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SIMPLE METHODS for ESTIMATING HIGHWAY NOISE

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ABSTRACT

Simple highway noise prediction methods that do not involve the rigor and detail of modeling using the FHWA Traffic Noise Model (TNM) are useful in land planning or to initially determine if additional, more thorough analysis is desirable. Candidate methods for this purpose include FHWA and HUD traffic noise prediction procedures dating from the 1970s and the more recent, TNM LookUp method which relies on TNM-generated data tables. Such preliminary estimates should tend to be conservative (i.e., overestimate TNM-modeled traffic sound levels) so that findings that further analysis is unnecessary can be made with confidence. The HUD method generally gave the greatest errors. The 1978 FHWA and HUD procedures became increasingly conservative with distance from the highway. On the other hand, the TNM LookUp method was very accurate for hard sites. TNM LookUp for soft sites usually gave the smallest errors also, but it was least accurate relatively close to the roadway and yielded *underestimates* at virtually all receptor distances. Although apt to be very conservative at large distances, the best results were obtained by calculations which utilized the 1978 FHWA noise propagation computation combined with the current TNM vehicle noise emission levels.

INTRODUCTION

Mathematical formulas have been derived which relate the noise generated by a stream of highway traffic to its volume, speed, and mix of vehicle types. In the late 1970s, the U.S. Federal Highway Administration (FHWA) established standard procedures for the prediction of noise from highway traffic over defined periods (usually 1-hr durations).[1] These procedures were disseminated in: manual computation, nomograph, and programmable calculator implementations—as well as the digital computer program known as STAMINA. In 1998, FHWA released the Traffic Noise Model (TNM) software that—by virtue of more up-to-date vehicle noise emission data and more scientifically rigorous computation of sound propagation behavior—provides more accurate results than previously obtainable.[2] TNM, while capable of modeling complex roadway and receptor geometries in considerable detail, is remarkably easy to use by virtue of its: graphical user interface, ability to accept input data from a digitizing table, and capability to read computer-aided drafting (CAD) files. The latest version of TNM is required for use in all new traffic noise analyses for Federal-aid highway projects.[3]

In spite of the ease of using TNM, simple highway noise prediction methods that do not involve the rigor and detail of TNM modeling remain useful. Such methods are desirable as:

- Quick preliminary estimators,
- Simple screening tools,
- Land planning guides, or
- Comparative calculators.

Simple procedures also minimize the risks of error that can arise from inexperienced analysts running the complex TNM program. Typical applications are—to establish setback limits for residential development in land planning or to initially determine if additional, more thorough analysis is desirable. Candidate methods for this purpose include FHWA and U.S. Department of Housing and Urban Development (HUD) noise prediction procedures dating from the 1970s and the much more recent, FHWA TNM LookUp Table method which relies on TNM-generated data tables. Use of the TNM LookUp Tables has been made even easier by the availability of a computerized version, TNMLOOK.[4] In fact, FHWA promoted the use of TNM Look UP/ TNMLOOK as "a screening tool to be used in simple applications of the FHWA TNM."[5]

Simple computation methods should be easy to use and yield results that are good estimates of TNM predictions. Since a simple procedure cannot be expected to be as accurate as a detailed analysis, errors should tend to be conservative, overestimates so that findings that further analysis is unnecessary can be made with confidence. Simple prediction procedures generally ignore (or should not be used to consider) the effect of—shielding from topography or barriers. Thus, barrier analyses should *not* be part of a simple prediction method since barrier performance is so dependent upon the three-dimensional site topography.

This study examines the suitability of the various methods for meeting these needs by comparing their results to TNM predictions for roadways of various widths with low- and high-speed traffic flows in soft- and hard-ground environments. Determining the accuracy of TNM to predict actual traffic sound levels that might be measured in reality *was not* an objective.

ANALYSIS PROCEDURES

Analyses were performed to determine the ability of simple computational methods to accurately estimate the traffic sound levels predicted from modeling with the full TNM computer program. Simple highway noise prediction methods ignore topography and the shielding afforded by any structures, and assume that the roads and receptors are coplanar. That is, the roadways are analyzed as being infinitely long, straight and flat; lying in the receptor ground plane. For comparison, TNM-predicted noise exposures were obtained from a very simple highway model consisting of one or more straight, 10,000-ft length roadways composed of 200-ft long segments. At the longitudinal midpoint of the highway, receptors were defined with 5-ft height at distances from the overall highway centerline of—50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 800, and 1000 ft.[*] The ground was taken as perfectly flat with surface conditions:

- *Soft*—"lawn" (300 rayls), or
- *Hard*—"pavement" or "water" (20000 rayls).

The pavement surface was taken as "average." The computations were performed using TNM Version 2.5.

Highway geometries consisted of—1-, 2-, 3-, 4-, 6-, 8-, and 10-lane configurations modeled as combinations of 1-, 2-, or 3-lane roadways, as defined in TABLE 1. Only traveled lanes were modeled, i.e., paved shoulders were not represented. Noise predictions were based upon maximum-noise, level-of-service (LOS) D traffic conditions, 1800 vehicles per hour per lane (VPHPL) with 5% medium and 5% heavy trucks.[†] The traffic was assumed to be uninterrupted (i.e., free flow at constant speed), at two speeds:

- *High*—70 MPH or
- *Low*—35 MPH

Simple estimates of the traffic noise were obtained using:

- *FHWA 78*—This calculation is a rudimentary implementation of FHWA procedures consisting of the noise propagation computations and vehicle noise emission levels of the 1978 FHWA highway noise prediction method.[6] (In this evaluation, sound levels were calculated at equivalent-lane[‡] distances from a roadway as a function of roadway width.)

[*] 984 ft with TNM LookUp

[†] Traffic noise increases with both vehicle speed and volume. When speeds drop with increasing volumes for deteriorating level of service, traffic noise decreases as well. Consequently, a level-of-service (LOS) condition will exist which produces the greatest noise. A freeway is likely to be noisiest at LOS D.

[‡] The single-lane equivalent distance is a useful characterization of source-receptor distance for wide roadways and is defined as

$$D_E = (D_N D_F)^{1/2}$$

where D_N is the distance to the centerline of the near lane and D_F is the distance to the centerline of the far lane.

- *HUD Noise Assessment Guidelines*. As part of its 1979 policy revision, HUD provided procedures with the intent that people without technical training would be able to assess noise exposures to housing sites.[7] The HUD Guidelines included simple methods for estimating exposures from aircraft, highway and railway operations using nomographs. In this study, computations identified as being in accordance with the HUD Guidelines will be derived from evaluation of the mathematical expressions upon which the Guidelines nomographs are based.[8] The HUD procedure does not differentiate for ground surfaces but has a propagation algorithm similar to the original, 1978 FHWA procedure for soft sites.[*] The HUD procedure can adjust predictions for heavy trucks traveling uphill and considers buses seating more than 15 passengers as heavy trucks.

- *FHWA TNM LookUp Tables*—These computations used Software Ver. 2.1, 22 February 2007 by the Volpe National Transportation Systems Center with lookup data generated by TNM Ver. 2.5 at distances from the centerline of a 12-ft wide, single-lane roadway with the intervening surface either all hard or all soft ground.[4]

- *FHWA 78/95*—This procedure was not disseminated by FHWA but was developed by the author in an effort to avoid unfavorable experience with the TNM LookUp method while obtaining better accuracy than from FHWA 78. It will be referred to as "FHWA 78/95" here. The method consists of a rudimentary implementation of the 1978 FHWA noise propagation computation—with sound levels calculated at equivalent-lane distances from a roadway as a function of roadway width—combined with the current (1995) TNM vehicle noise emission levels.[9] For the vehicle mix assumed in these analyses (5% medium and 5% heavy trucks), FHWA 78/95 yields 0.3-dBA *higher* sound levels than FHWA 78.

ANALYSIS RESULTS

The 1978 FHWA, TNM LookUp, and HUD procedures are compared in FIGURE **1** as a function of receptor distance from a four-lane roadway with soft-ground intervening. The error, ε, is defined as

$$\varepsilon = L_{Simple} - L_{TNM}$$

where L_{Simple} and L_{TNM} are the simple-method and TNM traffic noise predictions, respectively. Beyond 100 ft, FHWA 78 and HUD overestimated increasingly. The HUD method tended to give the greatest errors generally. At low speeds, the HUD procedure produced at least a 4-dBA overestimate for all distances. On the other hand, TNM LookUp generally gave the smallest errors although it yielded the greatest errors relatively close to the road (i.e., at about 100 ft from the roadway centerline) and *underestimated* virtually all receptor locations. The FHWA 78 results fell between those of the other two methods—ranging from slight underestimates close to the highway to substantial overestimates for distant receivers.

[*] The HUD procedure predicts traffic noise in terms of day-night average sound levels. The HUD results were compared to the peak-hour equivalent sound levels from the FHWA procedures by means of an adjustment factor considering the average daily traffic assumed distributed—10% in the peak-hour and 15% at nighttime.

The performance of the TNM LookUp, HUD, and FHWA 78/95 procedures are examined in greater detail below for the simple site model described above.

TNM LookUp. The ability of TNM LookUp to accurately predict TNM-modeled results is shown for 1–10-lane roadways in FIGURE **2** for hard ground and in FIGURE **3** for soft ground. For all 1-lane (12-ft-wide) roads, TNM LookUp produced results 0–½ dBA relative to TNM. Very close to very wide highways TNM LookUp tended to under-predict TNM—by up to about 1½ dBA at hard sites. At soft sites, TNM LookUp tended to under-predict TNM for roads greater than 1-lane in width—up to about –6 dBA relative to TNM for a very wide, high-speed highway. A simplified, summary presentation of these results for high-speeds and soft ground is provided as FIGURE **4** for 2–6-lane roadways—the roads most typical of those for which predictions will be made. For 2-6-lane widths, TNM LookUp under-predicted by up to 5 dBA at 100–200-ft distances at soft sites, although the under-prediction diminished to less than 1 dBA at very large distances (about 1000 ft).

HUD Guidelines. The performance of the HUD procedure with respect to TNM is provided in terms of 2–6-lane averages in FIGURE **5** for soft sites. The method over-predicted TNM for all roadway geometries and conditions. The error generally increased with receptor distance—reaching about 10 dBA at 1000 ft for both low- and high-speed highways. For low-speed roadways, the HUD Guidelines overestimated TNM by 4–10 dBA for all distances.

FHWA 78/95. The FHWA 78/95 results relative to TNM are shown for 1–10-lane roadways in FIGURE **6** for hard-ground and in FIGURE **7** for soft-ground. This method over-predicted TNM at hard sites for all roadway geometries and conditions. Provided the receptor equivalent-lane distance was at least 40 ft, the over prediction was about 1½–3½ dBA for hard sites—with the error generally increasing with distance ≥200 ft. At soft sites, the errors were greatest for 1-lane roads, much less for 2-lanes, and diminishing further with wider roadways. Errors became large at soft sites for equivalent-lane distances <30 ft. At about 50 ft equivalent-lane distances, FHWA 78/95 tended to *over-predict* by about ½–1 dBA. Other than for single-lane roads at soft sites, the procedure under-predicted TNM by 0–1 dBA for receptor distances between about 70–250 ft. At greater distances at soft sites, FHWA 78/95 increasingly over-predicted TNM—at 1000 ft, by as much as 5 dBA for low-speeds and nearly 10 dBA for high-speeds.

Relative to the HUD Guidelines at all distances from 2–6-lane highways: FHWA 78/95 produced about 1-dBA lower sound levels on average for high-speeds, and was consistently about 5-dBA lower for low-speeds.

In general, FHWA 78/95 tended to provide conservative, overestimates of TNM results. For 2-6-lane roadway widths:

- *At hard sites*—Predicted sound levels were about 1-3 dBA high relative to TNM for all centerline-receptor distances (1½–2 dBA high up to 500 ft). The least over predictions were for medium trucks, and the greatest over predictions were for heavy trucks.

- *At soft sites*—Predicted sound levels were ≤½ dBA *low* relative to TNM at 100 ft, and 2–5 dBA *high* at about 250–1000 ft from low-speed roads and at about 200–500 ft from high-speed roads (increasing to almost 9 dBA high at 1000 ft from high-speed roads). At receptor distances greater than 100 ft, the smallest errors were for heavy trucks, and the largest errors were for automobiles—as shown in FIGURE **8**.

Broadly, the best results were at distances 50-300 ft from the roadway centerline (–½/+4 dBA generally). At larger distances, the over-prediction increased. While FHWA 78/95 substantially overestimates traffic sound levels at large distances, this behavior may be desirable since actual traffic noise exposures are increasingly variable and full TNM-modeled results also become increasingly uncertain with increasing distance due to terrain and atmospheric influences.

TNM-Modeled Roadway Geometry. As defined in TABLE 1, the TNM computer model traffic noise predictions in these analyses were obtained with site model geometries generally utilizing combinations of 2- or 3-lane roadways—modeling likely used by many analysts. However, the most accurate TNM results are obtained by representing each lane of traffic as a separate roadway. To evaluate the possible worst-case extent of this influence, the 3-lane configuration of a single, 36-ft-wide roadway also was modeled as three 12-ft-wide roadways and comparison was made to the corresponding TNM LookUp results. TNM LookUp agrees better with the lane-by-lane TNM modeling with a maximum error of about 2 dBA at 250 ft (v. maximum error of 5 dBA at 150 ft for a single, 36-ft-wide roadway), as shown in FIGURE 9. Consequently, with respect to optimally modeled sites—TNM LookUp may give somewhat better performance but remains non-conservative for all receptor distances, while the tendency of FHWA 78/95 at middle distances to underestimate slightly may change to a tendency to overestimate slightly.

CONCLUSIONS

The performance of TNM LookUp, the HUD procedure, and the FHWA 78/95 computation are summarized for 2–6-lane roadways—at soft sites in FIGURE **10**, and for both hard and soft sites in

FIGURE 11. From these graphs, several conclusions can be drawn for simple, barrier-less sites:

- TNM LookUp is a very good estimator for TNM at hard sites. However, traffic sound levels—although fairly accurate at medium to large distances—are *underestimates* of TNM for all distances at soft sites.

- FHWA 78/95 is tends to overestimate TNM. Predicted sound levels are fairly accurate at short to medium distances, becoming considerable *overestimates* at large distances at soft sites.

- HUD (which can only evaluate soft sites) is similar to FHWA 78/95 at high speed but produces large overestimates of TNM for all distances with low-speed traffic.

RECOMMENDATIONS

Simple traffic noise prediction methods are useful particularly as quick screening tools to determine if further TNM modeling is necessary. Consequently, some overestimation of TNM by a simple method is a desirable, conservative feature. Since the TNM LookUp sound level database was computed from a single-lane road, soft sites with multi-lane highways can be *substantially underestimated*. TABLE 2 provides safety factor recommendations as a function of roadway width. Alternatively—and more simply, TNM LookUp should not be used for roads with total pavement widths (including shoulders and median) >100 ft at soft sites. Furthermore, a 6-dBA safety factor should be assumed for multi-lane highways <100-ft wide with soft sites, e.g., 66-dBA residential impacts may occur at a TNM LookUp-predicted 60-dBA exposure and should be examined rigorously with full TNM modeling.

A simple means of preventing TNM LookUp soft-site problems is to restrict the input range for its total hourly traffic volume to ≤4000 VPH, effectively a two-lane roadway limit. Ultimately, TNM LookUp could be modified to consider roadway width—perhaps by assuming a number of lanes from lane volumes corresponding to LOS-D for the analyzed hourly volume of vehicles. However, a better solution is to use a method such as FHWA 78/95.

REFERENCES

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[3] U.S. Federal Highway Administration, "Highway Traffic Noise Prediction," Procedures for the Abatement of Highway Traffic Noise and Construction Noise, 23 CFR 773.17, last amended 1 April 2005.

[4] Lau, M.C., C.S.Y. Lee, J.L. Rochat, E.R. Boeker, G.G. Fleming, K.L. Cummins, and J. Ruggiero, FHWA Traffic Noise Model® Version 2.5 Look-Up Tables User's Guide, U.S. Department of Transportation, Report No. FHWA-HEP-05-008, December 2004.

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[6] Barry, T.M. and J.A. Reagan, FHWA Highway Traffic Noise Prediction Model, U.S. Department of Transportation, Report No. FHWA-RD-77-108, December 1978.

[7] The Noise Guidebook, U.S. Department of Housing and Urban Development Report No. HUD-953-CPD, March 1985.

[8] Schultz, T.J., and W.J. Galloway, "Noise Assessment Guidelines—Technical Background," Office of Policy Development and Research, U.S. Department of Housing and Urban Development, 1980.

[9] Fleming, G.G., A.S. Rapoza, and C.S.Y. Lee, Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model, Version 1.0, U.S. Department of Transportation, Report No. FHWA-PD-96-008, November 1995.

TABLE 1. TNM Modeled Roadway Geometries

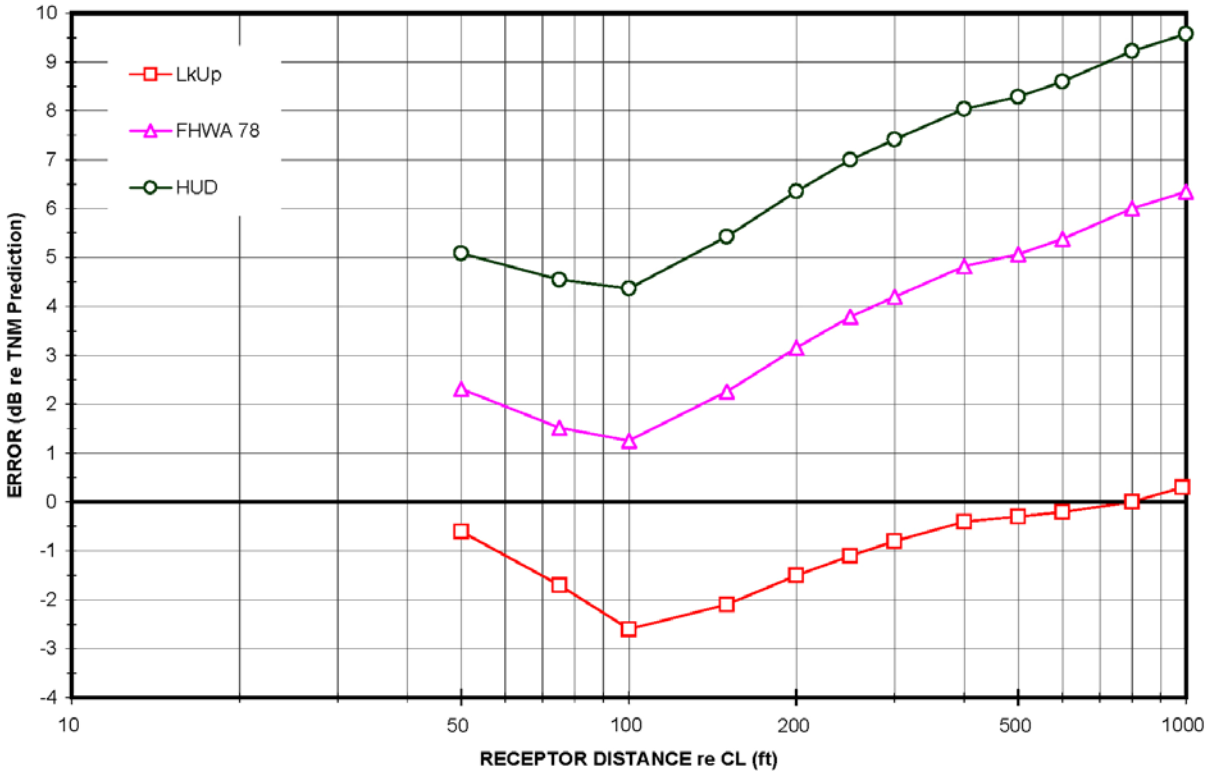
Analyzed Lanes	Configuration [roads X lanes]	TNM Roadways Number	TNM Roadways Width
1	1 x 1	1	12
2	1 x 2	1	24
3	1 x 3	1	36
4	2 x 2	2	25*
6	3 x 2	3	25*
8	4 x 2	4	25*
10	5 x 2	5	25*

* multiple roadways on 24-ft centers

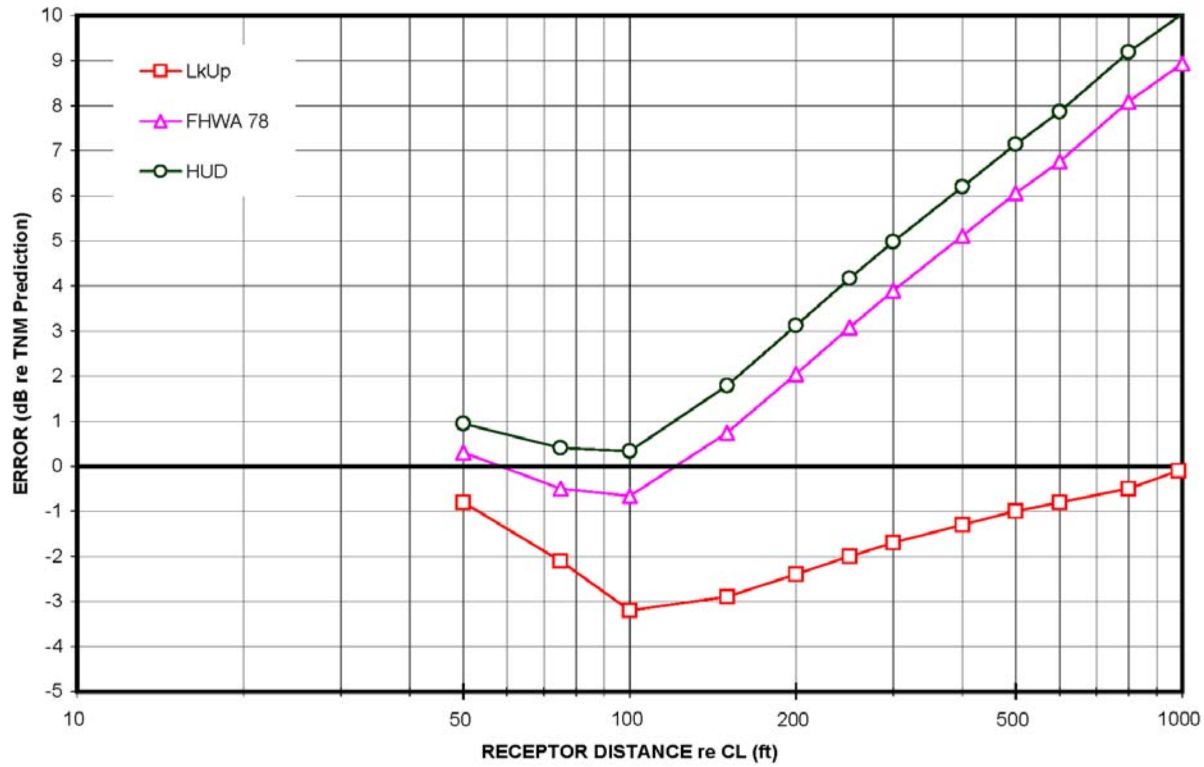
TABLE 2. Safety Factors for Use with TNM LookUp at Soft Sites
Safety factors are not needed at hard sites.

NUMBER LANES	ROAD-WAY WIDTH (ft)	MAX ERROR* (dBA)	PAVEMENT WIDTH RANGE† (ft)	RECOM-MENDED TNM LkUp SAFETY FACTOR (dBA)
1	12	-0.4	w≤12	0
2	24	-3.3	12<w≤24	4
3	36	-4.9	24<w≤75	5
4	48	-3.2		
6	72	-4.3		
8	96	-5.3	75<w≤100	6
10	120	-6.2	100<w≤120	7
			w>120	*Do Not Use TNM LookUp*

* for receptor distances ≤ 1000 ft over soft ground and high speed traffic
† including shoulders and median

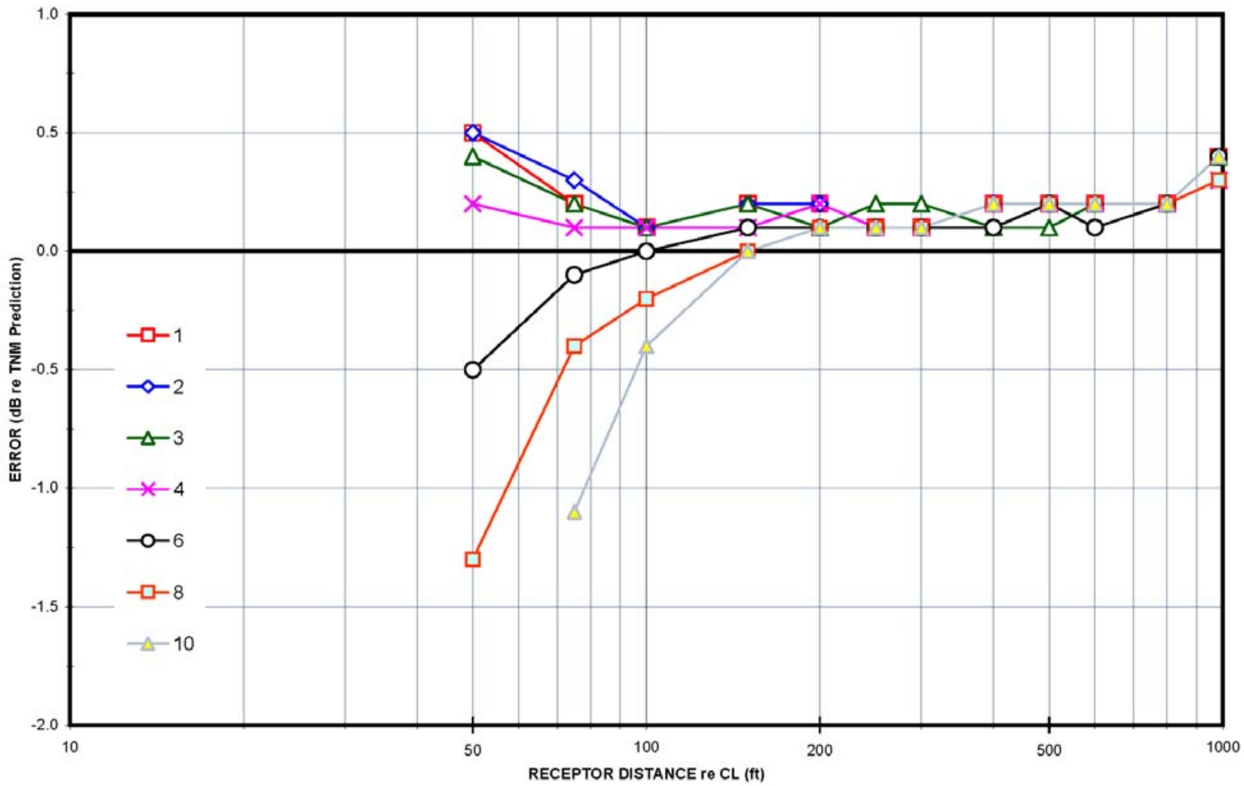


a. Low Speed

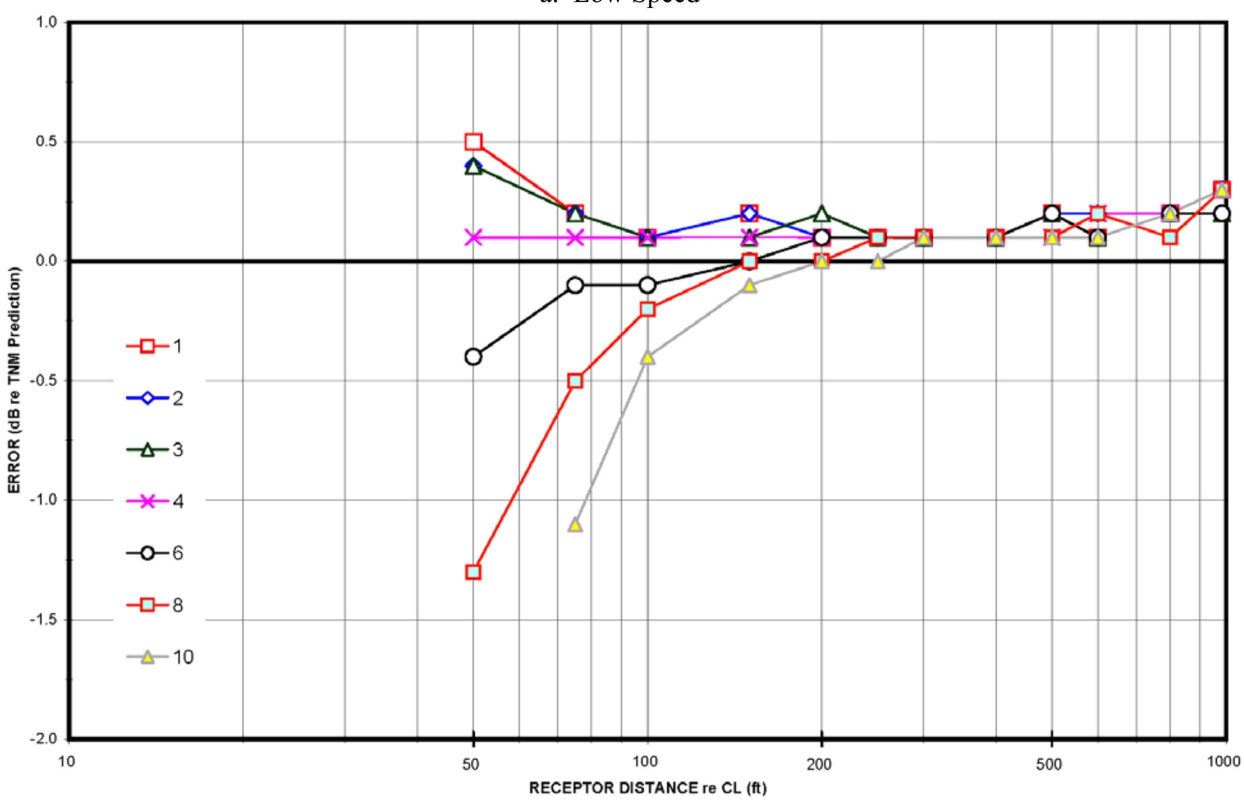


b. High Speed

FIGURE 1. Comparison of Simple-Method Highway Noise Predictions to TNM 2.5
at distances from the highway centerline of 4-lane roadway with 5% medium and 5% heavy trucks; soft ground between road and receptor



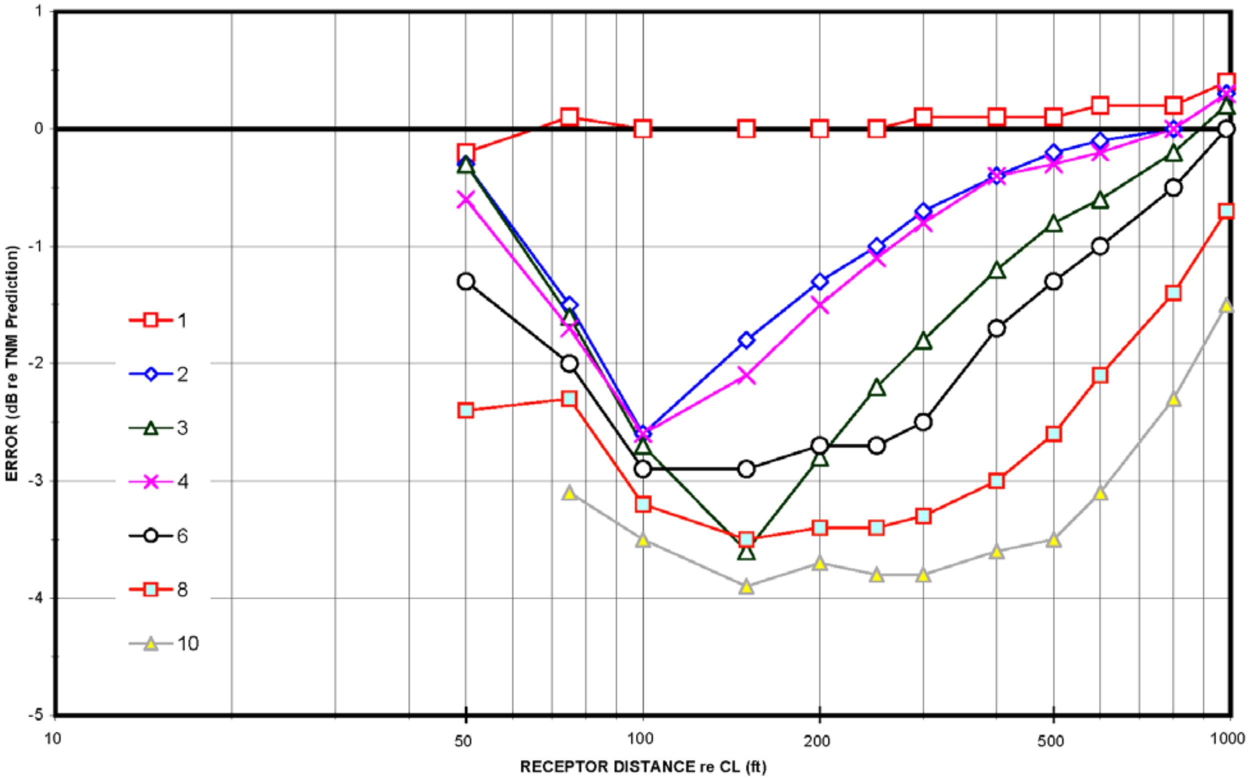
a. Low Speed



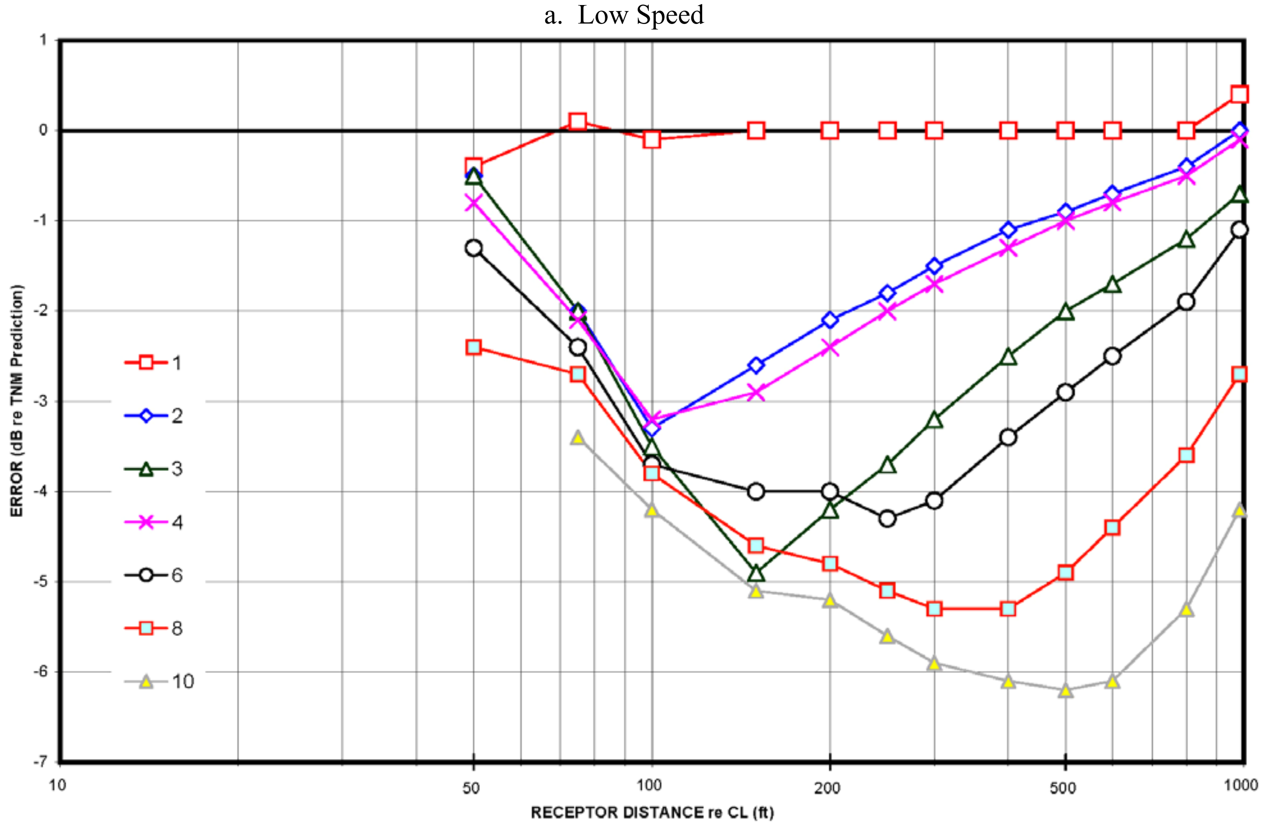
b. High Speed

FIGURE 2. TNM LookUp Hard Ground Predictions vs. TNM 2.5

1- to 10-lane roadways with 5% medium and 5% heavy trucks



a. Low Speed



b. High Speed

FIGURE 3. TNM LookUp <u>Soft</u> Ground Predictions vs. TNM 2.5

1- to 10-lane roadways with 5% medium and 5% heavy trucks

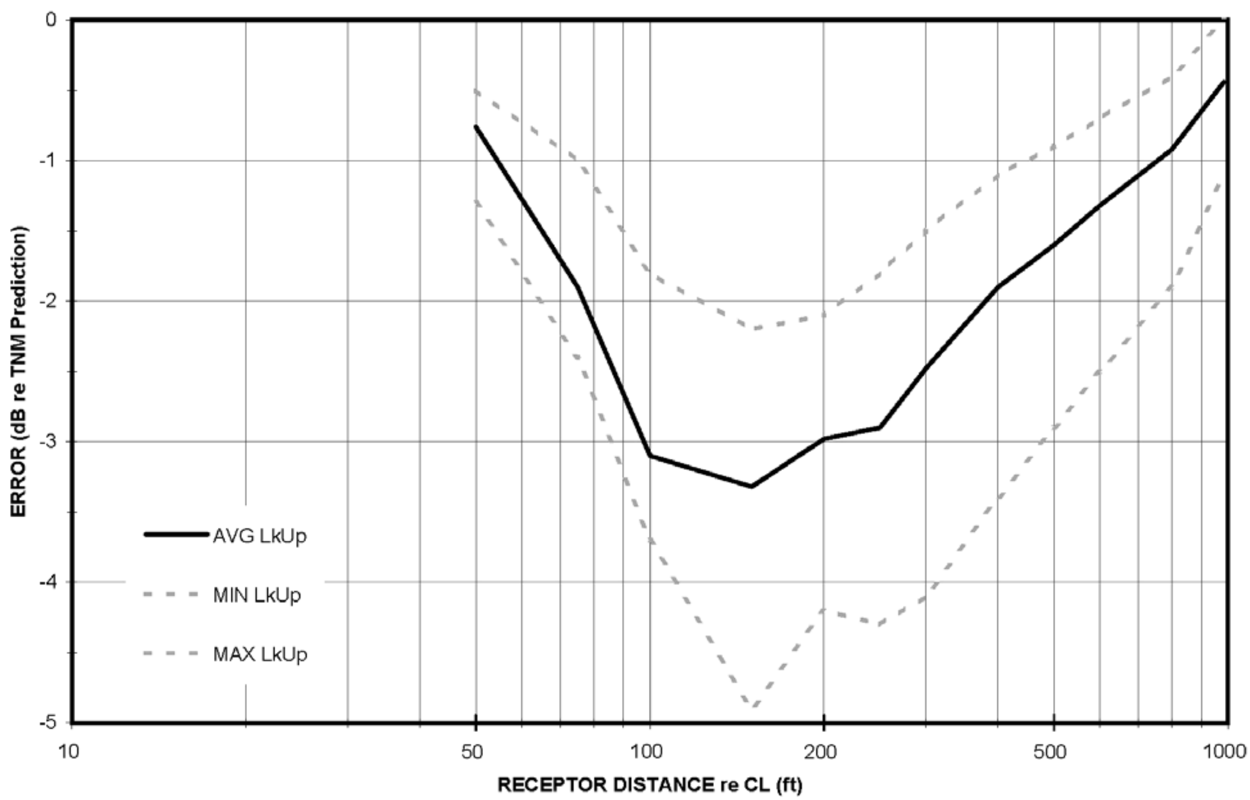


FIGURE 4. TNM LookUp Predictions vs.TNM 2.5—2–6-Lane Average
high-speed roadways with 5% medium and 5% heavy trucks; soft-ground propagation

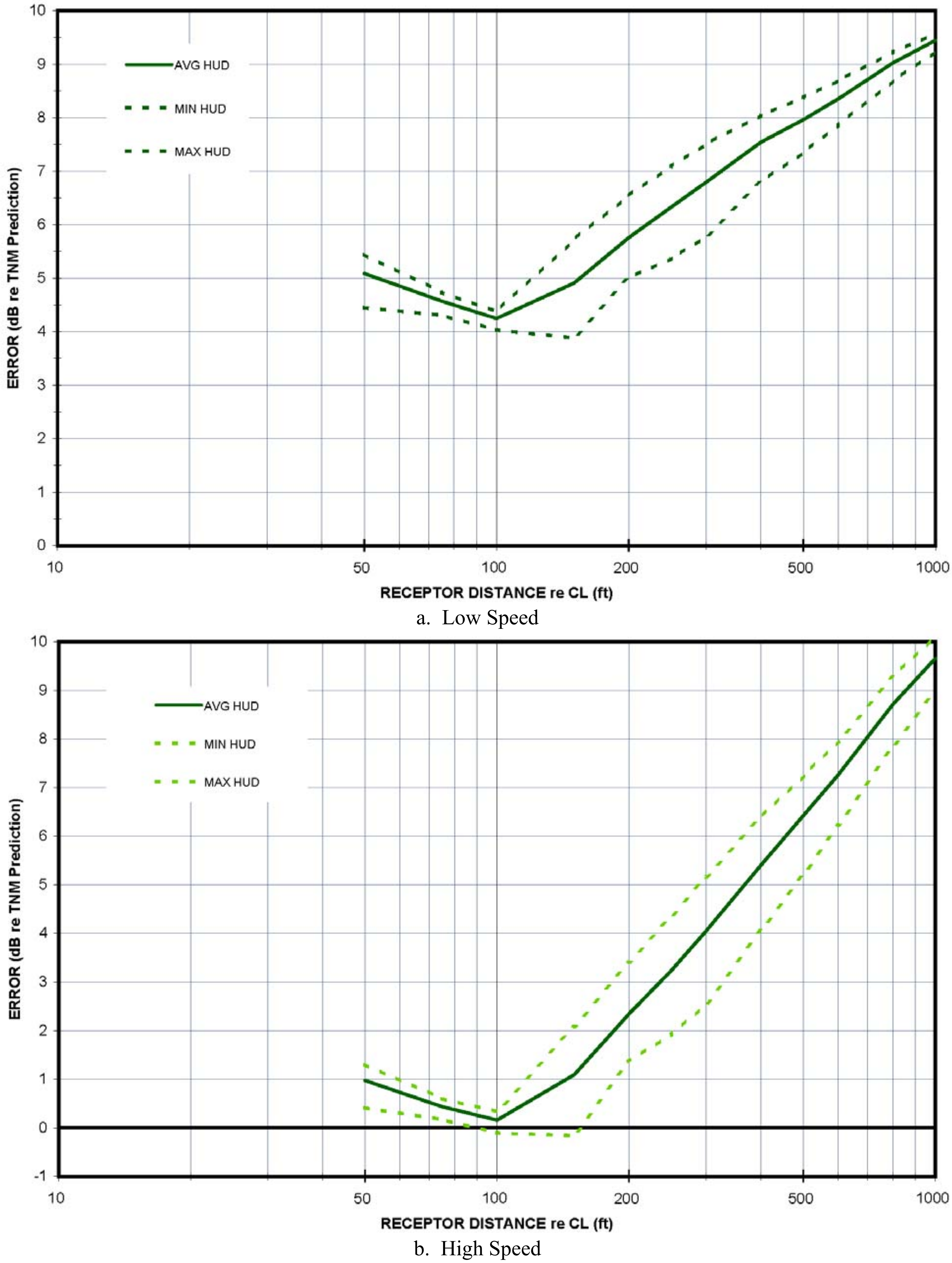
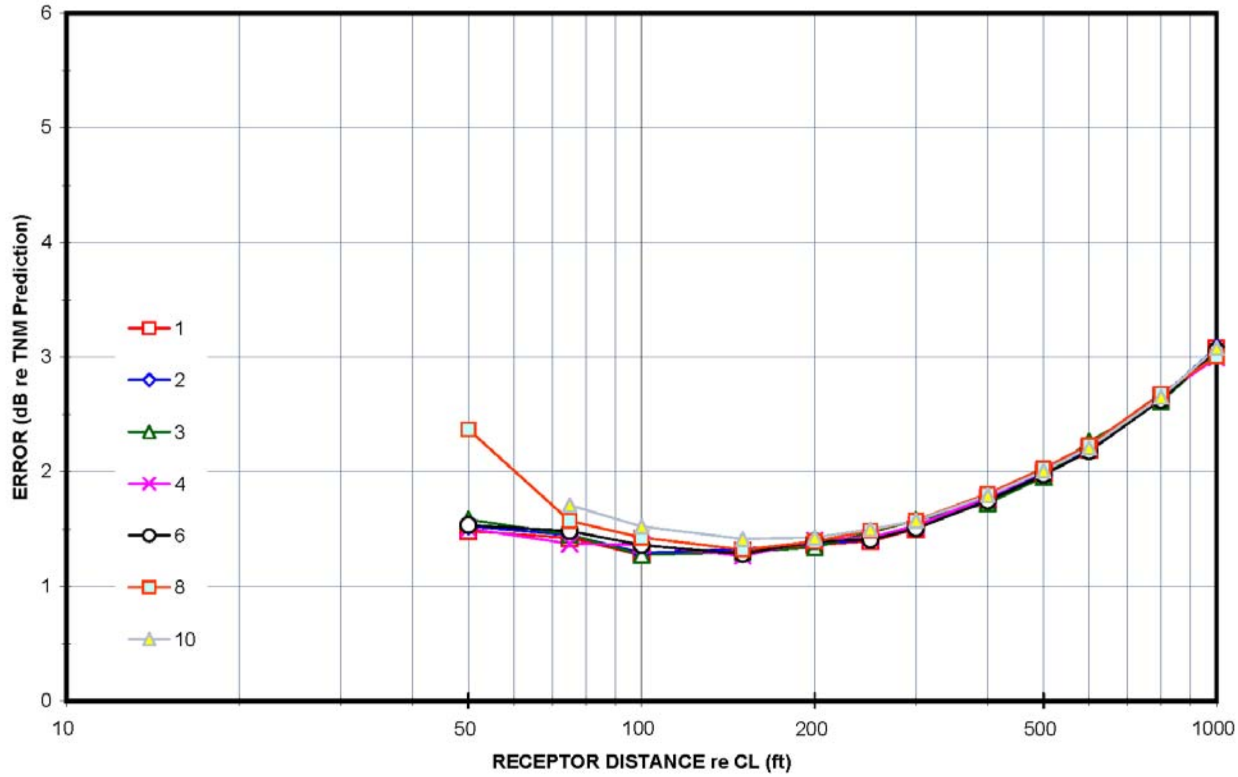
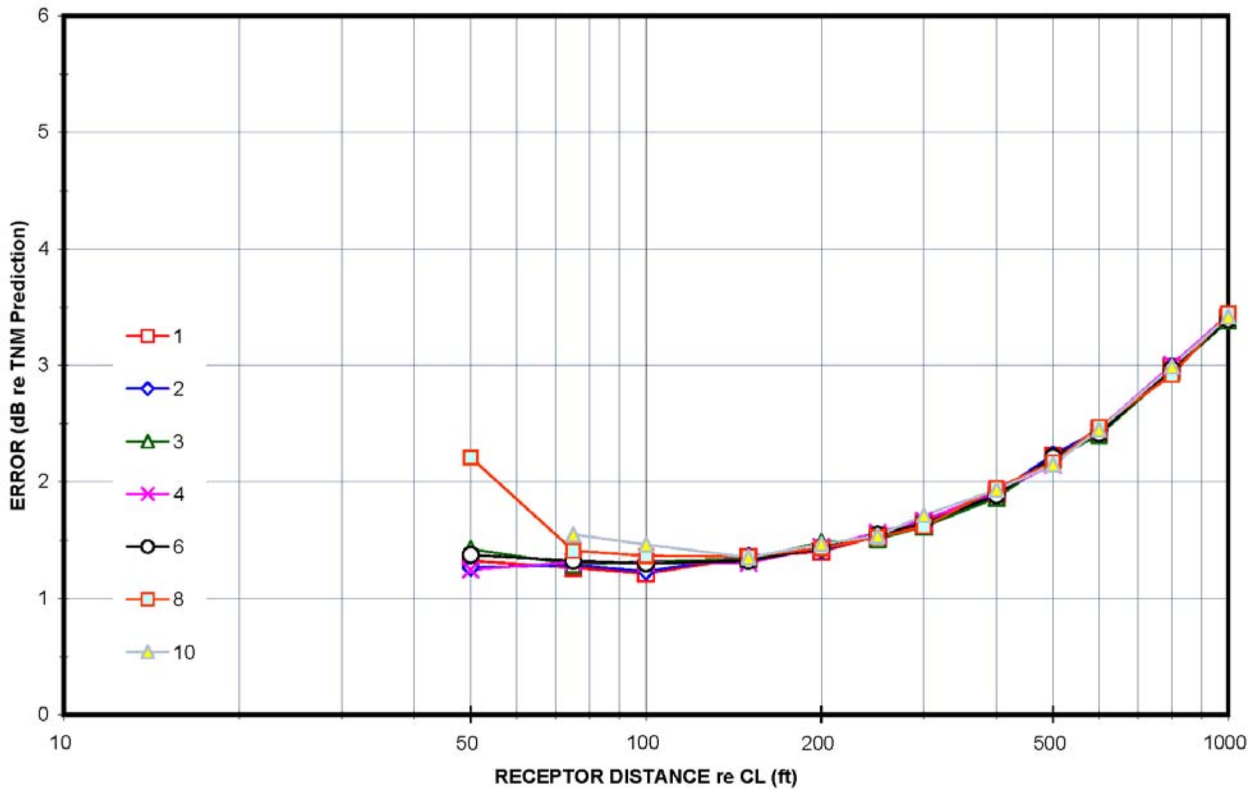


FIGURE 5. HUD Predictions vs. TNM 2.5

1- to 10-lane roadways with 5% medium and 5% heavy trucks; soft-ground propagation



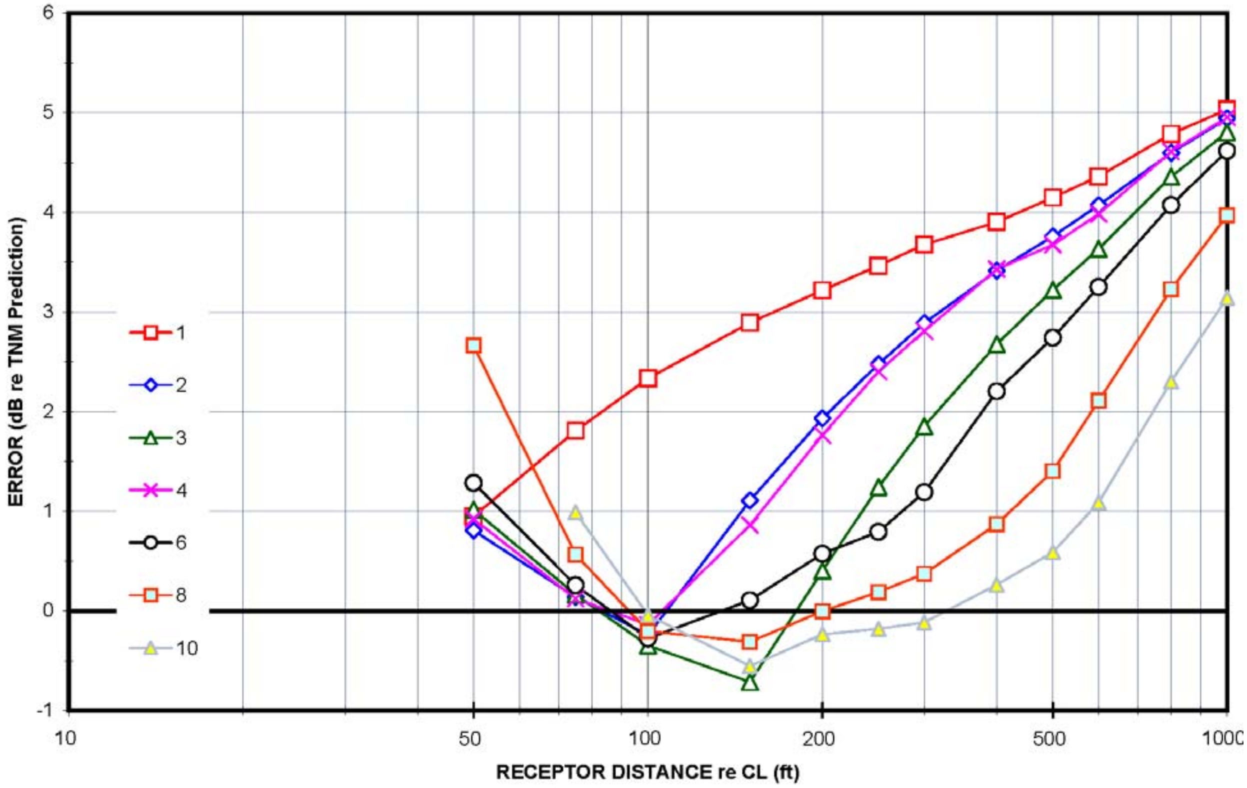
a. Low Speed



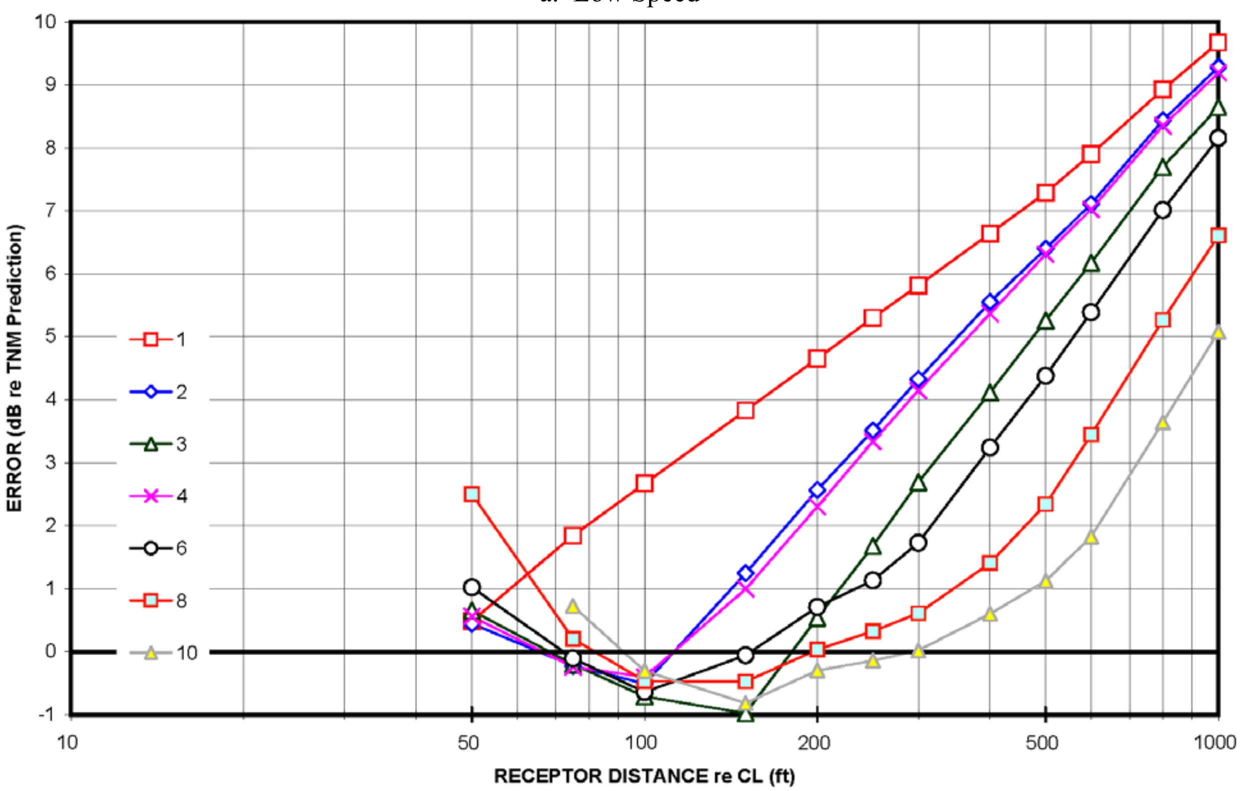
b. High Speed

FIGURE 6. FHWA 78/95 <u>Hard</u> Ground Predictions vs. TNM 2.5

1- to 10-lane roadways with 5% medium and 5% heavy trucks



a. Low Speed



b. High Speed

FIGURE 7. FHWA 78/95 Soft Ground Predictions vs. TNM 2.5

1- to 10-lane roadways with 5% medium and 5% heavy trucks

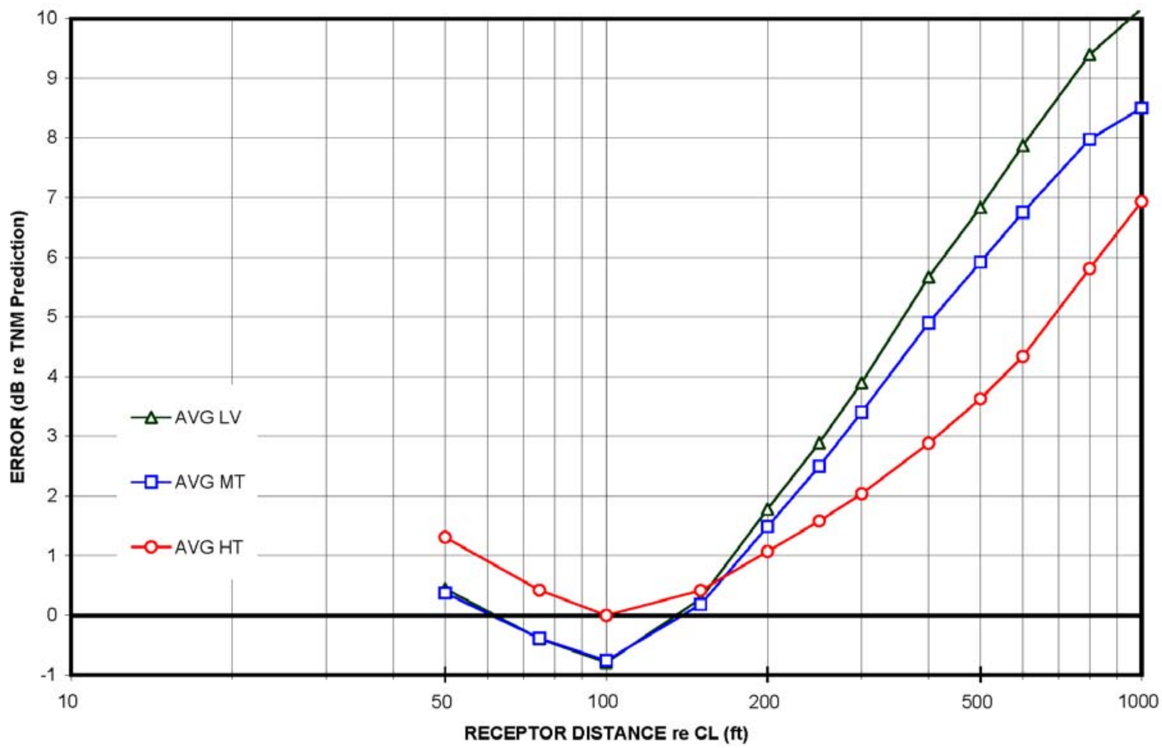


FIGURE 8. FHWA 78/95 Predictions vs. TNM 2.5 by Vehicle Type
averages for high-speed 2–6-lane roadways with soft-ground propagation;
LV = autos, MT = medium trucks, HT = heavy trucks

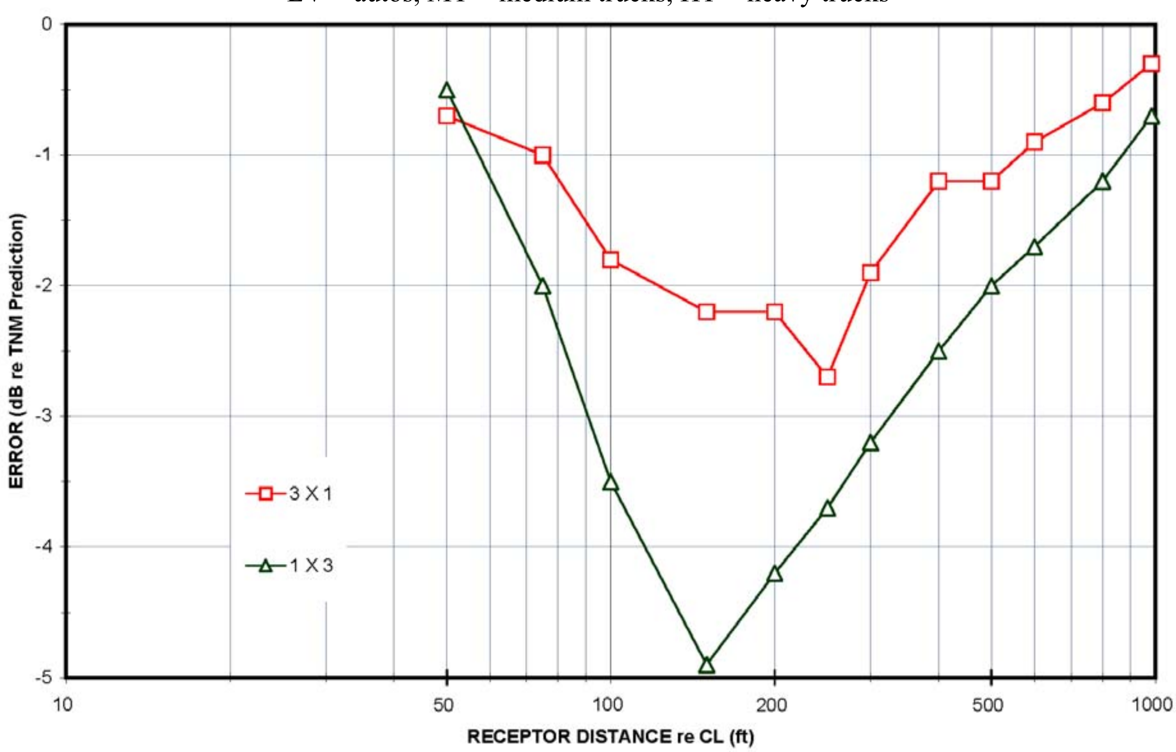
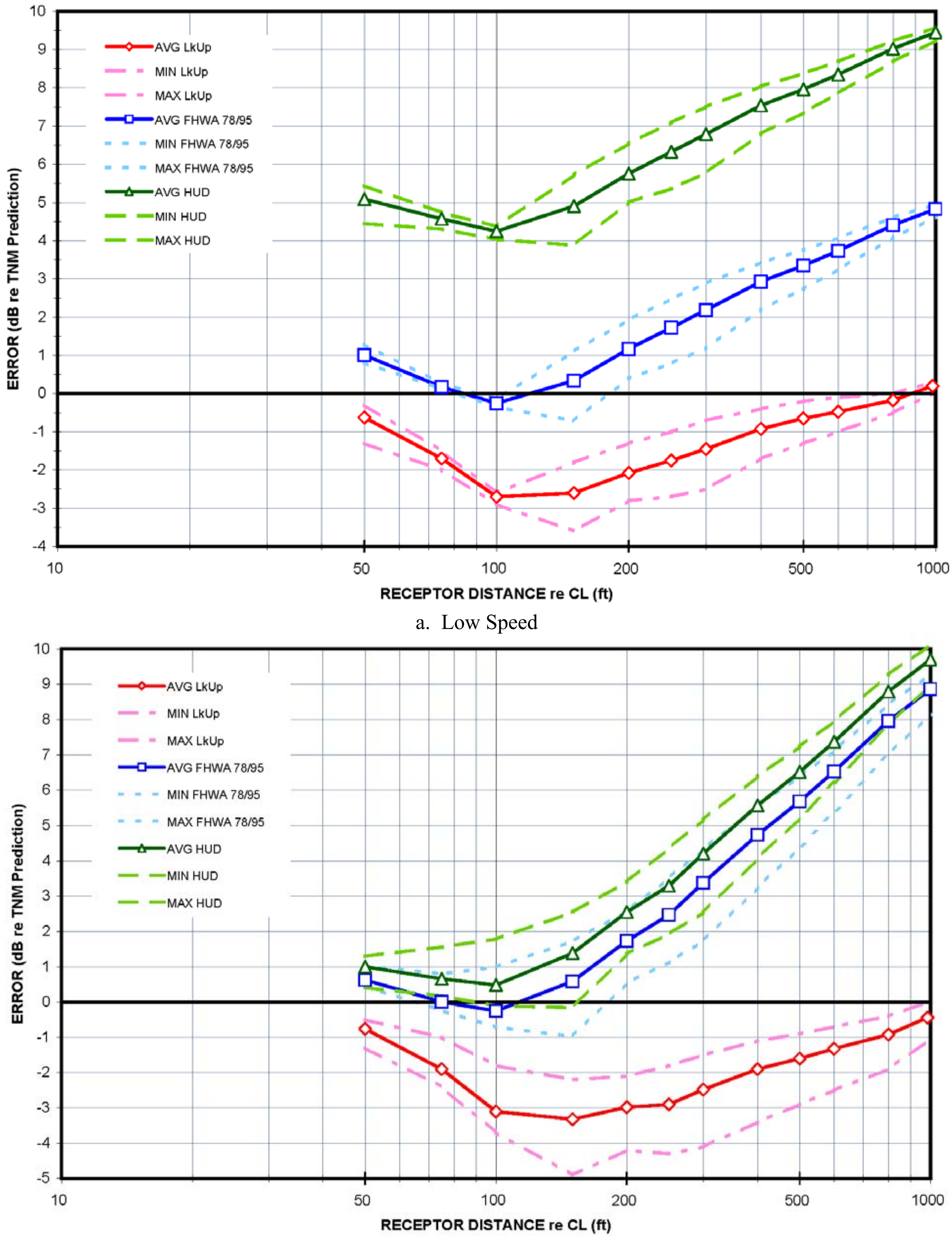


FIGURE 9. Effect of Modeled TNM Roadway Geometry
TNM LookUp error re TNM modeled lane-by-lane (3 x 1) and as single, 36-ft-wide roadway (1 x 3);
high-speed traffic and soft-ground propagation; 3-lane highway with 5% medium and 5% heavy trucks



a. Low Speed

b. High Speed

FIGURE 10. Simple-Method Highway Noise Predictions vs. TNM 2.5

averages for high-speed 2–6-lane roadways with 5% medium and 5% heavy trucks; soft-ground propagation

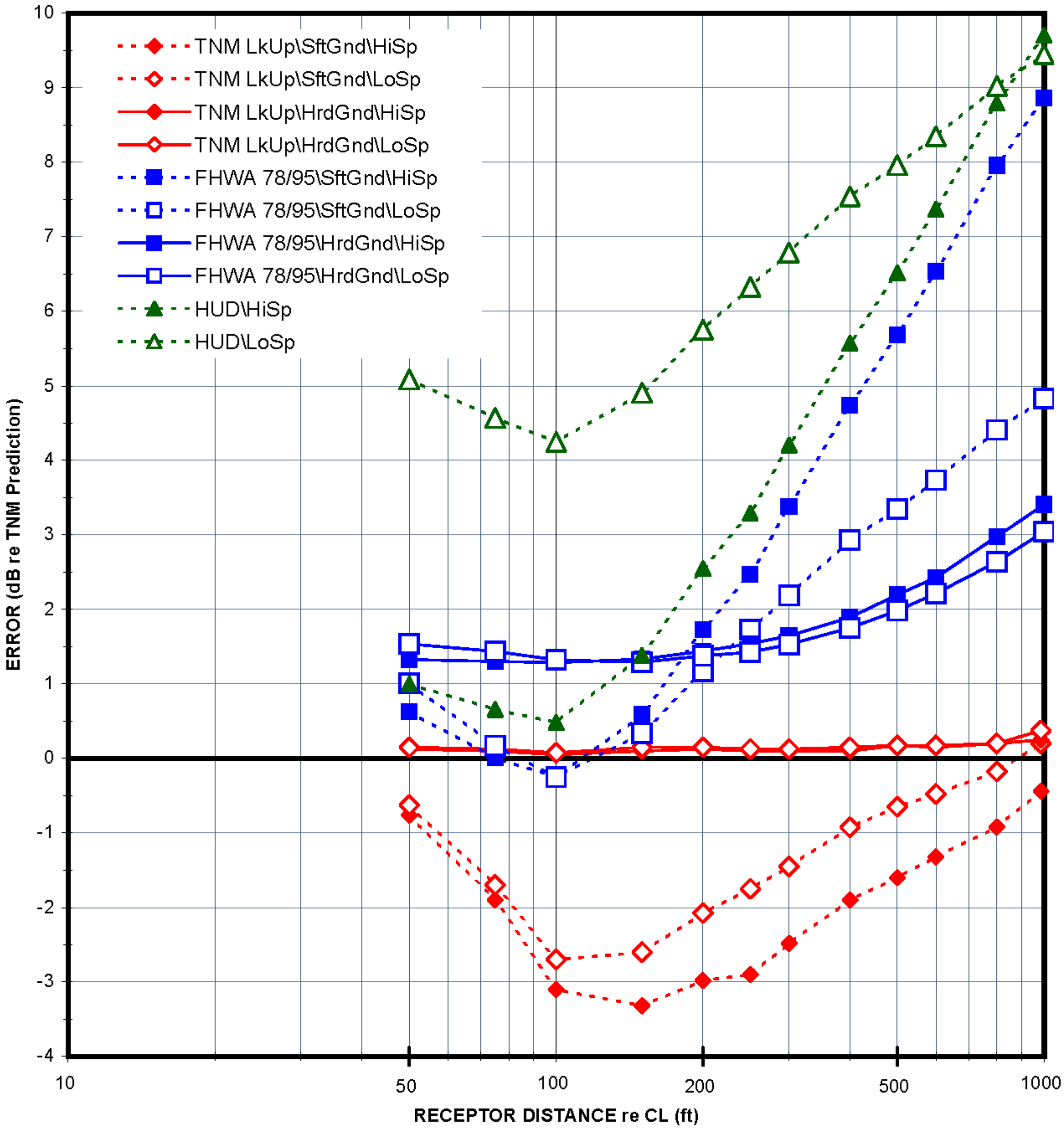


FIGURE 11. Overall Summary—Simple-Method Highway Noise Predictions vs. TNM 2.5
average for 2–6-lane roadways with 5% medium and 5% heavy trucks;

SYMBOLS:	◊	TNM LookUp
	□	FHWA 78/95
	Δ	HUD
	open symbols	low speed
	closed symbols	high speed
	solid lines	hard ground
	dashed lines	soft ground