SUPER-HIGHWAY TRAFFIC NOISE SIMULATING MODEL WITH CONSIDERATION OF LOCAL TRAFFIC VEHICLES

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abstract : This paper presents the analysis and simulation of a traffic noise model for the super-highway in Bangkok with special consideration on non-typical local traffic vehicles. Vibhawadee-Rangsit Super-Highway in Bangkok's suburban area was used for the study location. Data for this study was collected from several locations along this highway. It included traffic characteristics, traffic noise, and geometrical dimensions of highway sections. Characteristics of traffic noise from different types of vehicles on this highway were also analyzed. These vehicle types included two popular vehicles in Bangkok namely, the tuk-tuk (motortricycle taxi) and motorcycle in addition to the other typical highway vehicles. This data was then used to analyze and build the traffic noise simulating model. The results of the super-highway traffic noise model and its statistical performance with the measured data are also presented in this paper.

1. BACKGROUND

The Vibhawadee-Rangsit Super-Highway is one of the most important highways in the suburban area of Bangkok leading to the north and northeastern parts of Thailand. This super-highway consists of 10 traffic lanes where access is restricted despite the presence of frontage roads on both sides. Being the major highway with the highest daily traffic volume in Bangkok this super-highway results in the generation of high traffic noise levels in its surrounding land use along its highway corridors. In order to forecast the highway traffic noise level from this super-highway for use in the traffic noise impact assessment of this highway to the nearby land use development and also to the development of this highway itself or other similar highways, the U.S. model and U.K. model were used. These models built in the western countries based on their own vehicular types and characteristics gave errors when they were used for this traffic noise forecasting, due to the difference in vehicle types and characteristics of traffic between the western countries and Thailand.

2. STUDY OBJECTIVE

This study, therefore, was aimed at building an uninterrupted traffic flow noise model for the Vibhawadee-Rangsit Super-Highway. This model is being built based on highway traffic noise source from each type of vehicle which used this super-highway. It includes the tuk-tuk (motortricycle taxi) and motorcycle. These two types of vehicle are very popular on highways and roads in Thailand, but rarely seen on western country roads. From the previous studies, the U.S.'s FHWA model performed better in predicting highway traffic noise for uninterrupted flow in Thai and Asian cities than the U.K.'s DOE model from Europe. The findings led to the development of the first uninterrupted flow traffic noise model for traffic characteristics in Bangkok, Thailand. This study, therefore, utilized the knowledge from this previous research to build the more efficient uninterrupted flow traffic noise model for this super-highway. This process was done by application of reference energy mean emission level for each type of vehicle that appeared on the highway in Bangkok as the basic traffic noise source models for the overall prediction model.

3. LOCATION AND STUDY DATA

Data for the building of traffic noise model in this study was collected from several locations along the Vibhawadee-Rangsit super-highway which included traffic characteristics and traffic noises. The geometrical dimensions of super-highway sections at the data collection points were also measured. The highway traffic noise was measured using an integrated sound level meter with the L_{eq} A-weighted decibel scale dB(A) for one hour periods. The measurement of this super-highway traffic noise L_{eq} (1-hour) and traffic characteristics (traffic volume, combination of traffic, and traffic spot speed) were performed on a simultaneous and unbiased basis.

In the traffic noise source analysis, the traffic noise data for each vehicle type which appeared on this super-highway was collected in the field with on-road running conditions. These vehicle types included the two popular vehicles on highways in Thailand, namely, tuk-tuk and motorcycle in addition to the other typical vehicle types of automobile, truck (light, medium, and heavy), and bus (medium, and normal). The measurement of vehicle spot-speed and traffic noise generated by this particular type of vehicle were measured simultaneously on a road test sections under real vehicle running conditions. This data was later used in the traffic noise source analysis to generate the reference energy mean emission level (L_o) model for each type of vehicle in the super-highway traffic stream.

4. TRAFFIC NOISE SOURCES ANALYSIS

The relationship between vehicle noise which collected separately in L_{eq}(10 second) dB(A), from the test sites as previously mentioned and vehicle spot-speed were plotted for each type of vehicle on the highway. This basic traffic noise model, called reference energy mean emission level (L_o) was then analyzed for each type of vehicle. In this analysis, the previous log speed model as introduced by FHWA for U.S. vehicles as reference energy mean emission level (L_o) was firstly tested against the collected data. The test showed no significance results for any model type of L_o as given by the FHWA when fitted to any specified class of vehicles in Thailand. Therefore, new model were tested by using a regression analysis technique in order to determine the best fit L_o model for the Bangkok super-highway traffic noise sources. In this study, vehicles on the super-highway were grouped into 5 categories as follows.

(1) Automobile
(2) Medium vehicle , this category consisted of light truck (4 wheels), medium truck (6 wheels), and mini bus (medium bus)
(3) Heavy vehicle , this category consisted of heavy truck (≥ 10 wheels), and normal bus (normal city bus)
(4) Motorcycle
(5) Tuk-tuk (motortricycle taxi)

From this analysis, it was found that linear models between noise level in L_{eq} and the spot speed of a vehicle provided the best fit model for each type of vehicles that appeared on the super-highway. Table 1 showed the final results of this reference energy mean emission level (L_o) analysis for each type of vehicles in the traffic and, L_o as given by FHWA.

Table 1. Reference Energy Mean Emission Level (L_o) for Each Type of Vehicles in Bangkok in Comparison with (L_o) of FHWA

Vehicle Type	$(L_o)_i$	
	Bangkok	**FHWA**
Automobile	$L_{o(AU)} = 55.95 + 0.134\,S$	$L_{o(AU)} = 38.1 \log S - 2.4$
Medium Vehicle	$L_{o(MT)} = 66.43 + 0.089\,S$	$L_{o(MV)} = 33.5 \log S + 16.4$
Heavy Vehicle	$L_{o(HT)} = 73.81 + 0.035\,S$	$L_{o(HV)} = 24.6 \log S + 38.5$
Motorcycles	$L_{o(MC)} = 67.85 + 0.072\,S$	–
Tuk-Tuk (Motortricycle)	$L_{o(TT)} = 72.34 + 0.036\,S$	–

5. ANALYSIS OF SUPER-HIGHWAY NOISE MODEL

5.1 Application of Bangkok Vehicles $(L_o)_i$

A model of L_o from each type of vehicle in Bangkok obtained above were used for reference energy mean emission level (L_o) estimation of the basic vehicle traffic noise source input into the overall highway traffic noise model, which could be described as follows:

$$L_{eq}(\text{total}) = 10\text{Log}(10^{L_{eq}(\text{near})/10} + 10^{L_{eq}(\text{far})/10}) \qquad \text{\_\_\_\_\_\_ (1)}$$

where :

$$L_{eq}(\text{near}), L_{eq}(\text{far}) = 10\text{Log}(10^{L_{eq}(AU)/10} + 10^{L_{eq}(MT)/10} + 10^{L_{eq}(HT)/10}$$

$$+10^{L_{eq}(MC)/10} + 10^{L_{eq}(TT)/10}) \qquad \text{\_\_\_\_\_\_ (2)}$$

and $L_{eq}(1\text{-hour})_i$ =

$$(L_o)_{Ei} + 10\text{Log}(N_i \pi D_o / S_i T) + 10\text{Log}(D_o / D)^{1+\alpha} + 10\text{Log}[\Psi_\alpha(\phi_1,\phi_2)/\pi] + \Delta S \qquad \text{\_\_\_\_\_\_ (3)}$$

where :

$L_{eq}(total)$ = Total super-highway traffic noise level in equivalent noise level L_{eq} dB(A)

$L_{eq}(near)$, $L_{eq}(far)$ = Traffic noise level from near-side & far-side of highway, respectively dB(A)

$L_{eq}(1\text{-hour})_i$ = Equivalent noise level in 1 hour period for vehicle class i, dB(A)

and

$(L_o)_{Ei}$ or $(L_o)_i$ = Reference energy mean emission level term

$10\text{Log}(N_i \pi D_o/S_i T)$ = Traffic flow adjustment term

$10\text{Log}(D_o/D)^{1+\alpha}$ = Distance adjustment term

$10\text{Log}[\Psi_\alpha(\phi_1,\phi_2)/\pi]$ = Finite roadway adjustment term

ΔS = Shielding adjustment term

where :

i = Vehicle class i

N_i = Number of vehicle in each class 1 hour period

D_o = Reference distance where L_o are obtained = 15 m.

D = Distance from center line of traffic lane to receiver (m.)

S_i = Average spot speed of the i th class of vehicle (km./hr.)

T = Time of observation (1 hour)

α = Site parameter (0 or 1/2)

ψ_α = Adjustment for finite length of roadway

ϕ_1, ϕ_2 = Angles of roadway that contributing the noise (degree)

ΔS = Attenuation due to shielding dB(A)

and :

AU = Automobile

MT = Medium truck

HT = Heavy truck

MC = Motorcycle

TT = Tuk-tuk (motortricycle)

In this study, all of the road sections were straight, therefore, the finite roadway adjustment term became zero. The shielding adjustment term could also be excluded from the model due to the absence of an embankment or highway noise barrier along the side of this super-highway. Therefore, the final $L_{eq}(1\text{-hour})_i$ could be formulated as the following.

$$L_{eq}(1\text{-hour})_i = (L_o)_{Ei} + 10\text{Log}(N_i \pi D_o / S_i T) + 10\text{Log}(D_o / D)^{1+\alpha} \qquad \text{\_\_\_\_\_\_ (4)}$$

5.2 Application of Motorcycle and Tuk-Tuk in FHWA's L_o

This part of study utilized the model of L_o for the three categories of vehicles as given by FHWA, namely, automobile (< 1525 kg.), medium vehicle (1525 - 4500 kg.), and heavy vehicle (> 4500 kg.). The modification was then performed by inclusion of motorcycle's and tuk-tuk's L_o, the two popular vehicles on this Bangkok's super-highway normal traffic stream, into the heavy vehicle classification in estimating reference energy mean emission level. This application was done in line with results of a previous research in Singapore which found that when motorcycles which are the popular vehicles in Asian cities are grouped into the heavy vehicle class of FHWA's L_o, they could provide a better result in the prediction of highway traffic noise in an Asian city. Also a study in Thailand showed that the noise level generated by tuk-tuk was quite close to that of the heavy truck group.

This model could be mathematically described as the followings. The total highway noise level in L_{eq} for a 1-hour period L_{eq}(total) was the same as shown in equation (1), and the equivalent noise level for a 1 hour period for vehicle class i $L_{eq}(1\text{-hour})_i$ was also the same as in equation (3). The terms of L_{eq}(near) and L_{eq}(far) for this modified FHWA model were applied only to 3 classes of vehicles as automobile, medium vehicle, and heavy vehicle, with motorcycle and tuk-tuk were classified into the heavy vehicle group. These two terms could be stated as the following.

$$L_{eq}(\text{near}), L_{eq}(\text{far}) = 10\text{Log}(10^{L_{eq}(AU)/10} + 10^{L_{eq}(MV)/10} + 10^{L_{eq}(HV)/10}) \quad \text{\_\_\_\_\_\_ (5)}$$

6. STATISTICAL TESTS OF THE MODELS

A comparative statistical tests were applied to compare these two models by using the paired t-test technique in order to see how good these two models could be fitted to the observed highway traffic noise data. In this paired t-test, the predicted traffic noise levels from each model were compared with the measured ones. The null hypothesis of the paired t-test was that the mean valves of difference between pair of measured traffic noise levels and predicted ones is equal to zero. Therefore, the null hypothesis and formulation of this test were as follows.

$$\text{Null hypothesis } H_o: \quad \mu_{di} = 0 \quad \text{\_\_\_\_\_\_ (6)}$$

and

$$t = \frac{\bar{d}}{SE/\sqrt{n}} \quad \text{\_\_\_\_\_\_ (7)}$$

where :

- d_i = Difference between measured traffic noise value and predicted one at the i th pair (measured - predicted)
- $\bar{d}$ = Mean difference of all d_i
- SE = Standard error of the difference values
- n = Number of paired samples
- i = 1, 2, 3, ..., n

The testing result showed that the model that utilized L_o from Bangkok vehicle noise sources provided the statistical significance in fitting to the highway traffic noise data in Bangkok at both of 5% and 10% significance levels in the two tailed test of the paired t-test technique. On the other hand, the model which utilized the base L_o from FHWA with the inclusion of motorcycle and tuk-tuk into the heavy vehicle class could not provide any statistical significance in fitting to the observed data of Bangkok highway traffic noises. Details of this paired t-test analysis are shown in Table 2.

Table 2. Statistical Results from Paired t-test of the Models

Bangkok $(L_o)_{Ei}$ Model	Modified FHWA $(L_o)_{Ei}$ Model
$\bar{d}$ = - 0.167 SE = 1.223 n = 62 t-value = - 1.075 i = 5	$\bar{d}$ = 0.616 SE = 1.166 n = 62 t-value = 4.161 i = 3
and at (α = 5%, DF = 61) at (α = 10%, DF = 61)	$\pm$ t-table $_{\alpha/2, DF}$ = $\pm$ 2.00 $\pm$ t-table $_{\alpha/2, DF}$ = $\pm$ 1.67

where : $(L_o)_{Ei}$ or $(L_o)_i$ = Reference energy mean emission level of vehicle class i
i = Each class of vehicles (i = 5 classes for Bangkok L_o, i = 3 classes for modified FHWA L_o)
$\bar{d}$ = Mean of the difference values between observed and predicted noise levels
SE = Standard error of the difference values between observed and predicted noise levels
n = Number of paired samples
α = Significant level
DF = Degree of freedom (n-1)

7. CONCLUSIONS

Several conclusions can be drawn from this study including the following. The logarithmic models type of reference energy mean emission level (L_o) as given by FHWA could not statistically be fitted to traffic noise in L_{eq} generated by any class of vehicles in Bangkok, Thailand. The linear relationship between noise level in L_{eq} and speed of vehicle were the most suitable to highway traffic noise data in Bangkok's Vibhawadee-Rangsit Super-Highway in the analysis of reference energy mean emission level (L_o) for each type of vehicles in Bangkok traffic stream included motorcycles and tuk-tuk in additional to the other normal types of vehicle. Results from this study also show a significant improvement in the forecasting of the super-highway traffic noise in Bangkok by utilizing these new reference energy mean emission level (L_o) into the overall highway traffic noise model in comparison to the utilization of L_o as previously given by FHWA with the inclusion of motorcycle and tuk-tuk into the heavy vehicle class. This newly modified model gave statistically significance results in fitting to the observed traffic noise data on this super-highway in the paired t-test at both of the 5% and 10% significance levels test.

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