Reference Energy Mean Noise Emission Levels for Riyadh, Saudi Arabia

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In the oil-rich countries of the Persian Gulf, traffic noise pollution in rapidly developing urban areas has become a major source of concern for the public and for policy makers. The FHWA traffic noise model (STAMINA), because of its flexibility and adaptability to a changing environment, provides an effective tool for the analysis of traffic noise impact. However, no study has been undertaken to examine the applicability of the FHWA models to urban areas in the Persian Gulf region. In this study, noise emission data were collected for cars, medium trucks, and heavy vehicles. Using the data, reference energy mean noise emission levels were developed as a function of vehicle class and speed. These functions were used to predict traffic noise levels for two roadway locations in Riyadh. A comparison of model-predicted noise levels with field measurements indicated a significantly closer agreement between the Riyadh and the original FHWA models.

This paper reports the development of reference energy mean noise emission levels (REMNEL) for vehicles in Riyadh, Saudi Arabia. In rapidly developing urban areas of the oil-rich countries of the Persian Gulf, the problem of traffic noise pollution becomes complex. The complexity arises from a continuous migration of population from rural to urban areas, construction of hundreds of kilometers of urban expressways, and an intense rate of growth in household socioeconomic activities. Studies have shown that a major portion of the urban population in Saudi Arabia is annoyed with traffic noise (*1–3*).

A commonly used model for detailed noise impact analysis and forecasts is the Federal Highway Administration model FHWA/STAMINA (*4*). The model can easily be calibrated for new conditions since the REMNEL for various classes of vehicles are used as independent inputs to the model. FHWA has also published reference energy mean emission levels as a function of vehicle class and vehicle speed (*5*).

Several research studies in North America have shown that the use of the original REMNEL curves published by FHWA may result in a significant overestimation of noise levels in the vicinity of roadways where the studies were performed (*6–8*). However, no study has been performed to examine and evaluate the transferability of the FHWA traffic noise models to urban areas of the Persian Gulf region. A number of related factors in the region vary from those of the North American environment: poor vehicle maintenance practices, overloading of vehicles, and rough pavement surfaces caused by poor material characteristics and a lack of systematic and timely pavement maintenance.

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The specific objectives of the study were (*a*) to develop REMNEL curves for Riyadh and (*b*) to compare the Riyadh and FHWA noise emission curves.

DATA AND METHOD

The sampling plan was designed in accordance with the requirements established by FHWA (*9*). Five sites were chosen for field measurements. All sites were level (less than 2 percent grade) open spaces and were free of large reflective surfaces. The microphone was placed 15 m from the centerline of the near traffic lane and was mounted on a tripod at a height of 1.5 m.

The study instrumentation included a Bruel and Kjaer noise level analyzer, Type 4427; a sound level meter, Type 2209; a calibrator (pistonphone), Type 4220; a ½-in. microphone, Type 4165; an extension cable, Type A00029; a microphone windscreen; a tripod; and a radar vehicle speed detection unit.

Vehicles were classified into three groups in accordance with the FHWA procedure. The noise emission data were collected from vehicles moving at a constant speed under cruise conditions. Samples were grouped into speed ranges of ±5 km/hr and covered a range from 50 to 100 km/hr.

Statistical Analysis of the Sample Data

The required number of sample vehicles for each class and speed group was determined using the procedure recommended by FHWA (*10*). The number of sample vehicles for each class (automobiles, medium trucks, and heavy trucks) were 75, 108, and 94, respectively (error interval ±0.5 dBA and $\alpha = 0.05$, a 5 percent significance level). The number of vehicles actually monitored for noise emission data at each speed group was slightly higher: 80 for automobiles and light trucks, 110 for medium trucks, and 100 for the heavy vehicle group. Using the final sample size and the sample standard deviation, the actual confidence interval at the 95 percent confidence level was computed for each vehicle class and each speed group according to the Student's t distribution (since the true variance is unknown), shown by Equation 1:

$$\bar{x} - t_{\alpha/2,n-1}\frac{S}{\sqrt{N}} \leq \mu_{1-\alpha} \leq \bar{x} + t_{\alpha/2,n-1}\frac{S}{\sqrt{N}} \quad (1)$$

where

$\bar{x}$ = mean sample emission level,
$t_{\alpha/2,n-1}$ = the percentile value of the t distribution with $(n-1)$ degrees of freedom (*10*),
S = sample standard deviation,
μ = true mean emission level,
N = sample size for each vehicle class and speed group, and
α = significance level.

Table 1 presents the results of the statistical analysis of the sample emission data. Figure 1 shows variations in the mean ± one standard deviation for each speed group for automobiles, medium trucks, and heavy vehicles.

Computation of REMNEL

The following steps were taken to compute REMNEL:

1. The arithmetic mean emission level for the ith vehicle class, $(\bar{L}_o)_i$, was computed according to Equation 2:

$$(\bar{L}_o)_i = \left(\frac{1}{N}\right) \sum_{K=1}^{N} (L_o)_{Ki} \quad (2)$$

where $(\bar{L}_o)_{Ki}$ is the Kth measured emission level for the ith class of vehicles at a given speed group and N is the number of measured emission levels for the ith vehicle class at a given speed group.

2. The sample standard deviation of the ith vehicle class, $(S)_i$, was computed using Equation 3:

$$(S)_i = \sqrt{\left[\frac{1}{(N-1)}\right] \sum_{K=1}^{N} [(L_o)_{Ki} - (\bar{L}_o)_i]^2} \quad (3)$$

3. The REMNEL for each vehicle class and speed group, $(\bar{L}_o)_{Ei}$, was computed in accordance with the following equation:

$$(\bar{L}_o)_{Ei} = (\bar{L}_o)_i + 0.115(S)_i^2 \quad (4)$$

Equations 2 through 4 were used with the sample data to compute the REMNEL for the three vehicle classes and each speed group. Results are presented in Table 2. The data in Table 2 clearly indicate that the REMNEL values increase with increases in vehicle speed and vehicle size.

Using the REMNEL values from Table 2 and the midpoint of each speed group, a least squares regression analysis was performed to develop the equation for the reference mean emission levels for each vehicle class in Riyadh. The equations are as follows for automobiles, medium trucks, and heavy vehicles, respectively:

$$(\bar{L}_o)_E = 9.84 + 33.21\log(V) \qquad R^2 = 0.8779 \quad (5)$$

$$(\bar{L}_o)_E = 15.54 + 35.68\log(V) \qquad R^2 = 0.9765 \quad (6)$$

$$(\bar{L}_o)_E = 44.39 + 22.46\log(V) \qquad R^2 = 0.9433 \quad (7)$$

where V is vehicle speed in km/hr.

The high values of coefficients of determination (R^2) are in accordance with expectations. Since the sample observation values for both the dependent and independent variables are the mean values of emission levels and speed groups, respectively, the models only explain the in-between group variations of emission levels. The within-group variations are not explained by the models because of the use of the mean values.

A comparison of FHWA's regression curves and those developed for Riyadh indicated higher REMNEL values for all vehicles and all speed groups predicted by the Riyadh models. Important factors contributing to higher noise levels produced

TABLE 1 Statistical Analysis of Sample Data

Vehicle Class	Speed Class (km/h)	Mean Noise Emission Level (dBA)	Standard Deviation of Emission Level (dBA)	Sample Size	Confidence Interval 95% level (α=005) ± dBA
Automobiles	50	65.4	2.05	80	0.46
	60	66.8	0.83	80	0.28
	70	69.2	0.60	80	0.13
	80	70.8	1.71	80	0.38
	90	73.1	0.83	80	0.18
	100	75.0	2.20	80	0.49
				Σ=480	
Medium Trucks	50	74.5	1.22	110	0.23
	60	77.0	1.16	110	0.22
	70	79.4	1.04	110	0.19
	80	81.5	1.05	110	0.20
	90	83.5	0.86	110	0.16
	100	85.0	0.87	110	0.16
				Σ=660	
Heavy Trucks	50	81.6	0.86	100	0.18
	60	83.6	0.85	100	0.17
	70	85.6	0.78	100	0.15
	80	86.6	0.80	100	0.16
	90	87.4	0.69	100	0.14
	100	88.0	0.89	100	0.18
				Σ=600	

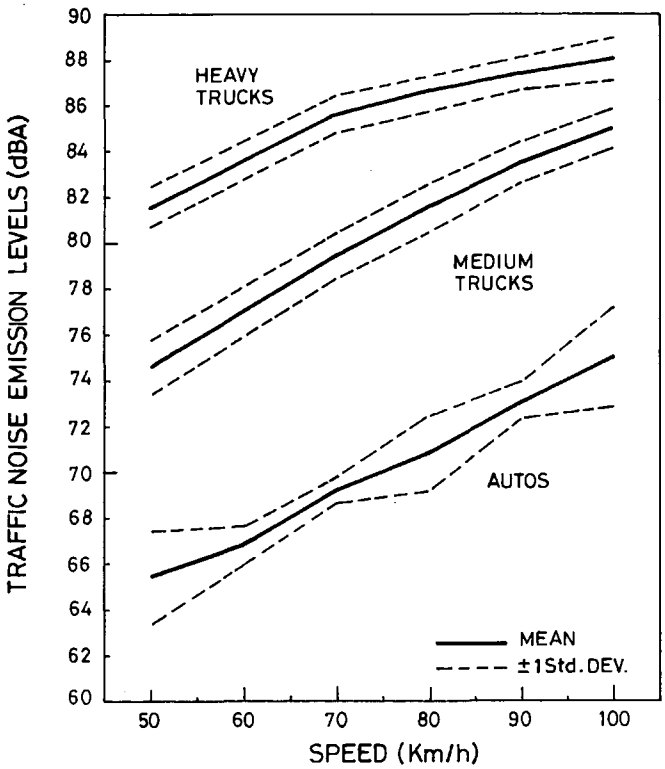

FIGURE 1 Mean and standard deviation of emission levels by vehicle class and speed group.

by vehicles in Riyadh were the generally poor level of vehicle maintenance, overloading of vehicles, and the rough pavement surface of urban roadways (due to the nonexistence of high-quality pavement materials in most parts of Saudi Arabia).

Model Validation

The Riyadh and FHWA emission level curves were used to compute reference energy mean noise emissions $(\bar{L}_o)_{Ei}$, and, subsequently, the equivalent noise levels, L_{eq}, for two roadway sites in Riyadh. Actual measurements of traffic volumes, speeds, and noise levels were made during five periods, covering the morning (7:00 to 9:00 a.m.), afternoon (4:30 to 8:30 p.m.), and night (9:30 to 11:00 p.m.).

Table 3 presents the measured and model-predicted hourly equivalent noise levels by monitoring period and vehicle class for the two study sites. The data in these tables clearly indicate that the use of FHWA-recommended curves consistently underestimated traffic noise at both sites.

The Student's t test for paired data was used to determine whether the difference between measured traffic noise levels and those predicted by the two models was statistically significant (*9*). A mean difference of 0.37 dBA was obtained by using the Riyadh noise emission data, and −2.02 dBA resulted from using the FHWA emission levels. The difference between the model-predicted $L_{eq}S$, using the FHWA emission data, and measured noise levels was significant at the 95 percent significance level ($\alpha = 0.05$). No significant difference, however, was found to exist between the model result using Riyadh emission levels and the measured noise levels.

CONCLUSION

This study indicates that the traffic noise emission data originally recommended by FHWA models are not representative of those measured from vehicles in Riyadh. The FHWA emission curves consistently underestimated traffic noise levels in Riyadh.

The Riyadh model, on the other hand, accurately predicted traffic noise levels at two independently monitored roadway locations in Riyadh.

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TABLE 2 REMNEL by Vehicle Class and Speed Group

Speed Group[a] (km/h)	Vehicle Class, i								
	Autos			Medium Trucks			Heavy Trucks		
	$(\bar{L}_o)_i$	$(S)_i$	$(\bar{L}_o)_{Ei}$	$(\bar{L}_o)_i$	$(S)_i$	$(\bar{L}_o)_{Ei}$	$(\bar{L}_o)_i$	$(S)_i$	$(\bar{L}_o)_{Ei}$
50	64.4	2.05	64.9	74.5	1.22	74.7	81.6	0.86	81.7
60	66.8	0.83	66.9	77.0	1.16	77.2	83.6	0.85	83.7
70	69.2	0.60	69.2	79.4	1.04	79.5	85.6	0.78	85.7
80	70.8	1.71	71.1	81.5	1.05	81.6	86.6	0.80	86.7
90	73.1	0.83	73.2	83.5	0.86	83.6	87.4	0.69	87.5
100	75.0	2.20	75.6	85.0	0.87	85.1	88.0	0.89	88.1

[a]Each speed group includes observations within ±5 km/h.

TABLE 3 Measured and Model-Predicted Hourly Equivalent Noise Levels—Ulayyah Arterial and Maccah Freeway

Variable Name	L_{eq} by monitoring Period and Vehicle Class								
	Morning			Afternoon			Night		
	Autos	Medium Trucks	Heavy Trucks	Autos	Medium Trucks	Heavy Trucks	Autos	Medium Trucks	Heavy Trucks
				(a) ULLAYYAH ARTERIAL					
Riyadh Model	69.1	66.6	66.5	68.5	69.0	68.1	68.6	64.2	64.1
FHWA Model	65.4	64.3	64.4	64.8	66.7	66.0	64.9	61.9	62.0
All Vehicles:									
Riyadh Model		72.4			72.0			71.0	
FHWA Model		69.5			69.1			67.9	
Measured		73.0			72.0			71.0	
				(b) MACCAH FREEWAY					
Riyadh Model	79.5	77.8	72.1	79.1	74.6	74.8	77.8	78.6	68.1
FHWA Model	76.7	75.2	70.4	76.3	72.0	73.1	75.0	76.0	66.5
All Vehicles:									
Riyadh Model		82.2			81.5			81.4	
FHWA Model		80.9			79.0			78.8	
Measured		81.7			79.9			80.7	

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