Road Traffic Noise for Asphalt and Concrete Pavement

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Abstract. Traffic noise has been recognized as the greatest source of noise pollution. This paper aims to assess roadside noise levels on asphalt and concrete pavements and evaluate the suitability of the existing traffic noise prediction models. Stretches with asphalt and concrete pavements on Skudai-Pontian Highway was selected to observe traffic noise during peak and off-peak periods together with observation of traffic flow characteristic. The finding showed that observed traffic noise falls in the range of 79 and 89 dBA with most of the higher noise found during the peak period for asphalt pavement and off-peak period for concrete pavement. A comparison of observed noise with 5 traffic noise models found that the Penang noise model pattern is almost close to the observed noise. Regression analysis was performed to develop a traffic noise model in order to predict noise generated by different types of pavements in different traffic conditions. All traffic noise models were found to be competent to predict the present traffic noise. Thus, it can be concluded that the pattern for traffic noise for different types of pavements is not similar under different traffic conditions and a new traffic noise model for a specific condition is needed for the better prediction of traffic noise.

1. Introduction

Environmental noise, defined as the unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity. Nowadays, environmental noise has become a worldwide problem [1] and road traffic noise (RTN) has been recorded to be the major contributor to the overall environmental noise [2]. Many previous RTN-related studies [3-6], [7] addressed that the sources of noise are generated by engine/drive train noise, exhaust noise, tyre/pavement interaction noise and aerodynamic noise (interaction between moving vehicles and the air that passes through). The parameters such as road condition and traffic management, vehicle speed, and traffic volume and composition also influenced RTN [8].

In urban areas, the engine and the exhaust system of automobiles, light trucks, buses, and motorcycles are an important source of noise and constitute a major environmental impact [9]. Davis and Cornwell [10] reported that for most automobiles running below 55 km/h, exhaust noise constitutes the main source of noise pollution. Some studies have demonstrated that tyre and pavement interface noise is the sub-source of dominant noise at speeds above 48 km/hr [11-12]. Tyre-pavement interaction noise dominates for passenger vehicles with a speed of above 40 km/h and for trucks with a speed of 70 km/h [13]. Many low noise pavement materials such as rubberized asphalt, rubber with porous concrete,
asphalt overlay, etc., have been suggested for reducing noise developed due to tyre and road friction [14-15]. A major factor that induces tyre and pavement interface noise in varied types of pavements is roughness [16]. Besides, surface texture and bulk properties govern the contribution of road surfaces to tyre-road noise [12, 17-18]. The aerodynamic noise depends on the vehicle's geometry and its speed and is generated due to aerodynamic friction and turbulence caused by the vehicles moving at higher speeds [19].

Traffic noise prediction models are commonly needed to predict sound pressure levels set by government authorities [20] and to facilitate planning for new roads or account for changes in traffic noise conditions [7]. Prediction of the RTN for a busy road or highway when used in design and planning ultimately results in the creation of a healthy and noise-free traffic environment [21-22]. Even though a number of noise prediction models [20], [23-24] have been developed for environmental estimation of traffic noise levels in terms of vehicle and pavement types, the present study is interested in assessing roadside noise levels on existing roadways involving asphalt and concrete pavements and evaluating the suitability of the existing traffic noise prediction models. This paper is organized as follows: section 2 describes traffic noise prediction models; section 3 explains materials and methods; and, section 4 presents results and discussion. The last section describes the conclusion of this research.

2. Traffic noise prediction models
Numerous traffic noise prediction models have been developed since the 1950s. One of the principal models, created in 1952, is the one revealed in the Handbook of Acoustic Noise Control [25-26]. This model expresses that 50 percentile of traffic noise for speed of 35-45 mph (around 55-75 km/h) and separations more noteworthy than 20 feet (around 6 meters) is given by equation (1):

\[ L_{50} = 68 + 8.5 \log Q - 20 \log d \]  

where \( Q \) is traffic volume in vehicles per hour and \( d \) is the separation from the perception point to focal point of the traffic path in feet.

The models created in the following years presented the proportionate level \( L_{eq} \) as the noise level marker. A standout amongst the most utilized ones is the Burgess model [20] [26] connected without precedent for Sydney in Australia. Utilizing similar documentation of the past articulation, the sound level is given by equation (2):

\[ L_{eq} = 55.5 + 10.2 \log Q + 0.3P - 19.3 \log d \]  

where \( Q \), \( P \), and \( d \), are traffic flow, percentage of heavy vehicles, and distance from centre of road (m), respectively.

Another most utilized calculation formula is called "Griffiths and Langdon Method" [27]. Specifically, they propose the assessment of proportional level beginning from the percentile level as in equation (3):

\[ L_{eq} = L_{50} + 0.018 (L_{10} - L_{90})^2 \]  

where the statistical percentile indicator has the expressions show in equation (4), (5) and (6):

\[ L_{10} = 60 + 8.4 \log (Q) + 0.15P - 11.5 \log (d) \]  

\[ L_{50} = 44.8 + 10.8 \log (Q) + 0.12P - 9.6 \log (d) \]  

\[ L_{90} = 39.1 + 10.5 \log (Q) + 0.06P - 9.3 \log (d) \]  

where \( Q \), \( P \), and \( d \) have the same meaning as in the previous formula.

Another model was created by the French "Focus Scientifique et Technique du Batiment" (C.S.T.B.), which proposed a prescient formula of proportionate emanation level [28] in view of the normal acoustic level (\( L_{50} \)) with the accompanying articulation as shown in equation (7):

\[ Leq = 0.65 L_{50} + 28.8 \text{ [dBA]} \]
The value of \( L_{50} \) is calculated taking into account only the equivalent vehicular flows (\( Q_{eq} \)), and is given by equation (8):

\[
L_{50} = 11.9 \log(Q) + 31.4
\]  

(8)

One additional model was put forward by Cyril and Koshy [29]. They proposed a traffic noise model cultivated by means of regression analysis. The model they found is as in equation (9):

\[
L_{Aeq} = 22.255 + 1.418 * S + 0.060 * T + 0.046 * V + 0.032 * H
\]  

(9)

where \( S \) is the average speed of the vehicles in km/h, \( T \) is the percentage of three-wheelers, \( H \) is the percentage of heavy vehicles, and \( V \) is the traffic volume (PCU/min).

In 2015, Rassafi and Ghasempour [30] proposed a traffic noise model on the basis of traffic volume and speed, and average noise level which is being shown in the equation (10) as below:

\[
L_{eq} = 0.001 * Volume + 0.094 * Speed + 1.022 * L
\]  

(10)

where \( L \) is the average noise level in dB.

Yap and Sulaiman [31] developed a traffic noise model for Expressway traffic noise in Penang, Malaysia, which used the number of heavy vehicles as a variable to predict noise emission. Their model was found to be working with efficacy in the Malaysian scenario. Validation of the model was performed by a scattered plot between predicted and measured noise levels and the \( R^2 \) value obtained was 0.7624, which shows that the noise model was workable for almost all of Malaysia. The noise model developed by them, called the Penang Noise Model, has been shown in the equation (11) below:

\[
L_{eq} = 81.4 + 0.00706N_{HV} + 0.000054N_{LV} + 0.00485N_B
\]  

(11)

where \( N_{HV} \) is the number of heavy vehicles, \( N_{LV} \) is the number of light vehicles, and \( N_B \) is the number of buses. They reported that 70% of total noise comes from vehicles, so it can be said that traffic noise is the greatest contributor to overall noise pollution. They also applied NAISS (model for traffic noise prediction) and Burgess models in the Malaysia traffic noise scenario and found that the NAISS model was the best fit to predict the noise emitted [31].

3. Materials and methods

A flat two-lane dual carriageway road stretch with different pavement types in Skudai-Pontian Highway route 5 was selected. The posted speed limit is 70 km/h. The pavement types chosen were asphalt and concrete, as shown in figure 1. Asphalt pavement is widely used in Malaysia and only a selected section of asphalt pavement was replaced by concrete pavement due to cost restriction. The method used to acquire the roadside traffic noise was the statistical pass-by method (SPB) described in ISO 11819-1: 2001: “Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method”. For the acquisition of the noise generated by the traffic, a sound level meter (SLM) was positioned on a tripod at a distance of 7.5 m away from the middle nearest travel lane, 1.5 m from the ground level, and 3.5 m away from any obstacles according to BSI [32] and the Department of Environment [33]. Traffic flow characteristics i.e., volume, speed, headway, and types of vehicle was measured using a video camera at two specified roadside locations representing asphalt pavement and concrete pavement together with the measurement of traffic noise. The arrangement of the SLM and video camera is shown in figure 2. The distance between SLM and video camera was 1 m. For measuring the speed and headway of vehicles, two cones were put having a distance of 2 m between them and the camera was set up to record the video in between these two cones. Types of vehicles observed were classified into six categories: (i) cars and taxis, (ii) small vans and utilities, (iii) moderate size lorries and large vans, (iv) trucks (\( \geq 3 \) axles), (iv) buses, and (v) motorcycles. Measurements were carried out for three days during weekdays (Monday, Tuesday and Wednesday), with the peak period from 5:00 to 6:00 pm and the off-peak period from 10:00 to 11:00 am.
4. Results and discussion
The percentage of each type of vehicle in traffic flow for different pavement types during peak and off-peak periods is shown in figure 3, while the comparison of average traffic noise level based on volume for a 1-hour period is presented in figure 4. Traffic noise pattern in the same period presented in Figure 5 shows the fluctuation of traffic noise level for both asphalt and concrete pavements under peak and off-peak periods. It is noticeable that asphalt pavement in peak periods has a higher noise level than the off-peak period due to high traffic volume. This result is consistent with results obtained in previous studies by Nataraja et al. [34], and Halim and Abdullah [35]. However, at some points in the observation period, off-peak noise level exceeds peak noise level. This may be the effect of greater speed of the vehicle in the off-peak period which considerably affects traffic noise level. On the other hand, for concrete pavement, the result is the reverse; the traffic noise is higher during the off-peak period as compared with the peak period. A high level of noise during the off-peak period may come from the 3% of trucks and 1% of buses driving on the concrete pavement.

Figure 1. Selected road stretch.

Figure 2. Measurement condition.

Figure 3. Observed traffic composition.
Figure 4. Comparison of observed traffic noise and volume.

Figure 5. Observed traffic noise pattern.

Figure 6 shows the result of the average noise level observed in 5 minutes interval during peak and off-peak periods. Five traffic noise prediction models, viz. Burgess model, Griffith-Langdon model, CSTB model, Rassafi and Ghassempour model, and Penang noise model (as discussed in Section 2), were selected to evaluate whether they can be used to predict traffic noise on selected pavement type during peak and off-peak periods. In order to apply these models, the recorded information related to traffic volume, composition of vehicles, speed, and noise level (dBA) were analysed and the results were presented in figure 6.

Overall, among the five models used in the study for traffic noise prediction, the Rassafi and Ghassempour model shows the highest LAeq prediction value followed by the Penang noise model, CSTB model, and Griffith-Langdon model. The lowest LAeq prediction value was presented by the Burgess model, and the range between the highest and lowest prediction values is around 40 dBA. Assessment of traffic noise at different pavement types and comparison of the different models shows that the Penang noise model is more suitable for both pavement types under peak and off-peak periods because the predicted traffic noise values fluctuate around observed noise values. Predicted traffic noise value using the Penang noise model, however, follows an almost similar trend for asphalt pavement during the off-peak period (Figure 6 (b)) and concrete pavement during the peak period (figure 6 (c)). Even though the Penang noise model is more preferable to other models, there is still a need to develop a new model for asphalt and concrete pavements for specific traffic flow conditions using multi-linear regression analysis.

The fundamental equation for the development of traffic noise model using regression analysis is as in equation (12):

\[ y = x_0 + m_1 x_1 + m_2 x_2 + \cdots + m_n x_n \]  

(12)

Mathematical models for the prediction of traffic noise usually extract the functional relationship between noise level and measurable traffic and road parameters. After evaluating possible parameters related to traffic and road, the chosen parameters in this model are percentage of heavy vehicles, traffic speed, and time headway. The models were developed using the SPSS package and presented as in equation (13), (14), (15) and (16):
Asphalt pavement (Peak Period):

\[ L_{Aeq} = 78.525 + 0.185S - 0.872H - 0.210H_v; \quad R^2 = 0.89 \]  

(13)

Asphalt pavement (Off-Peak Period):

\[ L_{Aeq} = 79.208 + 0.198S - 1.026H - 0.337H_v; \quad R^2 = 0.87 \]  

(14)

Concrete pavement (Peak Period):

\[ L_{Aeq} = 74.444 + 0.291S - 1.150H - 0.193H_v; \quad R^2 = 0.98 \]  

(15)

Concrete: Off-Peak Period:

\[ L_{Aeq} = 77.761 + 0.183S - 0.914H - 0.045H_v; \quad R^2 = 0.80 \]  

(16)

where \( S \) is speed in km/h, \( H \) is headway in seconds, and \( H_v \) is heavy vehicles in percent.

Based on \( R^2 \) for the above equations, a strong relationship was found between noise level and selected parameters. The developed model was then validated by comparing observed \( L_{Aeq} \) and predicted \( L_{Aeq} \) values using linear regression model 45-degree plot. Figure 7 shows the scatter plots of the observed and predicted \( L_{Aeq} \) values. As illustrated in this figure, \( R^2 \) shows a value of more than 0.8 except for validation of asphalt pavement during the off-peak period. All values, however, are acceptable and trustworthy, as any value of \( R^2 \) above 0.70 is considered to be good and fit \cite{31}. This assures that the established traffic noise models for this study are capable of predicting the noise precisely on the selected pavement types and time.

5. Conclusion

This study assessed the road traffic noise level on two different pavement types of Skudai-Pontian Highway route 5 located in Johor. The observed noise was found to fluctuate between 79 and 89 dBA, and the comparison with 5 traffic noise prediction models showed all models do not suit the observed noise, except the Penang noise model. The specific model for each type of pavement during peak and off-peak periods were also developed and it was found able to be useful for predicting traffic noise for specific conditions. Therefore, it can be concluded that the pavement type and traffic condition would influence the traffic noise, and subsequently, the development of a specific traffic noise model for each pavement and traffic condition will facilitate the planning for future changes in traffic noise conditions.
Figure 6. Observed noise $L_{Aeq}$ and predicted noise $L_{Aeq}$ using traffic noise models.
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