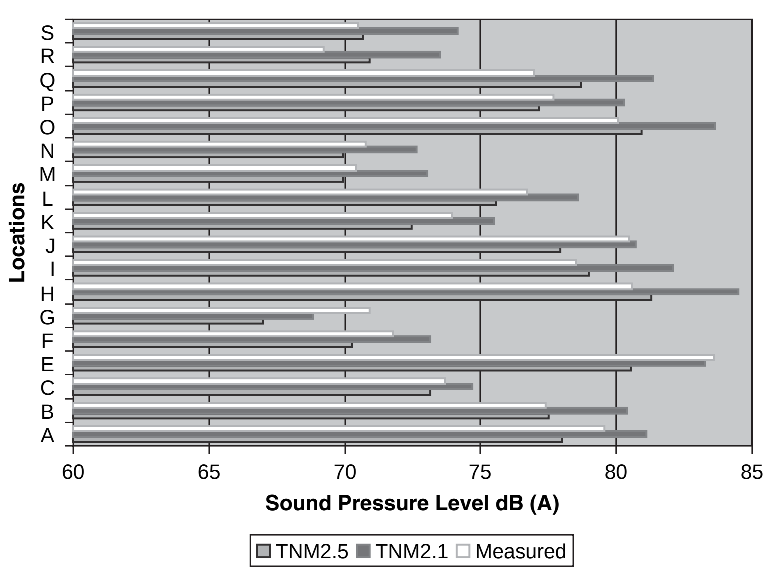

FIGURE 2 Predicted and measured data at reference microphone.

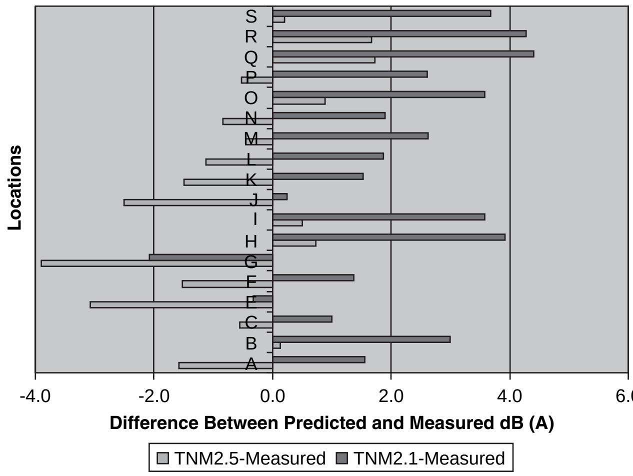

FIGURE 3 Differences between predicted and measured data at reference microphone.

TABLE 4 Summary of Average Error (Predicted – Measured) for All Sites

Version	Ref.	1	2	3	4	5	6
TNM2.1	2.2	0.7	1.5	2.4	0.5	1.3	1.3
TNM2.5	–0.7	0.1	0.7	0.7	0.0	0.8	1.6

Ref. = reference position.

Figures 6 and 7 repeat the data presented in Figures 4 and 5 for measurement Positions 1 and 4, respectively, but show the error and whether under- or overpredictions occurred. Again, TNM 2.5 performed better in more cases, but the figures indicate that the error is more evenly split between under- and overprediction, which is different than at the reference location. The source code is not available so the reason for this change in trends can only be guessed.

However, because of these variances, a direct comparison of the predicted results from TNM 2.1 and TNM 2.5 is beneficial. Table 5 presents this comparison. Predictions of TNM 2.1 at the reference position are greater than TNM 2.5 by an average of 2.8 dB(A). At measurement Position 1, TNM 2.1 predictions are greater by an average of 0.4 dB(A). At measurement Position 4, TNM 2.1 predictions are 0.7 dB(A) greater on average. In general, behind the barrier, TNM 2.5 results were always lower than TNM 2.1 by less than 1 dB(A). These results, along with the other presented results behind the barrier, indicate that a change has occurred not only in the reference levels but also in the propagation algorithms.

CONCLUSIONS

This research focused on evaluating TNM 2.5. Comparison of TNM 2.5 with results predicted from TNM 2.1 and measured data from 18 barrier locations was used in this evaluation. This allowed a comparison with quality-controlled, measured data and a direct comparison between TNM 2.5 and TNM 2.1.

This research demonstrated that TNM 2.5 results for the reference microphone positions are lower than results from previous versions by almost 3 dB(A) and more closely follow measured results. This affirms that the improvement made to the vehicle emission database in the newly released TNM 2.5 has improved the reference emission levels. Additionally, the error due to the difference between predicted and measured data for measurement positions behind the barrier are better on average and at more measurement positions for TNM 2.5 than for TNM 2.1. It also appears that revisions to the propagation algorithms have occurred when comparing TNM 2.5 with TNM 2.1.

Underprediction was shown for several positions and this means that greater care must be used when applying the results during barrier design. Previously, the conservatism in models that were used allowed for some error during the analysis without resulting in problems after barrier installation. This no longer appears to be true and the analyst must carefully consider this greater accuracy during project work.

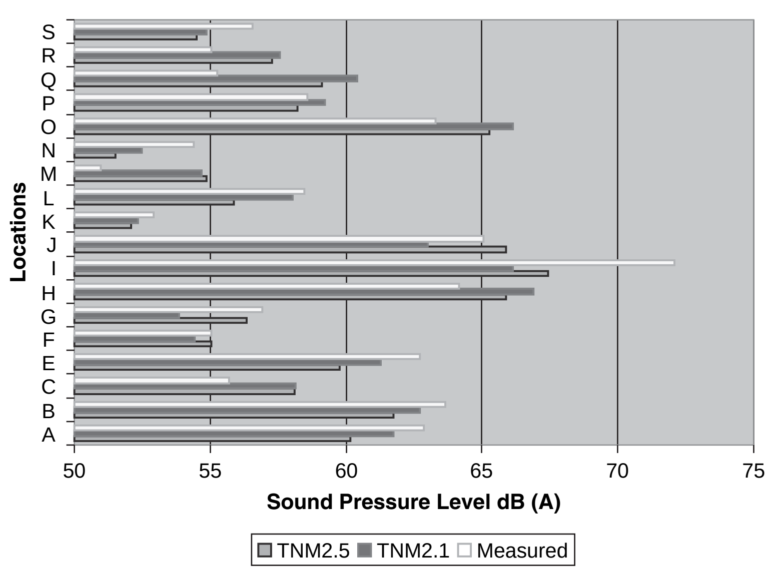

FIGURE 4 Predicted and measured data at Microphone Position 1.

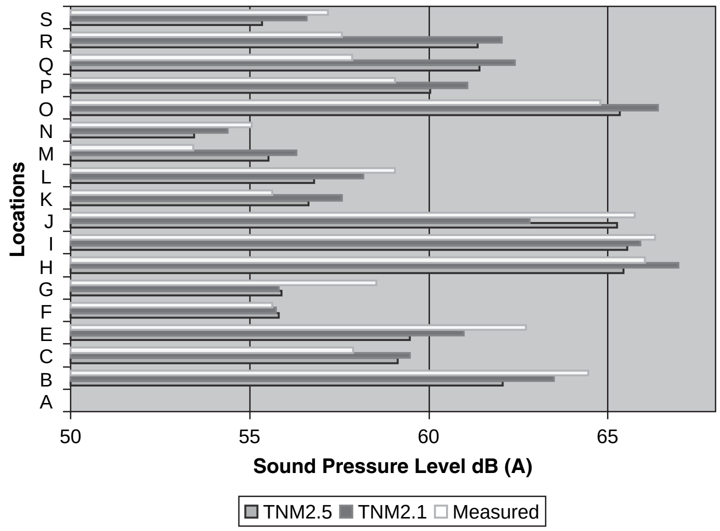

FIGURE 5 Predicted and measured data at Microphone Position 4.

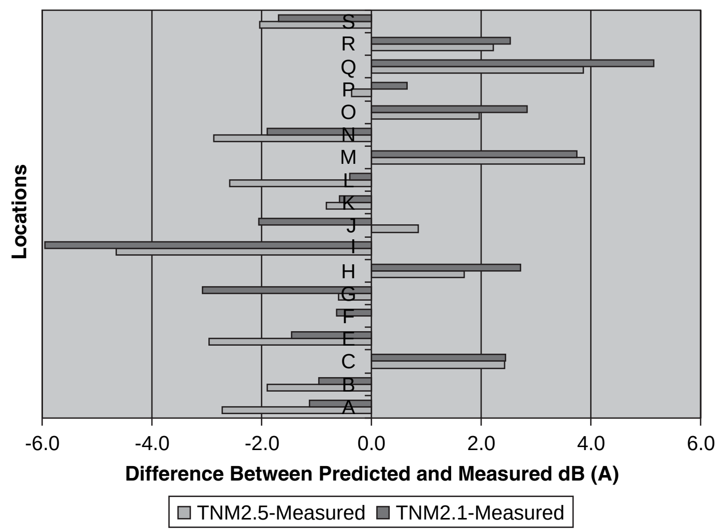

FIGURE 6 Differences between predicted and measured data at Measurement Position 1.

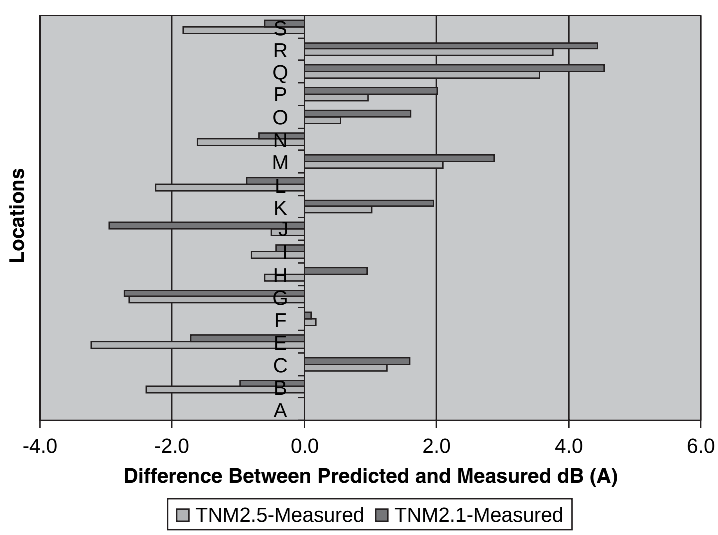

FIGURE 7 Differences between predicted and measured data at Measurement Position 4.

TABLE 5 Average Difference Between TNM 2.5 and TNM 2.1

Location	Ref.	1	2	3	4	5	6	A	C
A	3.1	1.5	1.4	1.4		1.5	1.4	1.5	1.5
B	2.9	1.2	1.3	–0.6	1.4	1.3	1.3	1.4	1.4
C	1.6	0.0	0.6	0.5	0.4	0.5		0.8	0.0
E	2.8	1.5	1.7	1.5	1.5	1.6	1.5	1.3	1.5
F	2.9	–0.6	–1.6	0.7	–0.1	–0.6	1.0	0.7	–0.6
G	1.8	0.2	0.4	0.0	–0.1	–0.1		0.2	0.0
H	3.2	1.0	1.4	0.6	1.6	1.8	0.0	1.6	1.4
I	3.1	–1.3	0.2	1.0	0.4	1.0	0.2	1.6	–0.8
J	2.8	–2.9	–2.3	–1.1	–2.5	–2.0	–3.5	–1.5	–2.9
K	3.0	0.3	0.6	0.8	0.9	0.7	1.6	1.0	1.0
L	3.0	2.2	3.0	1.7	1.4	1.6	1.9		1.4
M	3.1	–0.2	0.1	0.7	0.8	–0.3	1.5	1.0	–0.2
N	2.7	1.0	–0.1	0.1	0.9	0.8		1.1	0.9
O	2.7	0.9	0.7		1.1	1.3			
P	3.1	1.0	0.9		1.1	1.3	1.5	1.2	1.2
Q	2.7	1.3	0.2	0.8	1.0	0.8	0.8	0.9	1.6
R	2.6	0.3	0.3		0.7	1.4			0.4
S	3.5	0.4	0.4	0.5	1.2	0.7	0.4	1.4	
Average	2.8	0.4	0.5	0.6	0.7	0.7	0.7	0.9	0.5
SD	0.5	1.2	1.2	0.7	0.9	1.0	1.4	0.8	1.2

Ref. = reference position.

Finally, work on using proper pavement type and atmospheric input must be continued. This undoubtedly led to some error during the comparisons.

REFERENCES

1. Anderson, G. S., C. S. Y. Lee, G. G. Fleming, and C. W. Menge. *FHWA Traffic Noise Model, User's Guide*. FHWA-PD-96-09. FHWA, U.S. Department of Transportation, 1998.
2. Rochat, J. L., and G. G. Fleming. *Validation of FHWA's Traffic Noise Model® (TNM): Phase 1*. Report No. FHWA-EP-02-031 and DOT-VNTSC-FHWA-02-01. John A. Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, Mass., 2002.
3. Rochat, J. L. FHWA's Traffic Noise Model (TNM) Versions 2.4 Validation Results. Presented at National Conference and Exposition on Noise Control Engineering (Noise-CON 2004), Baltimore, Md., 2004.
4. Wayson, R., J. MacDonald, A. El-Aassar, W. Lindeman, and M. Berrios. Florida Noise Barrier Evaluation and Computer Model Validation. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1859*, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 72–78.
5. Wayson, R. L., J. M. MacDonald, and A. El-Aassar. *Continued Evaluation of Noise Barriers in Florida.* FDOT Project No. BD-355-2. Florida Department of Transportation, Tallahassee, 2002.
6. Lee, C. S. Y., and G. G. Fleming. *Measurement of Highway Related Noise.* FHWA-PD-96-046. John A. Volpe National Transportation Center, FHWA, U.S. Department of Transportation, Cambridge, Mass., 1996.
7. Wayson, R. L., J. M. MacDonald, W. Arner, W. M. Lindeman, and M. Berrios. Comparison of Measured and Modeled Sound Levels in the Vicinity of Traffic Noise Barriers. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1792*, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 57–64.

The Transportation-Related Noise and Vibration Committee sponsored publication of this paper.