Development of an individual vehicle noise model

Frits Kamst, Griffith University/ASK Consulting Engineers
Griffith University/ASK Consulting Engineers

Abstract

An individual vehicle noise model (IVNM) able to predict a time history of noise levels due to passing vehicles at locations alongside a road has been developed. Resultant vehicle noise levels for the various vehicle types are derived from the TNM model. The model has been developed to assist research into sleep disturbance due to road traffic noise. The output of the model allows one to investigate the noise parameters which are important with respect to sleep disturbance and determine whether these parameters are correlated with commonly used noise parameters such as L_{eq} and L_{10}.

Introduction

There are a number of commercial road traffic noise models on the market. These models tend to predict average noise levels over a period of hours, such as the L_{10}(18 hour), the L_{10}(1 hour), the daytime L_{eq}(15 hour), or the night-time L_{eq}(9 hour).

In other words these models predict one averaged noise level. These noise levels appear to correlate well with human responses such as annoyance.

The literature (eg [1], [2]) also makes it clear that human responses such as sleep disturbance do not appear to correlate well with average noise levels. The noise parameters which appear to correlate well with sleep disturbance are (i) the maximum noise level, Lmax, of a noise event (in this case a vehicle by-pass), (ii) the emergence of the Lmax above the ambient noise level and (iii) the number of noise events per night (eg [3]).

It is evident from the above that existing annoyance based noise models are not necessarily capable of dealing with sleep disturbance effects due to road traffic noise.

To deal with the parameters which are important with respect to sleep disturbance the noise model needs to be able to track the location of individual vehicles on a road in the vicinity of a receptor location.

This means that the resultant noise level at a location due to vehicles on a road needs to be able to be calculated so that a time history or "trace" of noise levels is obtained. A time history of noise levels will allow a time series analysis enabling quantification of the maximum noise levels due to individual vehicle by-passes, the ambient noise level (however defined), as well as the number of noise events. Of course the model would also enable the calculation of any desired noise parameter or statistic.

The model described in this paper is based on the NOYSIM model developed [4].

Input Parameters

The following input parameters are required by the model:

(i) roadway geometry (in this paper only a straight road with parallel lanes have been considered);
(ii) vehicle spacing;
(iii) vehicle categories;
(iv) vehicle noise emission levels;
(v) propagation of noise from source to receiver.

Items (i) and (ii) can be determined independent of the actual noise model used. The remaining items depend to some extent on the noise model used.

Individual Vehicle Noise Model Considerations

There is a choice in the approach of how to obtain a suitable individual vehicle noise model (IVNM) able to be used to obtain time a history of noise levels. The first choice, that of using an existing noise model, is, as discussed above, not available.

This limits the options to modifying an existing noise model or developing a new model from scratch.

It was decided that the former option, ie modifying an existing noise model, was the preferred way ahead.

Only one noise model seemed to fall into the category of being able to be modified to obtain the desired outcome and that is the TNM (Traffic Noise Model) noise model, developed by the Federal Highway Administration (FHWA) in the USA.

TNM uses 5 vehicle types (cars, buses, motorcycles, medium trucks (2 axles and 6 tyres) and heavy trucks (3 or more axles and 6 or more tyres). The effective noise source heights are 0 m and 1.5 m for all vehicles except heavy trucks, which have emission heights of 0 m and 3.66 m.

The advantages of the TNM model are that the noise emissions for each of these vehicle types are obtained from a large data base [9]. The noise level emissions represent the averages of the measured noise levels. The model in effect assumes that each vehicle within each vehicle type has the same noise level emissions.

The noise level emission data are in terms of 1/3 octave bands in the range 50 Hz to 10 kHz for vehicle speeds ranging from 5 km/hr to 130 km/hr for both cruise and full throttle settings for a number of road surfaces (Portland Cement Concrete, Dense Graded Asphaltic Concrete, Open Graded Asphaltic Concrete, as well as a composite pavement type consisting of data for DGAC and PCC combined.

[6] found that for Australian conditions the noise emission levels for each of vehicle type and road surface type was very close to those noted in TNM. They state "it may reasonably be concluded that there were no practical differences between the vehicle noise emission levels determined in the present study and those incorporated in TNM". Therefore the TNM emissions data would be applicable for Australian conditions.

Full details of the TNM model are contained in [6], including the way it deals with horizontal and vertical geometries.

Output from the TNM model is in terms of Leq(1hour) to the nearest 0.1 dB(A).

Usually TNM is used to predict Leq(1hour) noise levels for a road carrying many vehicles. For the current purposes of obtaining an IVNM it is required to obtain instantaneous noise levels for individual vehicles at various positions along this road. The methodology below indicates how this may be achieved.

Consider Figure 1, which represents a vehicle traveling along segment of road at a speed of v m/s. The time at which the vehicle passes the observer OB (located at a distance d from the center of the nearest traffic lane) occurs at time t1. Using a time step of Δt and letting $\Delta s = v\Delta t$ allows the position of the vehicle to be calculated at time t2, where $t2 = t1 \pm n\Delta t$.

The TNM model may now be used to obtain the Leq(1hour) contribution at the observer OB due to the vehicle for each segment of road represented by equal lengths Δs.

However the instantaneous noise level, rather than the Leq(1hour) contribution is required.

If it is assumed that the noise level for the duration of Δt as the vehicles traverses each segment Δs is constant (this is approximately true when Δt or Δs is sufficiently small) and equal to Z dB(A) then it can be shown that

$$Leq(1hour)=10*\log([\Delta t*10^{(Z/10)}+(3600-\Delta t)*10^{(-\infty/10)}]/3600) \text{ dB(A)} \quad (1)$$

where the term 3600 refers to 3600 seconds/hour. The first term inside the parentheses refers to the contribution to the Leq(1hour) made by the average noise level Z for a duration of Δt seconds. The second term is zero, since there is no contribution to the acoustic energy when the vehicle is outside the segment Δs under consideration.

Equation (1) may be rearranged and simplified to

$$Z=Leq(1hour)+10*\log(3600/\Delta t) \text{ dB(A)} \quad (2)$$

Equation (2) states that the instantaneous noise level at any time t is related to the TNM output Leq(1hour) noise level by adding $10*\log(3600/\Delta t)$ dB(A). This noise level may be assigned to the midpoint of each segment.

Time Step

The time step Δt requires some discussion. For the current purposes it is required to allow the calculation of any noise parameter, including for example L_1 and L_{10}. If Δt is sufficiently large, the differences in noise levels between locations along the road separated by Δs could be in excess of 5-10 dB(A), particularly for observer locations close to the road with vehicles traveling at high speeds.

In addition it is required to obtain an accurate L_{max}. To achieve this the location at which this occurs needs to be known. For the assumptions made above the L_{max} occurs when the vehicle passes the observer location. It is therefore necessary that this point be one of the points along the road at which the noise levels is calculated at the observer location.

This in turn means that the location of vehicles must be "quantised" along the road so that vehicles only pass the observer location in multiples of Δt. If Δt is too large then a true representation of road vehicle distribution would not be obtained.

On the other hand if Δt is too small then, particularly for low vehicle speeds or observer locations located well away from the road, the differences in noise levels between successive calculated noise levels are very small.

It was found that a suitable compromise for most instances is Δt=0.1s. For this case equation (2) becomes:

$$Z=Leq(1hour)+45.6 \text{ dB(A)} \quad (3)$$

Figure 2 shows the time histories for single vehicles using the TNM average source noise level on an "average" road surface for vehicles traveling at a speed of 60 km/hr. Shown are the time histories for (i) a car, (ii) a medium truck, and (iii) a heavy truck. The intervening ground comprises "short grass". The observer location is 20 m from the center of the traffic lane.

Other Considerations

The time histories in Figure 2 represent the "average" noise levels for each vehicle class. Within each vehicle class there is a variation about the mean noise level, which is more or less a Gaussian distribution [7]. [5] found that the standard deviation for the various vehicle types ranged from 1.0 dB(A) to 3.3 dB(A).

Since the noise emission for each vehicle is assumed to remain constant as it travels along the road, the variation about the mean is applicable to the whole of the journey along the road. This means that for a given vehicle the time history of that vehicle is simply the generic time history for the vehicle class shown in Figure 2, with the whole curve moved up or down.

The other consideration is the vehicle spacing. For this purpose the modified negative exponential distribution assumed for vehicles headways on each of the traffic lanes was used, based on the work by [8] and adopted by [4] was used. Using an initial by-pass time for the first vehicles then determines the by-pass time of each of the remaining vehicles in each traffic lane.

In addition road traffic data are required which have to be modified so that each vehicle is entered into one of the TNM vehicle types.

A measured background noise level would usually be input into the model. Otherwise a background noise level of typically 20-25 dB(A) would be used.

To avoid discontinuities in the noise level time history (ie not considering vehicles located further than a distance x along the road from the observer location, when the noise level is still well above the background noise level), the length of road to be considered is to be sufficiently large.

IVNM Output

Figure 3 shows an example of a noise level time history at an observer located along a 2 lane road at a distance of 20 m from the center of the nearest traffic lane for 64 vehicles per hour traveling at a speed of 60 km/hr. Figure 4 shows the case for 256 vehicles per hour.

References

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Conclusion

The paper outlines a methodology for obtaining an Individual Vehicle Noise Model (IVNM) able to predict noise level time histories. The model places particular emphasis in predicting the maximum noise level due to each vehicle pass.

Using the known effects road traffic noise has on sleep disturbance (ie sleep disturbance is related to the maximum by-pass noise level, number of noise events, and emergence above the ambient noise level), the model is able to be used as a research tool to investigate whether sleep disturbance is related to other noise parameters, such as Leq or L10.

References

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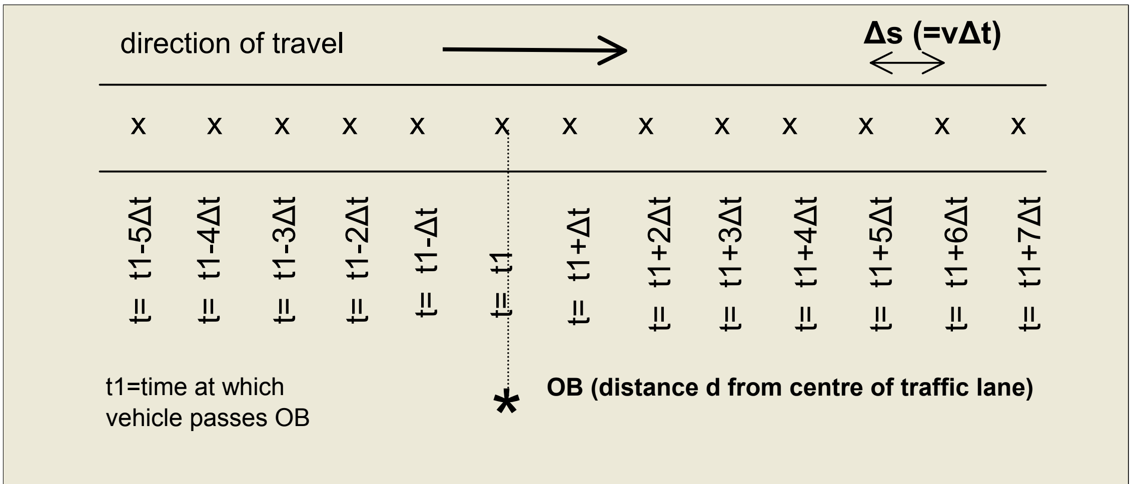

Figure 1. Simulation of vehicle travelling along traffic lane at speed v m/s

Figure 2. TNM output noise levels for single vehicle passing observer v=60km/hr; d=20 m

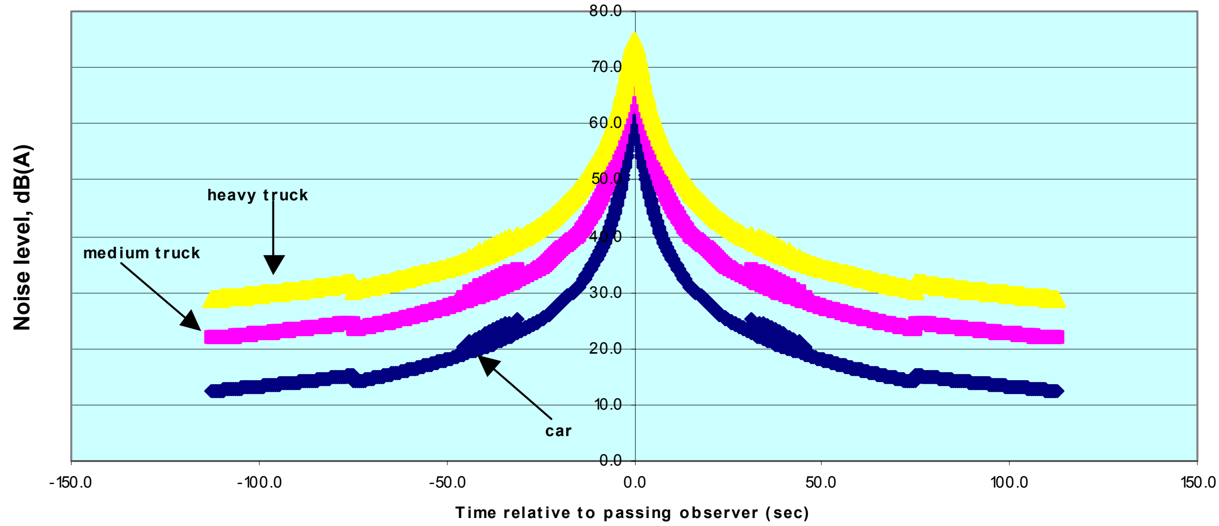

Figure 3. Predicted noise level time history
64 veh/hr; v=60 km/hr; d=20 m

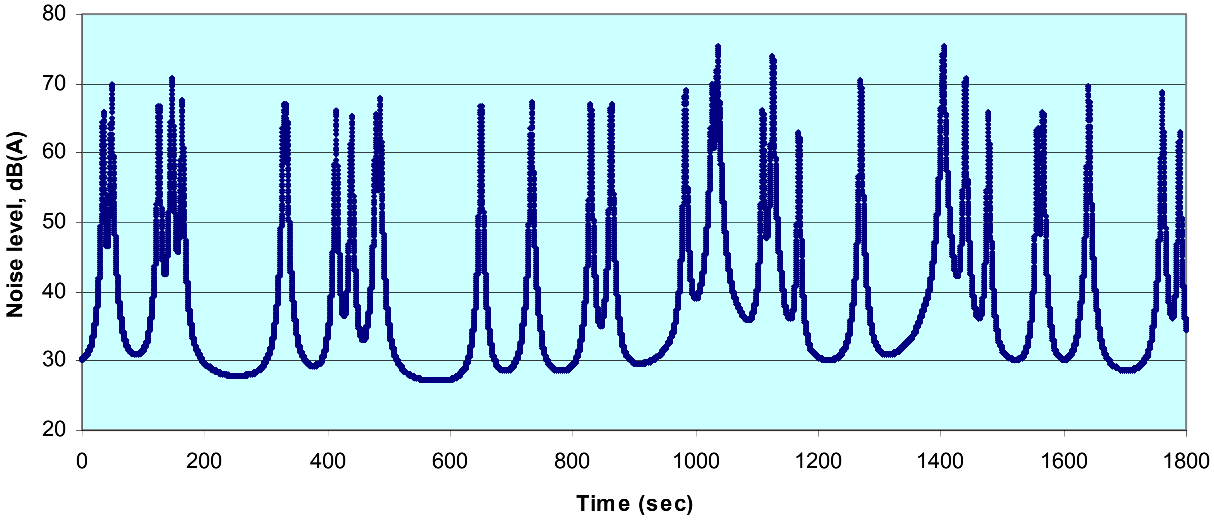

Figure 4. Predicted noise level time history
256 veh/hr; v=60 km/hr; d=20 m