A COMPARATIVE ANALYSIS OF URBAN TRAFFIC NOISE MODELS: KUWAIT URBAN AREA CASE

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Abstract
The Environmental Impact Assessment (AIA), is now a necessary requirement of any proposed infrastructural development in the State of Kuwait. The EIA calls for the identification and quantification of the magnitude of adverse impact of the proposed project on air, noise, waste, water, land, and marine environment. The assessment of noise is made by models that are employed to predict noise levels and impacts. In this paper, the result of a research study aimed at developing and comparing the predictive ability of disaggregate regression and the Traffic Noise Model (TNM) of the FHWA-USA, is presented. A correlation analysis was performed to identify the degree of associations between a number of independent variables (traffic volume, mix, speed, time of day, roadway type, number of traffic lanes, etc.), and the generated noise level (the dependant variable). Findings showed that the TNM model consistently underestimated the level of noise at nearly all measurement sites. The regression model on the other hand, overestimated traffic noise during the peak hours. A number of recommendations end the paper.

INTRODUCTION

This paper reports the findings of a research project aimed at measuring traffic noise level, calibrating an easy-to-use regression model, and comparing the predictive ability of the regression and the FHWA-TNM models.

Environmental Laws require an Environmental Impact Statement (EIS) for any proposed infrastructural development. The aim is to take into account the adverse effect of the development on all existing and potential elements of the environment. Traffic noise models are employed to aid in the design of roadways, as well as in the assessment of existing or envisaged changes in noise-generating land-uses.

Traffic noise models predict sound pressure levels, specified in terms of equivalent noise level, L_{eq}, or the highest 10 percentile level, L_{10}, by government agencies. These models are utilized by design engineers, and acoustical engineers and specialists.

Earlier traffic noise models predicted noise levels based on traffic speed, traffic volume, percent of trucks, and distance from the noise source (WADC 1952; Nickson, 1965; Lamure, 1965; Johnson and Saunders, 1969). Researchers have also developed analytic solutions of the problem of incoherent point sources in a traffic line with given spacings and angles of view (Rathe, 1969; Steele, 1985). Model modifications have replaced vehicle spacings (distance) with vehicle headways (time).

In the US FHWA-STAMINA model, standardized reference energy mean noise emission level (REMNEL) for the three classes: autos, medium trucks and heavy trucks, were developed and were incorporated in the model as input (Koushki and E-Rekhaimi, 1993).

The Department of Environment in the United Kingdom, has also developed a model for the Calculation of Road Traffic Noise (CRTN, 1975), which was later replaced by a more convenient Predicting Road Traffic Noise model (Delany et al., 1976). Studies showed that when the model was applied in Australia, significant differences were observed between the model-predicted and the measured noise levels depending upon the prevailing conditions (Samuels et al., 1982; Saunders and Samuels, 1983).

In this paper, a comparative analysis is made between the latest Traffic Noise Model (TNM) of the US Federal Highway Administration, and a multiple regression model developed in Kuwait. The regression model, regressed the measured traffic noise level on a number of explanatory variables which included traffic flow characteristics, roadway geometrics, and time of day.

THE DATA

Traffic noise and traffic flow variables were measured simultaneously at more than fourty local, collector, arterial, and freeway locations in thirteen urban districts in Kuwait. Measurements were made for 20-30 minutes at each roadway location, repeated five times during the peak and the off-peak hours of the day. Five teams of senior civil engineering students, supervised by a graduate student, measured traffic noise and flow variables. For each monitoring locations the mean noise and flow variables were computed. The computed mean noise indicators included the L_{eq}, L_{10}, L_{90}, L_{50}, L_{min}, and L_{max}.

RESULTS

The frequency distribution of the measured traffic flow volume (by mix) and speed is presented in Table 1. The volume of autos varied from 400 (cars/hour), or less (28.6%), to more than 1250 autos per hour (30.8%). In more than 55% of volume measurements, the hourly number of medium-size trucks was 300 or less. However, in 23.9%, the traffic flow included more than 600 medium-size trucks per hour. In more than 2/3 of the measured traffic flows, the volume of heavy trucks was 50 or less (Table 1). Motor cycles, although, low in frequency, are known to contribute significantly to noise levels especially at residential neighbourhoods. In only 11% of the flows monitored, the volume of motor cycles exceeds 5 cycles per hour. Overall, in nearly 48% of the measured flows, the total volume of traffic was 1000 (vph), or less, and

Table 1. Frequency distribution of traffic flow variables

Variable Name	Percent	Cumulative percent
Automobile Volume (vph):		
≤ 400	28.6	28.6
401 – 1250	40.6	69.2
> 1250	30.8	100.0
Medium Truck Volume (vph):		
≤ 300	55.4	55.4
301 – 600	20.7	76.1
> 600	23.9	100.0
Heavy Truck Volume (vph):		
≤ 50	67.4	67.4
50 – 100	19.6	87.0
> 100	13.0	100.0
Motor Cycles Volume (vph):		
0	78.0	78.0
1 – 5	11.0	89.0
> 5	11.0	100.0
Total Volume (vph):		
≤ 1000	47.8	47.8
1001 – 2250	31.5	79.3
> 2250	20.7	100.0
Average Speed (km/hr):		
≤ 45	32.6	32.6
46 – 65	23.9	56.5
> 65	43.5	100.0

in nearly 21%, the flow volume was in excess of 2250 (vph). The traffic speed varied from 45 (km/hr) or less, to more than 65 (km/hr), in 43.5% of the monitored flows (Table 1).

The frequency distribution of traffic noise indicators is presented in Table 2. The equivalent noise level during peak hours, ranged from a low of 65 (dBA) or less (44.6%), to more than 80 (dBA) (13%). The L_{10} – the highest 10 percentile noise levels during the peak hours ranged between 75 (dBA), or less, to more than 80 (dBA), in nearly 30% of the monitoring times. The L_{eq}, and L_{10}, during off-peak hours were somewhat less than those during the peak hours. It should be noted that during the off-peak periods, reductions in the volume of traffic is accompanied with an increase in traffic speed. The decrease in the noise level due to reduced volumes is generally offset by an associated increase in the generated noise due to a higher travel speed.

The variation in traffic noise levels with time of day is presented in Figure 1. Both the L_{eq} and L_{10} noise indicators reach their maximum levels during the morning period, with a mean value of nearly 78 and 81 (dBA), respectively. During the off-peak hours, the evening periods experience the highest traffic noise level, at approximately 74 (dBA).

Table 2. Frequency distribution of traffic noise indicators

Variable Name	Percent	Cumulative percent
Equivalent noise pollution level (dBA): (Peak Hour)		
≤ 65	44.6	44.6
65 – 70	4.4	49.0
71 – 75	7.6	56.6
76 – 80	30.4	87.0
> 80	13.0	100.0
Equivalent noise pollution level (dBA): (Off-Peak)		
≤ 65	64.1	64.1
65 – 70	6.5	70.6
71 – 75	13.1	83.7
> 75	16.3	100.0
Peak 10-percentile noise pollution level (dBA): (Peak Hour)		
≤ 75	51.1	51.1
76 – 80	19.6	70.7
> 80	29.3	100.0
Off-peak 10-percentile noise pollution level (dBA): (Off-Peak)		
≤ 75	66.3	66.3
71 – 75	9.8	76.1
76 – 79	17.1	93.5
> 80	6.5	100.0

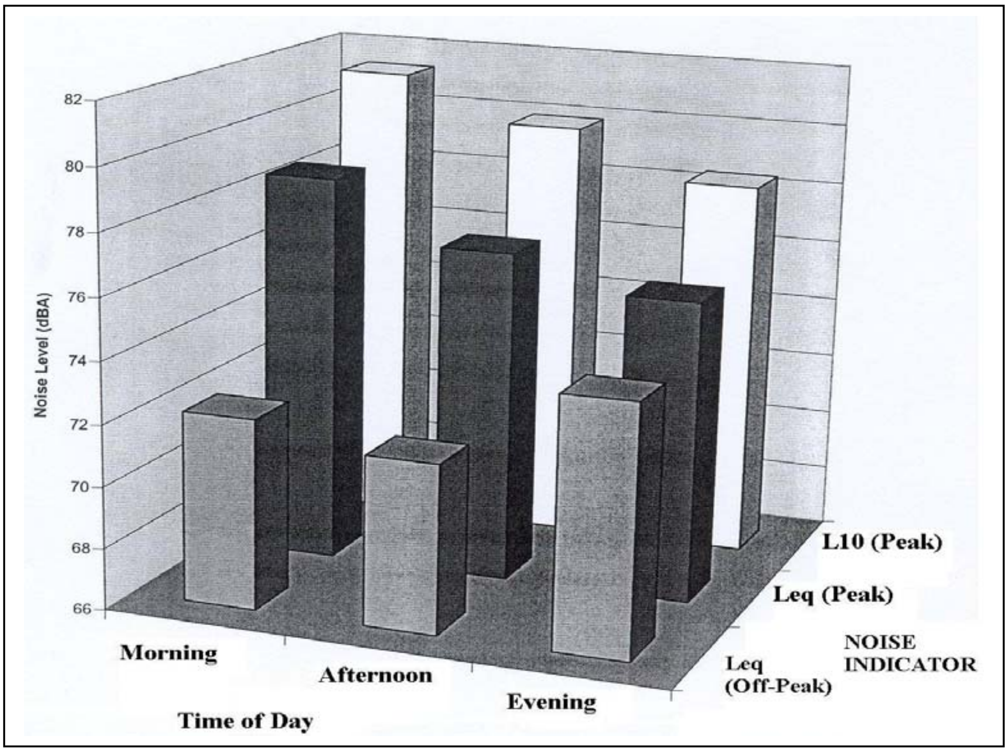

Figure 1. Traffic Noise Indicators and Time of Day

NOISE MODELS AND COMPARISON

Regression Model

The result of a correlation analysis performed on the data showed that traffic noise (L_{eq}) during the peak periods of the day were higher in the morning ($\gamma_{xy} = -0.327$), higher at major arterials and expressways ($\gamma_{xy} = 0.738$), increased with an increase in the number of traffic lanes ($\gamma_{xy} = 0.772$), and with traffic speed ($\gamma_{xy} = 0.6371$). Utilizing these variables as input, a linear regression model was calibrated. Since, the two variables roadway type and the number of lanes were also highly correlated, to avoid the problem of multi-colinearity, the roadway type was not included in the model. The developed model had the following form:

$$L_{eq}\text{ (Peak)} = 66.0038 - 1.4598 \text{ (Time of Day)} + 0.0911 \text{ (Mean Speed)} + 3.4905 \text{ (No. of Lanes)} \quad (1)$$

Coefficient of Determination, $R^2 = 0.71$ (71 %)

The result of the F-test, and the t-test, showed that both the independent variables and the parameters of the model were statistically significant at the 95 percent significance level ($\alpha = 0.05$).

The FHWA-TNM Model

The US Federal Highway Administration Traffic Noise Model (FHWA-TNM) computes noise level through a series of adjustments to a reference sound level. In TNM, the reference level is the vehicle noise emissions level, which refers to the maximum sound levels emitted by a vehicle pass by a reference distance of 15 m. Adjustments are then made to the emission level to account for traffic flow, distance, and shielding. These factors are affected by the following equation.

$$\text{Leaq 1 h} = \text{Eli} + \text{Atraffic (i)} + \text{Ad} + \text{As} \quad (2)$$

where,

Eli	=	vehicle noise emission level for the ith vehicle type,
Atraffic(i)	=	adjustment for traffic flow, the vehicle volume and speed of the i^{th} vehicle type,
Ad	=	adjustment for distance between the roadway and the receiver,
As	=	Shielding and ground effects.

The implementation of the FHWA-TNM, requires:

1) The hourly flow rates for each vehicle type (small, medium, and heavy),
2) The average operating speed of each vehicle type,
3) The distance of the receiver from the roadway edge,
4) The reference energy mean noise emission level (REMNEL), for each vehicle class.

The REMNEL used in the model includes those developed in the USA for small, medium, and large (heavy) vehicles sizes. Naturally, these values do not reflect the roadway geometries, pavement characteristics, vehicle condition and the driving behaviour, experienced in non-industrialized nations, such as Kuwait.

Following are the mean reference emission levels which have been developed in the USA for use in the TNM:

$$\text{Automobiles (Lo) e} = 38.1 \log v - 2.4 \text{ dBA} \quad (3)$$

$$\text{Medium Trucks (Lo) e} = 33.9 \text{ Log } v + 16.4 \text{ dBA} \quad (4)$$

$$\text{Heavy Trucks (Lo) e} = 24.6 \text{ Log } v + 38.5 \text{ dBA} \quad (5)$$

where v is the average operating speed in miles per hour (mph).

Model Predictions

The two models described - the regression and the FHWA-TNM, were employed to predict the level of generated traffic noise at a number of study roadway locations. The result of predictions by the TNM and the regression model for the peak hour noise, along with the actual measurements of traffic noise at selected roadway sites are presented in Table 3.

An examination of the data in Table 3 reveals that:

a) The TNM model consistently underestimates the generated noise in nearly all roadway sites (with one exception: the 6^{th} Ring Road at Mushrif).

b) The peak-hour regression model generally overestimates the traffic noise at all roadway sites.
c) The magnitude of underestimations and overestimations by the TNM and the regression model, respectively, were nearly the same when compared with the actual measured noise levels.

Table 3. Comparison of measured and model – predicted peak and off-peak noise levels

District / Roadway	Measured noise (L_{eq}) (dBA)	TNM predicted (L_{eq}) (dBA)	Difference: Measured vs. TNM	Regression predicted (L_{eq}) (dBA)	Difference: Meausred vs. regression
Rawda:					
Rawda St. (collector):					
Peak	72.6	70.6	-2.0	74.9	+2.3
Off-peak	68.8	62.6	-6.2	66.5	-2.3
Damascus St. (Arterial):					
Peak	77.6	71.2	-6.4	79.2	+16
Off-peak	70.8	62.7	-8.1	68.5	-2.3
Khaldiya:					
Al-Riyad FWY:					
Peak 1	77.6	73.7	-3.9	80.6	+3.0
Peak 2	77.9	72.3	-5.6	78.8	+0.9
Off-peak	75.1	73.1	-2.0	70.8	-4.3
Mushrif:					
6^{th} RR (FWY):					
Peak 1	76.2	76.2	0.0	81.6	+5.4
Peak 2	76.5	75.1	-1.4	78.8	+2.3
Off-peak	75.8	70.0	-5.8	71.9	-3.9
Fahaheel FWY:					
Peak 1	78.2	76.7	-1.5	84.4	+6.2
Peak 2	80.3	78.4	-1.9	82.8	+2.5
Off-peak	75.8	71.4	-4.4	72.2	-3.6

As stated before, the TNM employs REMNEL in the model. Studies show that the REMNEL varies significantly from geographical location to location. This is mainly due to variations in vehicle engine condition, pavement characteristics, and driving behaviour (Koushki and Al-Rekhaimi, 1993). The REMNEL developed for Riyadh traffic, Saudi Arabia, by the author was significantly higher than those developed by the FHWA in the USA. Most likely, the replacement of the (FHWA-TNM) reference noise emission levels with those developed for Kuwait (in Kuwait), will improve the underestimation of traffic noise by the TNM model. A research study is needed to address this deficiency.

CONCLUSIONS

The following conclusions are made:

- The equivalent noise level, L_{eq}, was negatively correlated with the time of day. Noise from traffic was higher during the morning rush hours.
- The L_{eq} was very strongly and positively correlated with roadway type: noise at freeways was significantly higher than that of the local streets.
- As the number of traffic lanes, traffic volume, and traffic speed increased the level of generated noise also increased.
- The results of predictions by the TNM and the regression model for the peak hour noise level along with the actual measurements of traffic noise at selected roadway sites showed that the TNM consistently underestimated, and the regression model generally overestimated, the traffic noise level at all roadway locations.

RECOMMENDATIONS

- Successful protection of the public from the negative impacts of urban traffic noise depends on the effective control of its undesirable effects. This requires the application of comprehensive and multi dimensional approach include source emission control, less emphasis on auto mode of travel, proper management of traffic system, and land-use control.
- A comprehensive, continuous and coordinated program of public education and awareness is essential to minimize the negative productivity, welfare and health impacts of noise pollution on urban residents.

REFERENCES

Handbook of acoustic noise control WADC technical report 52-204, Wright Air Development Center (1952).

Johnson, D.R. and Saunders, E.G., "The evaluation of noise from freely flowing road traffic", Journal of Sound and Vibration, 72, pp. 287-309 (1968)

Koushki, P.A., and T. El-Rekhaimi, "Reference Energy Mean Noise Emission Levels for Saudi Arabia, Transportation Research Board, TRR No. 1398, 163-167 (1993).

Lamure, C., "Niveaux de bruit au voisinage des autoroutes". In: Proc. 5th International Congress on Acoustics (1965).

Nickson, A.F., "Can community reaction to increased traffic noise be forecast ?" In: Proc. 5th International Congress on Acoustics (1965).

Rathe, E.J., "Note on two common problems of sound propagation", Journal of Sound Vibration, 10, pp. 472-479 (1969).

Steele, C.M., "A mathematical model of the environmental impact of traffic noise", Australian Acoustical Society, 1985 Conference, (1985).