ANALYSIS AND SIMULATION OF TRAFFIC NOISE FROM HIGHWAY

by

Dr. Pichai Pamanikabud

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ABSTRACT

This paper present the analysis and building of mathematical simulating model for highway traffic noise which is generated by traffic and geometric conditions of the highway. Data for this study project were collected from several highway locations in Singapore which included highway traffic characteristics and environmental traffic noises which were generated by these traffic conditions. These studied sites were chosen based on the criteria of length and contributing roadway, type of intervening ground cover, road surface texture, road gradient, and effect of reflection. The geometric dimensions of these highway sections and their nearby barriers were measured together with the collection of environmental conditions of these barriers. Environmental traffic noises were measured by using the integrated sound level meters in Leq value with A weighting scale of decibel (dB) for one hour period. The data on traffic characteristics and traffic noises were collected on a simultaneous basis in order to avoid any bias in data collection and the relationship between these two groups of data.

The statistical comparative study were performed based on this database in order to select the best fit model from the existing models which were built in other western countries. The best fit model was then further modified to improve its effectiveness in forecasting the traffic noise under the local traffic conditions. This modification was done by means of the application of correction factor to each group of basic noise level parameters and the attenuation parameters in the simulating model. These two collection factors were defined as a ratio of the measured to the predicted noise level, and they were obtained by iterative procedure with the assistance of a written computerized program. The final simulating model showed a significant improvement in the prediction of overall traffic noise due to the significant improvement in the part of attenuation values prediction with approximately 42.24% of improvement.

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1. INTRODUCTION

Traffic noise from highway is the noise produced by traffic operating on the highway system. Traffic characteristics on the highway such as vehicle size, height of vehicle and exhaust pipe, engine size, composition of traffic, lane width, etc. Which are normally different between the conditions in Asian contries and those in the US and European countries. Highway traffic noise prediction models which were developed in the US and in Europe gave an error when they were used to predict highway traffic noise in Asian's traffic condition. In order to provide a more accurate forecasting result to the highway noise for traffic and highway condition in Asian country, the new highway traffic noise prediction model should be built and tested based on the general traffic and highway conditions of the Asian country.

2. OBJECTIVE

This research study aimed at the building of new highway traffic noise prediction model which was sensitive to traffic, vehicle, and roadway characteristics in the Asian country. The new model was also expected to be able to give a better result with higher accuracy in prediction of the highway noise than the two previously used models which were developed in the US and UK.

3. SCOPE OF THE STUDY

This study investigated into two existing and widely used traffic noise prediction models which were developed in two different western countries namely, the FHWA model of the US which was developed by the United State Federal Highway Administration, and the UK's DOE model which was developed by the United Kingdom's Department of Environment. These two models were tested in order to see their effectiveness when they were applied to the highway traffic and roadway conditions in Singapore which is one of the Asdian countries. The better model from these two existing models were furthur developed to improve its highway traffic noise forecasting accuracy by using data on traffic noise, vehicle composition, highway geometry, and surrounding barrier and environment as the data base of model development. Statistical tests were also given in order to see how efficient this new model could perform in comparison to the previous models from US and UK.

4. SITE SELECTION

The sites for this study were chosen from highway and roadway network in Singapore based on the following criteria :

(1) The site had to have the greatest possible length of visually unobstructed roadway (other than obstruction by the barrier). It had to subtend an angle of at least 150 at the greatest observation distunce form the road. The alignment of the associated roadway had to be as straight as possible to avoid fluctuation in speeds that arise while vehicles were moving in the curve.

(2) Both the intervening ground cover and the road surface texture had to be of high uniformity.

(3) The gradient of road had to be as constant as possible. Sites with the flattest possible grade were chosen to minimize its effect.

(4) Sites had to be such that the traffic on the roadway have attained constant speed conditions, that is, with minimum of accelerations and brakings, Thus sites with intersections and/or approach roads in their vicinity were avoided.

(5) In order for the affects of reflection to be neglected, the measuring equipment had to be able to be set at least 15 m from any reflecting surface other than the ground.

(6) The barrier (earth berm, wall, elevated and depressed roadway configuration) should be as long as possible. Variation in the cross section (height and width) should be minimal.

From these criteria, 19 different sites were selected altogether from the roadway network in Singapore. The locations of these sites are shown in the roadway network map in Fig. 1.

5. DATA COLLECTION

Data on traffic characteristics and traffic noises, which were generated by these traffic conditions, were collected from these 19 locations.

On each study site, the geometric dimensions of these highway sections such as lane width, median width, shoulder width, number of lane, and right-of-way width were measured together with the dimension of height, width, and length of the nearby barrier. The environmental conditions of these barrier and roadways were also collected, these included type of barrier (i.e.

6. EVALUATION OF THE EXISTING MODELS

The detailed study of the US's FHWA model and UK's DOE model were done so that each parameter in the models could be investi-ated based on the traffic and highway conditions in Singapore. These two models can be expressed as the followings :

FHWA Model

The basic emission and propagation equaton of this model can be mathematically stated as (2) (4) :

$$L_{eq}(h)_i = (\overline{L}_o)_{Ei} + 10\log(N_i \pi D_o / S_i T) + 10\log(D_o/D)^{1+\alpha} + 10\log(\psi_\alpha(\Phi_1, \Phi_2)/\pi) + \Delta_S$$

where

$L_{eq}(h)_i$ = Hourly equivalent A-weighted sound level of the ith class of vachicles

$(L_o)_{Ei}$ = Reference energy mean emission level of the ith class of vehicles

N_i = Number of vehicles in the its class passing the highway section during the 1 hour period

D = Perpendicular distance in metres, from the centerline of the traffic lane to the receiver.

D_o = Reference distance (15 m) at which L_o values are obtained.

S_i = Average speed of the ith class of vehicles measured in kilometres per hour.

T = Observation period, 3600 seconds

α = Site parameter equal to 0 or 1/2 depending on site condition

Φ_1 , Φ_2 = Roadway angles in degrees which describe the roadway segments that contribute acoustically.

ϕ = Adjustment for finite length roadways.

Δ_S = Attenuation in dBA, provided by shielding such as barriers, foliage and houses (standard barrier theory is applied).

The overall L_{eq} for the traffic mix, L_{eq} (total) is then obtained in the unit of decibel (dB), or logarithmic additon as shown :

$$L_{eq}(\text{total}) = \Sigma L_{eq}(AU + MT + HT) \text{ (in dB)}$$
$$= 10\log[10^{L_{eq}(AU)/10} + 10^{L_{eq}(MT)/10} + 10^{L_{eq}(HT)/10}]$$

where AU = Automobiles (< 1525 kg.)

MT = Medium trucks (1525 - 4500 kg)

HT = Heavy trucks (> 4500 kg)

The $(\overline{L_o})_{Ei}$ for various class of vehicles are as follows :

Automobiles : $(\overline{L_o})_E(AU)$ = 38.1 log S - 2.4 dBA

Medium trucks : $(\overline{L_o})_E(MT)$ = 33.9 log S - 16.4 dBA

Heavy trucks : $(\overline{L_o})_E(HT)$ = 24.6 log S - 38.5 dBA

In The model, the shielding adjustment (Δ_S) is in the effect of shielding upon the overall traffic stream and its L_{eq}, and it is given as the following :

$$(\Delta_s)_{traf.str.} = +10\log \sum_i (1/\Delta\theta_i) 10^{-(\Delta_s)_{pt.}/10}$$

Where $\Delta\theta_i$ = angle (in radians) subtained by barrier

$$(\Delta_s)_{pt} = \begin{cases} 20\log(\sqrt{2n\pi}/\tanh\sqrt{2n\pi}) + 5, & (N \geq -0.2) \\ 0, & (\text{otherwise}) \end{cases}$$

$N = 2(\delta/\lambda)$

λ = composite wavelength for traffic noise taken at 0.67 m. (2.2 ft.)

δ = the Fresnel number

DOE Model

The prediction of noise level at the reception point of the UK's DOE model consists 2 parts (9) :

(1) prediction of basic noise level at 10 m. away from the nearside road edge.

(2) Application of correction factors to the above predicted basic noise level.

This basic noise level can be stated as follows :

$$L_{10}\ (1\ \text{hour}) = 41.2 + 10\log N$$

where

L_{10}(1 hour) = Noise level that is exceeded 10% of the time (1 hour)

N = Total vachicle flow within the hour (for both directions in the normal road)

The corrections factors in this model consist of the followings :

. Correction for mean traffic speed and traffic composition of two classification of vehicles :
  - Automobile (< 1525 kg.)
  - Heavy truck (< 1525 kg.)
. Correction for gradient
. Correction for road surface
. Hard/soft ground, glass land propagation
. Obstructed barrier propagation
. Angle of view

7. EVALUATION OF THE MODELS

7.1 Classification of Motorcycle

Since both of the FHWA and DOE models were developed under the conditions where motorcycles form a low percentage in the averge vehicle flow, therefore, both of them recommednd that motorncycles be classified subjectively into either the automobile or heavy truck category, on the basis of the noise produced by each cycle as it passes the observer.

In the study of specific noises the Society of Automotive Engineers have found that the noise level from motorcycles lies between that of automobiles and heavy trucks with the highest noise level coming from the heavy trucks (8)

In the Asian country such as Singapore, motorcycles form a significant percentage of the traffic flow, Collected data in this study showed the percentage ranging from 6% to 17.2%. Therefore, for the purpose of analysis of these two models, motorcycles were grouped into two categories, automobile and heavy truck in order to determine the classification that would give the better results. Thus, the models were analysed under the following terms :-

UK (DOE) model - Motorcycles under automobile category (UK_{AU})

- Motorcycles under heavy truck category (UK_{HT})

US (FHWA) model - Motorcycles under automobile category (US_{AU})

- Motorcycles under heavy truck category (US_{HT})

7.2 Conversion of L_{10} to L_{eq}

The term of sound level prediction from UK and US models are different. The UK model gives the prediction value in terms of L_{10} while the US model gives in terms of L_{eq}. In order to do the comparative analysis of the efficiency of these two prediction models against the field measurement of traffic noises, the L_{10} values predcted by using the UK model were converted into L_{eq} values usint the following equation (2) :

$$L_{10} - L_{eq} = 5.57 \sqrt{\ln\left(1 + \frac{0.371 \times 5280}{A}\right)}$$

$$-2.18 \ln\left(1 + \frac{0.371 \times 5280}{A}\right)$$

wher A = ND/S

N = traffic volume

S = traffic speed

D = $\sqrt{d(d+a)}$

d = distance from receiver to the nearer edge of the carriageway

a = width of the cariageway

7.3 Evaluation Aspects of the Models

The efficiency of the models were investigated in terms of three major components :

(1) Prediction of the basic noise level generated by the traffic

(2) Prediction of the amount of attenuation to the basic noise level as it propagates from sources to the receiver

(3) The overall prediction, that is, the noise level that finally reaches the receiver behind a barrier.

In order to examine these three aspects, data on traffic noise levels was collected at the reference points (10 m. from the edge of the nearside carriageway for UK model, and 15 m. from the center of the carriageway for the US model), in front of the barrier, and behind the barrier. This traffic noise data was collected simultaneously with the collection of traffic characteristic data in each studied site.

7.4 Comparative Analysis

Data on traffic characteristics, geometric conditions of the roadway and barrier, the ground surface conditions, and the surrounding environment were collected from 19 locations and input into the highway traffic noise prediction models of both US and UK. The predicted values of traffic noise were calculated from these two models for each sections of highway for the reference points near the side of the roadway, in front of the barrier, and behind the barrier.

Comparative analysis was then given in order to investigate how these predicted values fitted to the field measurement noises, so that the efficiency of the models could be examined. The prediction efficiency of these models were studied in terms of the degree of deviation about the balance line, that is, the 45° line passing fthrough the origin of a plot of predicted values versus measured values. Two approaches for this study were adopted to define the degree of dispersion, namely :

(1) A confident band about the 45° line, and

(2) The standard error of estimate about the 45° line (se).

The results from this comparative study showed that the US model with motorcycles classified under heavy trucks category gave the smallest standard error of estimate (se) of 1.45 about the balance line for the comparative test of predicted and measured noises at the reference point in front of the barrier. The plotting provided the highest values of 84.2 % of points fall within the 95 % confident interval band, and all of the points were within the 90 % confident interval band. Fig 2 shows the result of this plot, and Table I shows the comparative values of the standard error of estimate (se) respestively.

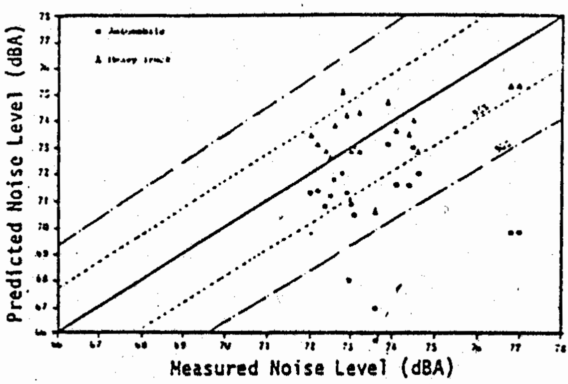

FIGURE 2 PLOT OF PREDICTED AND MEASURED NOISE LEVELS (US'S FHWA MODEL) IN FRONT OF BARRIER

TABLE I STANDARD ERROR OF ESTIMATE FOR PREDICTION OF NOISE LEVEL IN FRONT OF BARRIER

	UK_{AU}	UK_{HT}	US_{AU}	US_{HT}
standard error of estimate, se	1.74	2.92	3.55	1.45

For the test of overall predicted noises at eht locations behind the barrier in comparison to the measured noises at the same locations, this US model with motorcycles classified under the heavy truck also gave the smallest value of standard error of estimate (se) of 3.61 about the balance line, and the highest percentage of plotting points of 89.5 % that fall with in the 90 % confident interval band and 68.4 within the 95 % confident interval band. The result of plot and the se values of these tests are show in Fig. 3 and Table II respectively.

8. IMPROVEMENT OF THE MODEL

From the result of the comparative tests of the US and UK models, the US_{HT} model with motorcycles classified under heavy trucks category which gave

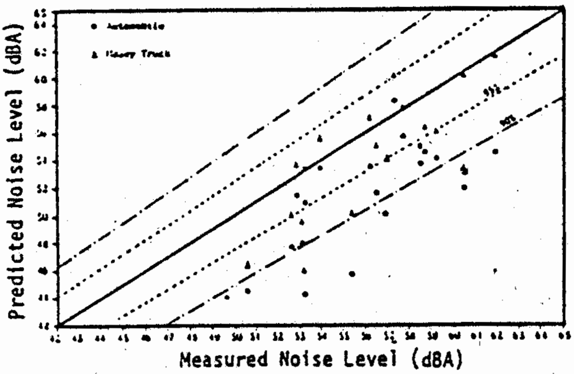

FIGURE 3 PLOT OF PREDICTED AND MEASURED NOISE LEVELS (US'S FHWA MODEL) BEHIND BARRIER

TABLE II STANDARD ERROR OF ESTIMATE FOR PREDICTION OF NOISE LEVEL BEHIND BARRIER

	UK_{AU}	UK_{HT}	US_{AU}	US_{HT}
standard error of estimate, se	4.75	5.86	5.91	3.61

the smallest se was therefore selected for further improvement in order to build the new model that could give a higher efficiency in predicting highway traffic noise in this Asian country

The improvements were done by mean of applying the correction factors to the two main groups of parameters in the selected model, namely, the basic noise level parameters, and the attenuation parameters. This can be presented mathematically as follows :

Noise Level = F_1(Basic Noise Level) - F_A(Attenuation)

where F_1 and F_A are the correction factors for the groups of basic noise level and attenuation respectively.

These two correction factors are the ratio of the measured to the predicted noise levels at the same location. The iterative procedure was then given in order to obtain thses F_1 and F_A factors as described in a flow chart in Fig. 4.

The collected data was then input into this iterative procedure program and the factors F_1 and F_A were calculated iteratively until the stabilised correction factors could be obtained. The values of correction factors at each stage of iteration until it reaches the stabilised stage are shown in Table III.

TABLE III CORRECTION FACTORS AT EACH STAGE OF ITERATION

correction factor for	number of iteration			
	1	2	3	4
basic noise level, F_1	1.002	1.003	1.003	1.003
attenuation F_A	0.920	0.939	0.919	0.919

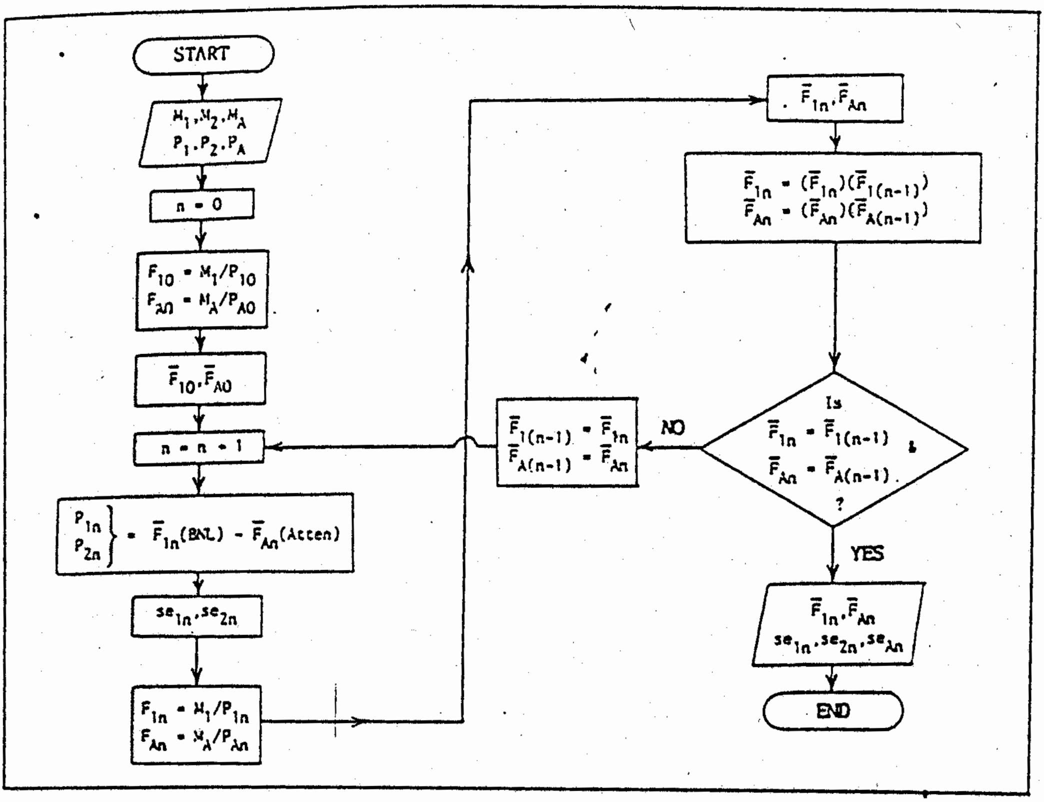

FIGURE 4 FLOW CHART OF ITERATIVE PROCESS FOR DETERMINING THE CORRECTION FACTORS

The final model for highway traffic noise prediction, therefore can be stated as the following.

Noise Level = 1.003 (Basic Noise Level)

-0.919 (Attenuation)

At each stage of iteration the adjusted noise level was matched against the field measurement value and the standard error of estimate about the balance line was calculated as shown in Table IV.

TABLE IV STANDARD ERROR OF ESTIMATE ABOUT THE BALANCE LINE FOR EACH SET OF CORRECTION FACTORS

stardard error of estimate for	number of iteration			
	1	2	3	4
se_1 (in front of barrier)	1.45	1.53	1.44	1.44
se_2 (behind barrier)	3.61	3.10	2.83	2.71
se_A (attenuation)	3.48	3.80	2.60	2.01

From this table, the modified noise prediction model could provide the smallest value of standard error at estimate (se) of 2.71 for the overall comparison of predicted and measured highway noises at the location behind the barrier. It also provided the smallest se values of 1.44 and 2.01 for the tests of the noises at the location in front of the barrier and the attenuation part respectively.

9. CONCLUSION

From this study, the newly modified model which was based on the application of correction factors to each group of the basic noise level parameters and the attenuation parameters of the FHWA model with motorcycles classified under the heavy truck category could provide a significant improvement to the highway traffic noise prediction in Singapore.

The statistical tests showed that standard error of estimates for the overall prediction of traffic noise behind the barrier of this new model improved from 3.61 to 2.71, which was about 24.93 % of improvement. In the part of prediction of attenuation values, its standard error of estimates also improved significantly from 3.48 to 2.01 or approximately 42.24 % of improvement.

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