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COMPARISON BETWEEN MEASURED TRAFFIC NOISE IN KLANG VALLEY, MALAYSIA AND EXISTING PREDICTION MODELS

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ABSTRACT

Many road traffic noise models are available around the world. However, these models cannot be simply generalized because local conditions affecting such noise (e.g., vehicle type and weather) vary from one locality to another. Two traffic noise models used in this study are the L10 Calculation of Road Traffic Noise (CRTN) model and Traffic Noise Model of Ontario Ministry of Transportation. Using regression analysis, it was found that the predicted traffic noise levels by the CRTN model gave satisfactory correlation with the measured values (R2 of 0.7109). The Traffic Noise Model Of Ontario Ministry Of Transportation overestimated traffic noise level by 3.46 dB(A) on average. This study proves that the improved Ontario Ministry of Transportation Traffic Noise model is satisfactory in predicting traffic noise in a city with high percentage of motorcycle usage. This study also implies that CRTN model is a valid model in predicting traffic noise levels for a city with high rates of motorcycle use such Klang Valley, Malaysia.

1. INTRODUCTION

Transportation systems are key features of any developed society, as they provide the required infrastructure to satisfy mobility and accessibility needs of societies. Yet the unprecedented growth in travel demand experienced in the last few decades has led to a range of significant environmental problems. One of these rising problems is noise pollution resulting from transportation activities, mainly road traffic. Many authorities around the world tend to underestimate the harmful effects of noise pollution compared to other types of pollution such as water, land, or air pollution. Nevertheless, recent research shows that noise pollution can pose serious risks to health such as hypertension [1-3], annoyance [4], sleep disturbance [5], and myocardial infarction [6,7].

Road traffic noise is the most prevalent form of environmental noise pollution, and it can either be measured in the field or predicted through verified mathematical models. While many road traffic noise models are available around the world, these models cannot be simply generalized because local conditions affecting such noise (e.g., vehicle type and weather) vary from one locality to another.

Even though many traffic noise prediction models are available around the world, the models cannot be easily generalized because there are many varying factors and conditions affecting the produced noise. Examples of such factors include vehicle specification, vehicle classification, and meteorological conditions. Furthermore, for large-scale studies [8] suggested that combining the use of verified predictive models with field measurements is preferred, to avoid relying on field measurements, which consumes considerable resources.

In traffic noise modeling, the noise level at a receiver location due to traffic noise source is usually modeled as a function of the parameters such as, traffic conditions (traffic volume, traffic speed, and traffic composition), gradient of road, the nature of road surface, absorbent ground cover percentage, road configuration, and distance between the traffic noise source and the receiver [9]. The traffic noise source can be considered as point or line source. There are two types of traffic noise model assumptions; line source and point source. Different countries design different types of noise prediction models [9-10]. United States Federal Highway Administration Traffic Noise Model (FHWA) and the model by the Acoustical Society of Japan (ASJ) use point source assumption, while the Calculation of Road Traffic Noise (CRTN) model in the United Kingdom and the RLS-90 model in Germany use line source assumption [10].

1.1 The Traffic Noise Model of Ontario Ministry of Transportation

Another noise prediction model is the Traffic Noise Model of Ontario Ministry of Transportation, which was developed by Ontario Ministry of Transportation, Canada. The model assumes point sources travelling at constant speed. The accuracy of the method was found to depend on the distance of the receiver from the source, and also on vehicular composition [11].

Traffic noise prediction models are required as aids in the design of roads and sometimes in the assessment of existing or of envisaged changes in traffic noise conditions. They are commonly needed to predict sound pressure levels, specified in terms of LAeq and L10. Since the accuracies of several prediction models were similar, the decision of which model to use was based on additional considerations such as their analytical qualities, flexibility, and expected enhancement. The prediction model analysed use only the basic customary variables of highway noise prediction, distance from observer to source, traffic volume and composition, and average speed of traffic flow [11].

1.2 Calculation of Road Traffic Noise (CRTN)

Many traffic noise prediction models have been designed for traffic noise assessment in different countries. In the calculation of Road Traffic Noise (CRTN), all the levels are expressed in terms of the A-weighted sound level exceeded for 10% of the time, that is the hourly L10 index. This is often used to give an indication of the upper limit of fluctuating noise. United Kingdom, Australia, New Zealand, and Hong Kong use the CRTN model. In Hong Kong and United Kingdom, CRTN model is the only tool for the assessment of the environmental impact of road traffic by their local authorities. Many researches have been carried out to study the validity of traffic noise prediction by applying the CRTN model.

The calculation of the CRTN model used in this study assumes typical traffic and noise propagation conditions that are consistent with moderately adverse wind velocities and directions during the specified periods. The algorithm is as follow:

$$L_{A10,1h} = L_0 + \Delta f + \Delta g + \Delta p + \Delta d + \Delta a + \Delta r \quad \text{(Equation 1)}$$

At a reception point with a reference distance of 10 m away from the nearside carriageway edge, the basic hourly noise level can be calculated by

$$L_0 = 42.2 + 10\log_{10} q \quad \text{(Equation 2)}$$

Where q is the hourly traffic volume of all heavy and light vehicles and L_0 is the hourly noise level.

The adjustment for actual mean traffic speed of the percentage of heavy vehicles Δ_f can be applied by

$$\Delta_f = 33\log_{10}\left(V + 40 + \frac{500}{V}\right) + 10\log_{10}\left(1 + \frac{5P}{V}\right) - 68.8 \qquad \text{(Equation 3)}$$

Where V is the average traffic speed and P is the percentage of heavy vehicles, which calculated using equation 4 below:

$$P = \frac{100f}{q} \qquad \text{(Equation 4)}$$

where f is the flow of heavy vehicles for every hour. The adjustment of basic noise level for road gradient Δ_g is given by

$$\Delta_g = 0.3G \qquad \text{(Equation 5)}$$

The pavement type adjustment (road surface correction), Δ_p = -1 dB(A) for impervious bituminous and concrete road surfaces, when the traffic speed (V) is less than 75 km/h.

Other corrections to the basic noise level need to be taken into consideration are the effects of distance from the source line, and reflections from facades and building. The distance correction, Δ_d can be calculated by

$$\Delta_d = -10\log_{10}\left(\frac{d'}{13.5}\right) \qquad \text{(Equation 6)}$$

Where d' is the minimum incline distance from the source point provided by d'= $\sqrt{(d+3.5)^2 + h^2}$, where d is the minimal horizontal distance between the nearside highway edge and the receiver point, and h is the vertical distance between the source point and the receiver point. The assumption made for the shortest horizontal distance, d is more or equal to 4 m.

The angle of view adjustment, Δ_a is as follow:

$$\Delta_a = 10\log_{10}\left(\frac{\theta}{180}\right) dB(A) \qquad \text{(Equation 7)}$$

θ is the angle view in degrees.
In the CRTN method, the reflection correction, Δ_r is calculated by

$$\Delta_r = 2.5 + 1.5\left(\frac{\theta'}{\theta}\right) \qquad \text{(Equation 8)}$$

Where, 2.5 dB(A) is the correction taken into account for the reflection of noise from the adjacent facade to the receiver point. 1.5 dB(A) represents the correction for reflection from opposite facade facing the receiver point. θ' is the sum of the angles subtended by all the facades facing the receiver point located on the opposite side of the road, and θ is the total angle of view at the receiver point.

Noise pollution is by now recognized worldwide as a major problem for the quality of life in urban areas [12]. The rapid industrialization, commercialization, and urbanization witnessed by many developing countries in recent years have given rise to the steady increase in the environmental noise climate. The environmental noise climate is influenced drastically by road traffic noise because that type of noise produces a continuous sound which fluctuates from hour to hour in irregular trend with the passage of individual vehicles. Thus, road traffic noise has become a fundamental issue of immediate for both the public and policy-makers.

Road traffic noise from especially highways increases due to many factors including noise generated from a vehicle's engine, exhaust, contact between the tires and road surface and inter- action between moving vehicles and air that pass through, road condition and traffic management, vehicle speed, and traffic composition [13-16]. Nulty [17] reviewed that the impact of traffic noise is because of a trend of enhancing the noise output from noise-emitting machines by suitably adjust- ing the vehicle's silencer. A study conducted in South Eastern Nigeria [18] and in Kolkata, India revealed that sirens and horns are caused to the high environmental noise climate in these cities. A recent study carried out by [19] stated that the distance between source and receiver of the noise influence the noise level in studying areas. However, although much research has found that noise level increase are influenced by driver behaviour and source-receiver distance, little attention has been paid to the relationship between noise level and total number of vehicles on the road. Thus, this study was conducted to reveal the relationship between number of vehicles on the road and noise level at two different types of highways which the first one used by more than 500 vehicles for every 15 min representing heavy traffic flow highway while the second one used by less than 500 vehicles for the same measurement period representing low traffic flow highway. Measurement was carried out during peak hour (0700 to 0900) and off peak hour (2300 to 0100). Due to the lack of studies concerning the effects of a number of vehicles on noise levels in Malaysia, this study aimed to evaluate and analyse the relationship between number of vehicles and noise level considering Malaysia scenario and traffic pattern.

2. MATERIALS AND METHOD

The highways involved in this study were Sungai Besi Highway, DUKE Highway, and KESAS Highway. Noise level in 'A' weighting network was measured using the Sound Level Meter (SLM) which complies with the International Electrotechnical Commissioning (IEC) 61672 Class 1 standard. The SLM used was Blue Solo 01 model that has been manufactured by 01dB-Metravib. The noise measurements at Sungai Besi Highway, DUKE Highway, and KESAS Highway were carried out for five days with two hours of monitoring during peak time (0700 to 0900, 1200 to 1400 and 1700 to 1900) as well as off peak time (2300 to 0100). These measurements were conducted at each sampling location with three sets of measurements. The data of number of vehicles and the composition of traffic were recorded for every 15 minutes. The meter was held at 1.5 meter above the ground surface on the highway shoulder at a distance of 3 m from the pavement edge. All noise monitoring experiments were carried out under ideal meteorological condition with relative humidity, temperature and wind speed of sites varied from 76% to 93%, 25.3 to 43°C and 0 to 0.7 m/s. In addition, sound measurements should not be made outdoors when the following meteorological conditions exist: wind speed excess of 12 to 15 km/h; temperature range -10°C to 50°C, humidity exceeds 95%.

2.1 Traffic noise prediction model

Two traffic noise models used in this study are the L10 Calculation of Road Traffic Noise (CRTN) model and Traffic Noise Model of Ontario Ministry of Transportation.

2.1.1 CRTN

The calculation of the CRTN model used in this study assumes typical traffic and noise propagation conditions that are consistent with moderately adverse wind velocities and directions during the specified periods [9]. The algorithm is as follow:

$$L_{A10,1h} = L_0 + \Delta f + \Delta g + \Delta p + \Delta d + \Delta a + \Delta r \qquad \text{(Equation 9)}$$

At a reception point with a reference distance of 10 m away from the nearside carriageway edge, the basic hourly noise level can be calculated by

$$L_0 = 42.2 + 10\log_{10} q \qquad \text{(Equation 10)}$$

Where q is the hourly traffic volume of all heavy and light vehicles and L0 is the hourly noise level.

The adjustment for actual mean traffic speed of the percentage of heavy vehicles Δ_f can be applied by

$$\Delta_f = 33\log_{10}\left(V + 40 + \frac{500}{V}\right) + 10\log\left(1 + \frac{5P}{V}\right) - 68.8 \qquad \text{(Equation 11)}$$

Where V is the average traffic speed and P is the percentage of heavy vehicles, which calculated using equation 12 below:

$$P = \frac{100f}{q} \qquad \text{(Equation 12)}$$

Where f is the hourly flow of heavy vehicles.
The adjustment of basic noise level for road gradient Δ_G is given by

$$\Delta_G = 0.3G \qquad \text{(Equation 13)}$$

In this study, the gradient is assumed to be zero percent for all highways.
The pavement type adjustment (road surface correction), Δ_p=-1 dB(A) for impervious bituminous and concrete road surfaces, when the traffic speed (V) is less than 75 km/h.

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Δ_d Other corrections to the basic noise level need to be taken into consideration are the effects of distance from the source line, and reflections from facades and building. The distance correction, can be calculated by

$$\Delta_d = -10 \log_{10}\left(\frac{d'}{13.5}\right) \qquad \text{(Equation 14)}$$

Where d' is the minimum incline distance from the source point provided by d'= $\sqrt{(d + 3.5)^2 + h^2}$, where d is the minimal horizontal distance between the nearside highway edge and the receiver point, and h is the vertical distance between the source point and the receiver point. The assumption made for the shortest horizontal distance, d is more or equal to 4 m. Therefore, in this study, the prediction model used d = 5 m representing the nearest measured point in the study.

The angle of view adjustment, Δ_a is as follow:

$$\Delta_a = 10 log_{10}\left(\frac{\theta}{180}\right) dB(A) \qquad \text{(Equation 15)}$$

θ is the angle view in degrees? In this study, the angle taken into account is 180^0, since the angle between the source and receiver is perpendicular to each other.

In the CRTN method, the reflection correction, Δ_r is calculated by

$$\Delta_r = 2.5 + 1.5\left(\frac{\theta'}{\theta}\right) \qquad \text{(Equation 16)}$$

Where, 2.5 dB(A) is the correction taken into account for the reflection of noise from the adjacent facade to the receiver point. 1.5 dB(A) represents the correction for reflection from opposite facade facing the receiver point. θ' is the sum of the angles subtended by all the facades facing the receiver point located on the opposite side of the road, and θ is the total angle of view at the receiver point.

Simultaneous measurement of traffic noise and traffic characteristics including traffic composition, traffic volume, and speed of vehicles on the road were carried out for the prediction purposes. In the CRTN model, traffic compositionis generally divided into light vehicles (<1525 kg unladen weight) and heavy vehicles (>1525kg unladen weight).

2.1.2 The Traffic Noise Model of Ontario Ministry of Transportation

The Traffic Noise Model of Ontario Ministry of Transportation analyzed use only the basic customary variables of highway noise prediction, distance from observer to source, traffic volume and composition, and average speed of traffic flow [9]. The empirical equation is given by:

$$L_{eq} = 21.5 + 11.1 \log_{10}(V_C + 10\, V_{MT} + 15\, V_{HT}) - 15.4 \log D + 15 \log C$$

Where L_{eq} = energy equivalent sound level, dB(A)
V_C = volume of cars, vehicle per hour
V_{MT} = volume of medium trucks, vehicle per hour
V_{HT} = volume of heavy trucks, vehicle per hour
D = equivalent distance, m
C = average operating speed of traffic flow in 1 hour, km/h

The multiplication factors of 10 and 15 for medium and heavy trucks, respectively, were obtained by substituting trial factors into the equation and selecting the factors which resulted in the smallest standard deviation of differences between predicted and measured sound levels. Originally, the model uses only two fixed vehicle classes, namely cars and trucks, and tends to predict well only for average traffic conditions and for typical highway facilities. In order to determine the potential accuracy attainable, these variables are employed and an empirical prediction equation (Equation 17) was constructed and calibrated to fit the survey data.

In order to further improve the empirical model leading to the implication in the prediction of the traffic noise level in Malaysia, the motorcycle composition (Vm) was included as the additional variable into the empirical equation. Therefore, the improved formula is as follows:

$$L_{eq} = 21.5 + 11.1 \log_{10}(2\, V_m + V_C + 10\, V_{MT} + 15\, V_{HT}) - 15.4 \log D + 15 \log C \qquad \text{(Equation 18)}$$

3. RESULTS AND DISCUSSION

3.1 Calculation of Road Traffic Noise (CRTN)

The comparison of on-site measured L10 and predicted CRTN L_{10} is shown in Table 1.

Table 1: Measured and Predicted L_{10} using CRTN at studied sites.

Site		Measurement Period	L_{10} measured	L_{10} CRTN predicted
Sungai Besi Highway	weekdays	Morning	75.5	78.4
		Afternoon	76.2	79.1
		Evening	75.9	79.2
		Night	74.8	77.4
	Weekends	Morning	76.7	79.3
		Afternoon	75.5	79.4
		Evening	75.6	80.0
		Night	75.0	77.9
DUKE Highway	weekdays	Morning	74.0	74.1
		Afternoon	71.1	75.3
		Evening	72.4	78.8
		Night	68.8	72.3
	Weekends	Morning	71.5	72.4
		Afternoon	72.7	76.2
		Evening	71.8	76.0
		Night	69.8	73.5
KESAS Highway	weekdays	Morning	75.8	80.2
		Afternoon	74.7	79.3
		Evening	75.0	80.1
		Night	71.9	75.8
	Weekends	Morning	74.8	77.9
		Afternoon	74.7	78.8
		Evening	74.4	79.8
		Night	73.4	76.5

This study examined the reliability and suitability of the CRTN model in predicting traffic noise in a city with high percentage of motorcycle use. 72 on-site measurements with different measurement time were conducted at roadsides in Klang Valley, Malaysia with around 30% of licensed motor vehicles is motorcycles. Comparison between traffic noise measurements and CRTN predictions was made for the validation of CRTN model as shown in Table 1. The difference between the measured and predicted traffic noise levels at 6 sites was less than 7 dB(A). The highest overestimation was 6.3 dB(A) at DUKE highway in the evening during weekdays. The average of overestimation of CRTN model on the traffic noise level was 3.6 dB(A). Figure 1 illustrates the scatter plot between the measured and predicted results of traffic noise.

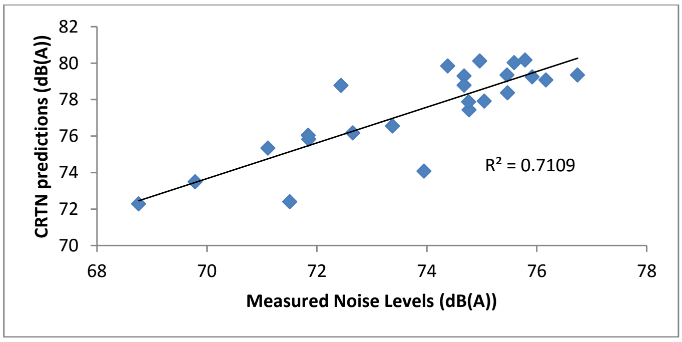

Figure 1: Predicted noise levels against measured values at 72 measurements period in 3 sites of Sungai Besi, DUKE, and KESAS Highway.

Using the regression analysis, it was found that the predicted traffic noise levels by the CRTN model gave satisfactory correlation with the measured values (R^2 of 0.7109). Generally, this study implies that CRTN model is a valid model in predicting traffic noise levels for a city with high rates of motorcycle use such Klang Valley, Malaysia.

Different performances of the CRTN model were found while under different conditions [10]. Study in Australia revealed that the average overestimation by the CRTN model obtained for free field conditions was 0.7 dB(A), while 1.7 dB(A) of overestimation was computed in front of facades [20]. However, a study in Hong Kong showed that the increment of error when adopting the CRTN model might occur by more than 10 dB(A), especially when there were buildings on both sides of a road [21]. Another study in Hong Kong by [22] discovered an overestimation of 2 to 6 dB(A) produced by the CRTN model. On the other hand, [23-24] studies in Hong Kong showed that the CRTN model accuracy is at the satisfactory level and the correlation between predicted and measured results of the CRTN model produces an R2 of 0.7742 to 0.9331 and a mean difference of +0.4 dB(A) to + 2.0dB(A). The model is useful since motorcycles occupy more than half of the traffic composition in many Asian urban areas such as Taiwan, India, Vietnam, Thailand, and Macau [25-26]. Their results indicate that around 80% of traffic noise levels at the roadsides investigated in the studies exceed the L10 benchmark of 70 dB(A). These results clearly show that the countries are experiencing a serious situation of severe traffic noise pollution.

3.2 The Traffic Noise Model of Ontario Ministry of Transportation

The validation of The Traffic Noise Model of Ontario Ministry of Transportation model was carried out by comparing the on-site traffic noise measurements with the corresponding results of The Traffic Noise Model of Ontario Ministry of Transportation predictions. Table 2 shows the measured and predicted traffic noise level at studied sites during weekdays and weekends.

Table 2: Measured and predicted traffic noise level using The Traffic Noise Model of Ontario Ministry of Transportation model

Site		Measurement period	Mic Location (m)	Measured	Predicted
SungaiBesi Highway	weekdays	Morning	5	74.1	76.9
		Morning	10	73.7	72.3
			15	73.5	69.6
		Afternoon	5	74.9	82.0
			10	75.2	77.4
			15	75	74.7
		Evening	5	74.5	81.3
			10	74.8	76.6
			15	74.3	73.9
		Night	5	73.1	78.1
			10	73.5	73.5
			15	73.2	70.8
	weekends	Morning	5	73.9	80.3
			10	73.2	75.7
			15	73	73.0
		Afternoon	5	74.1	80.5
			10	74.6	75.9
			15	74.3	73.1
		Evening	5	74.4	81.2
			10	72.7	76.6
			15	71.1	73.9
		Night	5	73.5	78.7
			10	73.3	74.0
			15	73.1	71.3
DUKE Highway	weekdays	Morning	5	72.2	75.8
			10	67.8	71.2
			15	66.6	68.5
		Afternoon	5	68.3	77.1
			10	65.1	72.5
			15	64.3	69.8
		Evening	5	70.1	80.5
			10	67.5	75.9
			15	66.7	73.2
		Night	5	65.1	74.0
			10	61.6	69.4
			15	60.5	66.7
	weekends	Morning	5	68.7	74.6
			10	66.6	70.0
			15	64.4	67.2
		Afternoon	5	70.4	78.6
			10	68.4	74.0
			15	66.6	71.2
		Evening	5	69.3	77.9
			10	66.3	73.3
			15	65.7	70.6
		Night	5	66.4	74.9
			10	63.3	70.2
			15	62.8	67.5
KESAS Highway	weekdays	Morning	5	74.2	81.7
			10	70.1	77.0
			15	69.4	74.3
		Afternoon	5	72.7	82.1
			10	70.4	77.4
			15	69.2	74.7
		Evening	5	73.4	82.2
			10	71.5	77.5
			15	68.9	74.8
		Night	5	68.8	74.4
			10	67.5	69.7
	weekends		15	64.7	67.0
		Morning	5	72.5	79.8
			10	71.6	75.2
			15	70.6	72.5
		Afternoon	5	73	81.2
			10	70.5	76.6
			15	69.2	73.8
		Evening	5	72.7	81.1
			10	71.6	76.5
			15	69.4	73.8
		Night	5	70.9	76.7
			10	70.3	72.1
			15	68.9	69.4

In Table 2, the deviation between the measured and predicted traffic noise level at the study sites with different microphone locations ranged between 0.006 to 7.355 dB(A). The maximum noise level predicted was an overestimation, which was 80.5 dB(A) at 5m microphone location of DUKE Highway during evening on weekdays. The Traffic Noise Model Of Ontario Ministry Of Transportation overestimated traffic noise level by 3.46 dB(A) on average. Deviations of more than 0.4 dB(A) were found at 79% of 5 m, 37.5% of 10 m and 12.5% of 15 m microphone locations, respectively. The average standard deviation for Sungai Besi Highway, DUKE Highway, and KESAS Highway were 2.16 dB(A), 4.41 dB(A), and 3.82 dB(A), respectively.

This study proves that the improved Ontario Ministry of Transportation Traffic Noise model is satisfactory in predicting traffic noise in a city with high percentage of motorcycle usage. Three on-site measurements were conducted at highway sides in Klang which represented traffic characteristics with 20% to 30% of licensed motor vehicles being motorcycles. Therefore, an improved traffic noise model is needed to consider not only automobiles (passenger cars) and trucks as heavy vehicles but also motorcycles as a significant and distinctive category since Malaysia like many other cities in developing countries motorcycles occupy high percentage of the traffic on the roads [26-28]. Nevertheless, much needed improvement on the accuracy of The Traffic Noise Model of Ontario Ministry of Transportation model for countries that have high frequency of usage of motorcycle is required in the near future with the inclusion of the consideration of the effects of the percentage of motorcycles in light vehicles.

4. CONCLUSIONS

This study examined the reliability and suitability of the CRTN model and The Traffic Noise Model of Ontario Ministry of Transportation model in predicting traffic noise in a city with high percentage of motorcycle use. 72 on-site measurements with different measurement time were conducted at roadsides in Klang Valley, Malaysia with around 30% of licensed motor vehicles is motorcycles. Comparisons between traffic noise measurements and traffic characteristics measurements with the model's predictions were made for the validation of each model. Using the regression analysis, it was found that the predicted traffic noise levels by the CRTN model gave satisfactory correlation with the measured values (R2 of 0.7109). Generally, this study implies that CRTN model is a valid model in predicting traffic noise levels for a city with high rates of motorcycle use such Klang Valley, Malaysia.

The validation of The Traffic Noise Model of Ontario Ministry of Transportation model was carried out by comparing the on-site traffic noise measurements with the corresponding results of The Traffic Noise Model of Ontario Ministry of Transportation predictions. This study proves that the improved Ontario Ministry of Transportation Traffic Noise model is satisfactory in predicting traffic noise in a city with high percentage of motorcycle usage.

Nevertheless, much needed improvement on the accuracy of a traffic noise prediction model for countries that have high frequency of usage of motorcycle is required in the near future with the inclusion of the consideration of the effects of the percentage of motorcycles, since in Malaysia, like many other cities in developing countries, the motorcycles occupy high percentage of the traffic on the roads.

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