urban area from estimated CO emission rates within a grid square that surrounds the receptor. The calculation, of course, can be achieved with a desktop calculator. At present, when the reliability of the necessary input parameters is questionable, the use of such an approximation may be preferable to the use of the more-complex dispersion models.

Of the two emission inventory grids tested, the 2.0x2.0-km square grid (which had the larger squares) is probably preferable from two standpoints. First, a sensitivity analysis showed that calculated CO concentrations were relatively less sensitive to an error in emission rates when estimated by using the grid that consisted of the larger squares. Second, an examination of the performance of Equation 7 for the eight individual measurement sites in Richmond also favored that grid.

ACKNOWLEDGMENT

I wish to express my appreciation for the assistance provided by personnel of the Virginia State Air Pollution Control Board and the Environmental Quality and Traffic and Safety Divisions of the Virginia Department of Highways and Transportation. The valuable assistance given by various personnel of the Virginia Highway and Transportation Research Council is also acknowledged. The study was conducted with Highway Planning and Research Program funds administered through the Federal Highway Administration of the U.S. Department of Transportation. The contents of this paper reflect my views and do not necessarily reflect the official views and policies of the sponsoring agencies.

REFERENCES

1. F.L. Ludwig, P.B. Simmon, R.C. Sandys, J.C. Bobick, L.R. Seiders, and R.L. Mancuso. User's Manual for the APRAC-2 Emissions and Diffusion Model. Stanford Research Institute, Menlo Park, CA, June 1977.
2. S.R. Hanna. A Simple Method of Calculating Dispersion from Urban Area Sources. Journal of the Air Pollution Control Association, Vol. 21, 1971, p. 774.
3. Richmond Area Transportation Study--1976 24-Hour Traffic Volumes. Virginia Department of Highways and Transportation, Richmond, 1976.
4. City of Norfolk--1977 24-Hour Traffic Volumes. Virginia Department of Highways and Transportation, Richmond, 1977.
5. City of Virginia Beach--24-Hour Traffic Volumes. Virginia Department of Highways and Transportation, Richmond, 1977.
6. D.S. Kircher and M.E. Williams. Compilation of Air Pollutant Emission Factors (AP-42), Supplement 5, 2nd ed. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, 1975, Chapter 3.
7. R.I. Larsen. Calculating Air Quality and Its Control. Journal of the Air Pollution Control Association, Vol. 15, 1965, p. 565.
8. R.I. Larsen. Determining Reduced-Emission Goals Needed to Achieve Air Quality Goals--A Hypothetical. Journal of the Air Pollution Control Association, Vol. 17, 1967, p. 829.

Publication of this paper sponsored by Committee on Transportation and Air Quality.

Evaluation of the Federal Highway Administration Procedure for Highway Traffic Noise Prediction

KENNETH R. AGENT

Procedures for predicting traffic noise are used in the design of new highways to determine whether noise is limited to specific levels. A previous study evaluated the procedure outlined in National Cooperative Highway Research Program (NCHRP) Report 117 and developed a correction factor that was incorporated into Kentucky's noise-prediction procedure. This adjusted NCHRP 117 procedure has been used in Kentucky for the past several years. The Federal Highway Administration has developed a new procedure to predict traffic noise levels. The objective of this study was to evaluate the new prediction procedure, designated Simplified Noise Analysis Program (SNAP 1.0). Comparisons of measured and predicted noise levels showed that better predictions are obtained from SNAP 1.0 than from the adjusted NCHRP 117 procedure. Therefore, it was recommended that the SNAP 1.0 prediction procedure be adopted. There was no need for a general correction factor; however, adjustments in specific portions of the procedure may be necessary to optimize the predictions.

A policy and procedure memorandum from the Federal Highway Administration (FHWA) directed that, after July 1, 1972, all highways constructed must conform to specific design noise levels (1). Several procedures have been developed to predict future noise levels of highways. The prediction procedure originally used in Kentucky was developed in the National Cooperative Highway Research Program (NCHRP) Report 117 (2). The accuracy of this procedure was questioned and therefore an evaluation was conducted. The evaluation revealed significant discrepancies between measured and predicted values; a correction nomograph developed in this study was incorporated into Kentucky's procedure (3). This nomograph used roadway-to-receiver distance, truck volume per hour, and car speed to determine a correction factor to be applied to values as determined by the method outlined in NCHRP 117. Approval was granted by FHWA in October 1974.

Research has continued toward the objective of developing a more-accurate procedure. A new procedure was reported in NCHRP 174 (4), and a traffic-noise-prediction model was developed by FHWA (5). FHWA then developed computer programs (6,7);

Table 1. Traffic noise-measurement sites.

Site No.	Route	City	Road Name	Type of Location	Speed Limit (m/s)	Average Speed (m/s)	No. of 10-min Measurements
1	US-27	Lexington	South Limestone Street	Urban	18	17	120
2	US-68	Lexington	Harrodsburg Road	Rural	25	24	90
3	I-75	Lexington	Interstate 75	Rural	25	28	123
4	I-264	Louisville	Watterson Expressway	Urban	25	21	99
5	US-60	Lexington	Winchester Road	Rural	25	24	58
6	US-31W	Louisville	Dixie Highway	Urban	18	16	42

Note: 1 m/s = 2.2 mph.

Table 2. Summary of data by test site.

	Average Volume (vehicles/h)					Average L10 Noise Levels [dB(A)] by Prediction Procedure			Average Measured L10 Noise Level [dB(A)]	
Site No.	Automobile	Medium Truck	Heavy Truck	Total Truck	Total	NCHRP 117	Adjusted NCHRP 117	SNAP 1		No. of Measurements
1	2064	41	6	47	2110	69.0	61.5	62.9	62.9	120
2	477	27	16	43	519	68.6	64.3	64.1	64.3	90
3	1153	70	245	315	1469	74.9	74.4	71.5	72.9	123
4	3701	150	180	330	4030	79.3	78.1	74.9	73.3	99
5	453	22	8	30	483	65.8	62.0	62.9	63.8	58
6	2740	127	64	191	2931	77.7	71.4	68.7	68.2	42
Overall	1767	70	100	170	1937	72.6	68.9	67.8	67.9	532

these were called the Simplified Noise Analysis Program (SNAP). SNAP 1.0 is used for relatively simple site geometry, whereas the FHWA level 2 model is used for more-complex situations. The objective here was to evaluate the accuracy of SNAP 1.0.

PROCEDURE

To evaluate SNAP 1.0, it was necessary to obtain noise measurements and compare them with those predicted by SNAP 1.0. Data were taken at sites that had relatively simple geometry. Sites were selected near straight, level sections of roadway on unobstructed terrain so that the number of variables that might affect the evaluation would be minimal. All data were taken at a measurement height of 1.5 m (5 ft) over a ground cover of short grass. All data were taken in terms of A-weighted decibels.

The majority of measurements were made by using a precision sound-level meter (Bruel and Kjaer type 2209) and strip-chart recorder (Bruel and Kjaer type 2306) to make 421 recordings of 10-min each. From the 10-min recordings, noise levels at intervals slightly greater than 1 s were determined in the laboratory by using a digital data-reduction system. The output was punched onto computer cards through direct coupling with a card-punch unit. By means of a computer program, the L10 and Leq noise levels were computed. (The L10 noise level is the level exceeded 10 percent of the time and is the level currently used in federal traffic noise standards. The term Leq is used for the noise equivalent level.) Additional data were taken in 10-min sets by using a noise-level analyzer (Bruel and Kjaer type 4426); 111 sets were taken. A total of 532 data sets of 10 min each were used in the analysis.

Information about the traffic stream at the measurement sites is given in Table 1. Data were taken at six sites chosen so that there would be a wide range of speeds [16 m/s (36 mph) at site 6 to 28 m/s (62 mph) at site 3], traffic volume, and truck volume.

Three predicted values were determined for each noise recording. First, the method outlined in NCHRP 117 was used to predict a value. Then the correction factor developed in the previous Kentucky research report (3) was applied to this value, which yielded an adjusted NCHRP 117 value. Finally, SNAP 1.0 was used to predict the noise level. Comparison of the difference between the measured and predicted values showed which prediction procedure was most accurate. The comparisons among the prediction procedures were based on L10 noise levels because only the SNAP 1.0 procedure yielded an Leq value. In addition, the measured Leq values were compared with the SNAP 1.0 predicted Leq values.

The average absolute differences between the measured and predicted noise levels were compared as a function of several variables. If this difference varied substantially as a given variable changed, it would mean that the variable in question had an effect on the error. For example, if the difference between the predicted and measured noise levels was much greater at short roadway-to-receiver distances, it would imply that a correction factor should be applied to data taken close to the roadway. Also, the average measured and predicted L10 noise levels for each variable range were determined.

RESULTS

A summary of data by test site is given in Table 2. The average total volume (vehicles per hour) ranged from 483 at site 5 to 4030 at site 4. The total volume was composed of the number of automobiles, medium trucks, and heavy trucks, as required by the procedure outlined in SNAP 1.0. Medium trucks are defined as vehicles that have two axles and six tires; heavy trucks have three or more axles. There was a very large range in the volume of heavy trucks--245/h at site 3 to 8/h at site 5. These two vehicle types are considered identical when NCHRP 117 is used.

The average measured L10 noise level as well as the three average predicted L10 values are given in Table 2 by site. The discrepancies previously reported when the NCHRP 117 procedure was used were manifested again as overpredictions at every site. The largest differences were found at sites that had low truck volumes and speeds. The maximum difference between the average predicted and measured noise levels was an overprediction of almost 10 dB(A) at site 6. Again, improvement in

Table 3. Distribution of differences between measured and predicted noise levels.

Noise-Level Difference Range [dB(A)]	Measured Greater Than Predicted				Predicted Greater Than Measured			
	NCHRP 117 (L10)	Adjusted NCHRP 117 (L10)	SNAP 1		NCHRP 117 (L10)	Adjusted NCHRP 117 (L10)	SNAP 1	
			L10	Leq			L10	Leq
<1.0	18	44	65	64	23	46	65	74
1.0-1.9	14	40	60	57	40	64	76	72
2.0-2.9	8	35	62	55	46	42	63	73
3.0-3.9	4	28	39	34	52	50	35	40
4.0-4.9	4	27	21	13	64	44	13	24
5.0 or more	4	27	14	5	255	77	10	14

Table 4. Comparison of measured and predicted L10 noise levels as function of magnitude of measured noise level.

Measured Noise Level [dB(A)]	No. of Measurements	Average Difference [dB(A)] Between Predicted and Measured L10 by Prediction Procedure			Average L10 Noise Level [dB(A)]			
		NCHRP 117	Adjusted NCHRP 117	SNAP 1	SNAP 1	NCHRP 117	Adjusted NCHRP 117	Measured
<55	11	5.0	2.9	3.4	56.7	58.6	56.4	53.6
55-59.9	46	5.0	2.1	2.0	58.8	63.0	58.4	58.3
60-64.9	125	5.2	2.6	2.0	63.5	67.8	62.6	62.8
65-69.9	161	5.2	3.3	1.8	67.6	72.4	68.3	67.4
70-74.9	92	5.1	3.2	2.4	71.4	77.1	74.4	72.5
75-79.9	77	4.9	3.6	3.3	76.5	81.8	80.1	77.5
80 or more	20	3.2	3.2	3.3	77.8	81.7	80.0	81.0

the predictions resulted when the adjusted NCHRP 117 procedure was used. The correction factor improved the average predicted value at each site and provided a very significant improvement at some of the sites. However, the predictions obtained from the SNAP 1.0 procedure provided the best results. For example, at site 6, the NCHRP 117 procedure overpredicted the measured value by 9.5 dB(A). The correction factor reduced this error in average values to 3.2 dB(A), but the error in the SNAP 1.0 procedure was only 0.5 dB(A). Considering the average of all measurements, there was a difference of 4.7 dB(A) between the measured and the predicted L10 NCHRP 117 noise levels. This difference was reduced to 1.0 dB(A) by the correction factor applied to results from the NCHRP 117 procedure. However, the difference between the average measured and SNAP 1.0 predicted L10 noise levels was only 0.1 dB(A).

The average absolute differences between measured and predicted noise levels were also determined [in dB(A)]:

Site No.	Prediction Procedure: NCHRP-117 (L10)	Adjusted NCHRP-117 (L10)	SNAP 1.0 L10	SNAP 1.0 Leq
1	6.1	2.5	1.8	1.8
2	4.4	2.1	2.5	2.4
3	3.0	2.8	2.5	2.5
4	6.1	4.8	2.0	1.7
5	3.2	3.5	1.4	1.8
6	9.5	3.5	1.4	1.4
All sites	5.0	3.0	2.1	2.0

These data also showed that SNAP 1.0 provided the best results and that the procedure in NCHRP 117 gave the worst results. The average difference for all sites was 5.0 dB(A) by using the NCHRP 117 procedure. This difference was decreased to an average of 3.0 dB(A) by the correction factor. The smallest difference was 2.1 dB(A) when SNAP 1.0 was used. The differences between measured and SNAP 1.0 values were very similar for the L10 and Leq values.

The distribution of the differences between measured and predicted L10 values is summarized for each prediction procedure in Table 3. [The measured and predicted L10 noise levels were equal in eight cases for the adjusted NCHRP 117 and in nine cases for the SNAP 1.0 prediction procedures. They were never equal when the NCHRP 117 procedure was used. The actual and predicted Leq noise levels were equal in seven cases when the SNAP 1.0 procedure was used.] The problem with the NCHRP procedure was that it overpredicted in 90 percent of the cases, and the overprediction was 5 dB(A) or more in almost 50 percent of the cases. There was still a tendency to overpredict when using the adjusted NCHRP procedure. There was overprediction in 64 percent of the cases, but the percentage of cases that had a difference of 5 dB(A) or more was reduced by 60 percent. SNAP 1.0 L10 predictions were equally distributed above and below the measured noise levels. There was a slight tendency (in 56 percent of the cases) for the SNAP 1.0 procedure to overpredict the Leq levels. The large differences were reduced substantially by using SNAP 1.0; that is, there was a difference of less than 3 dB(A) in about 75 percent of the cases.

The distribution of differences between measured and predicted L10 values for each of the six sites was analyzed. The major differences between measured and SNAP 1.0 predicted noise levels occurred at two sites. SNAP 1.0 underpredicted at site 3. Site 3 was unique in that it had a very high proportion of heavy trucks. The large differences occurred when the measured noise was particularly high [more than 80 dB(A)]. Site 2 had very low volumes, and large differences occurred when data were taken at large distances from the roadway where noise levels were very low. At these very low-volume locations, the 10-min sample periods could have been inadequate. Also, the usefulness of the L10 parameter breaks down at very low traffic volumes.

A comparison was made between measured and predicted L10 levels as a function of the magnitude of the measured noise level (Table 4). The largest differences between measured and SNAP 1.0 predicted values occurred when the actual L10 level was either very low [less than 55 dB(A)] or very high [80 dB(A) or more]. The SNAP 1.0 procedure overpredicted at the very low level and underpredicted at the very high level. Measured and SNAP 1.0 predictions were very close for levels measured between 55 and 80 dB(A). The NCHRP predictions improved as the measured noise level increased and were better than SNAP 1.0 predictions when the measured L10 level was 80 dB(A) or more.

The SNAP 1.0 procedure also enables prediction of the Leq level. The measured Leq level is compared with the SNAP 1.0 value below:

	Leq Noise Level [dB(A)]	
Site No.	Measured	Predicted
1	60.7	61.0
2	61.4	62.9
3	69.4	68.2
4	70.6	71.8
5	60.3	60.9
6	65.5	65.7
All	65.0	65.4

The overall average measured and predicted Leq levels were very close. When measured and predicted Leq levels were compared site by site, the largest difference in average values was only 1.5 dB(A).

In the previous evaluation of the NCHRP procedure, discrepancies found between predicted and measured noise levels were related to certain factors (3). These factors were then used to develop the correction nomograph. Here, comparisons of the difference between measured and predicted values have been made for the following variables: traffic volume, automobile volume, truck volume, heavy-truck volume, medium-truck volume, and roadway-to-receiver distance.

As was learned earlier (3), the difference between measured and NCHRP 117 levels varied with distance and truck volume, specifically heavy-truck volume: The difference was greater at short distances and low heavy-truck volumes. This did not occur with the adjusted NCHRP 117 values. None of the other variables showed a definite relationship between the differences in the measured and the predicted values. There did not appear to be a relationship between any of the variables and the difference between measured and SNAP 1.0 levels.

The average measured and predicted noise levels were determined as a function of each variable. The results clearly showed that the NCHRP 117 procedure consistently overpredicted noise. This overprediction became worse at close roadway-to-receiver distances, low truck volumes, and low speeds. The error associated with the adjusted NCHRP 117 procedure was substantially lower; however, the remaining error was still consistently an overprediction. The SNAP 1.0 procedure did not overpredict or underpredict noise consistently.

There was an overall average absolute difference between measured and SNAP 1.0 predicted values of 2 dB(A). Differences of about 2 dB(A) existed for each of the variables tested; however, when average measured and SNAP 1.0 values were compared for each variable, there was very close agreement. Since the average values were in agreement, much of the 2-dB(A) difference may be attributable to errors in data collection.

RECOMMENDATION

It was recommended that the SNAP 1.0 prediction procedure be adopted, and it was adopted for use in Kentucky starting January 1, 1980. There is no need for a general correction factor; however, adjustments in specific portions of the procedure may be necessary to optimize the results. For example, reference vehicle noise-emission levels need to be determined specifically for Kentucky vehicles to replace the nationwide levels currently used in the prediction methodology. The new emission levels can be input into the prediction procedure to determine the effect on its accuracy. Also, adjustment factors for different textures of pavement need to be applied (8). It is recommended that these adjustments be incorporated into the SNAP 1.0 procedure.

REFERENCES

1. Policy and Procedure Memorandum 90-2. Federal Highway Administration, U.S. Department of Transportation, April 26, 1972.
2. C.G. Gordon, W.J. Galloway, B.A. Kugler, and D.L. Nelson. Highway Noise: A Design Guide for Highway Engineers. NCHRP, Rept. 117, 1971.
3. K.R. Agent and C.V. Zegeer. Evaluation of the Traffic Noise Prediction Procedure. Division of Research, Kentucky Department of Transportation, Frankfort, Rept. 379, Nov. 1973.
4. B.A. Kugler, D.E. Commins, and W.J. Galloway. Highway Noise: A Design Guide for Prediction and Control. NCHRP, Rept. 174, 1976.
5. T.M. Barry and J.A. Reagan. FHWA Highway Traffic Noise Prediction Model. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-77-108, July 1978.
6. F.F. Rudder, Jr., and D.F. Lam. User's Manual--FHWA Highway Traffic Noise Prediction Model SNAP 1.0. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-78-139, July 1979.
7. F.F. Rudder, Jr., and P. Cheung. User's Manual--FHWA Level 2 Highway Traffic Noise Prediction Model. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-78-138, July 1978.
8. K.R. Agent and C.V. Zeeger. Effect of Pavement Texture on Traffic Noise. Division of Research, Kentucky Department of Transportation, Frankfort, Rept. 417, Feb. 1975.

Publication of this paper sponsored by Committee on Transportation-Related Noise.