# Evaluate Traffic Noise Level based on Traffic Microsimulation Combined with a Refined Classic Noise Prediction Method

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Abstract: In this paper, a refined classic noise prediction method based on the VISSIM and FHWA noise prediction model is formulated to analyze the sound level contributed by traffic on the Nanjing Lukou airport connecting freeway before and after widening. The aim of this research is to (i) assess the traffic noise impact on the Nanjing University of Aeronautics and Astronautics (NUAA) campus before and after freeway widening, (ii) compare the prediction results with field data to test the accuracy of this method, (iii) analyze the relationship between traffic characteristics and sound level. The results indicate that the mean difference between model predictions and field measurements is acceptable. The traffic composition impact study indicates that buses (including mid-sized trucks) and heavy goods vehicles contribute a significant proportion of total noise power despite their low traffic volume. In addition, speed analysis offers an explanation for the minor differences in noise level across time periods. Future work will aim at reducing model error, by focusing on noise barrier analysis using the FEM/BEM method and modifying the vehicle noise emission equation by conducting field experimentation.

## 1 INTRODUCTION

As a result of rapid economic development of in developing countries such as China, freeways and motorways are being widened in many rural areas, contributing to noise pollution in the vicinity of the road. The variation in traffic flow rate and speed before and after widening strongly influences the emission of traffic noise, and single vehicle speed is largely dependent on single vehicle dynamics induced by a vehicle interactions model. Thus in order to improve traffic noise estimation for freeway widening, an accurate car following model and a precise noise estimation model must be used to analyze the interaction between traffic characteristics and noise emission.

In the classic static traffic noise prediction model, roads are divided into basic sections where the traffic characteristics are considered smooth and homogeneous. Examples of such models are the US Federal Highway Administration model (FHWA 1978), the German RLS90 model (Steele C. 2001), and other models which refine the emission law to reveal different driving conditions, like the Nordic model (Leclercq. 2001) and the ASJ RTN Model(Yoshihisa et al. 2004).

To increase the accuracy of noise prediction, some analytic models modify the vehicle speed calculation algorithm in the static models. Each subdivided segment in those models is no longer speed-homogeneous; the speed-variation pattern for a single isolated vehicle must be captured to attain the mean speed profile, while the average speed is needed to determine the acoustical energy at the receiver from the traffic on the related roadway sub-segment. Analytic models are often used as some national standards, such as the US Federal Highway Administration's TNM model (Christopher W. Menger et al. 1998) and the French noise estimation model (A. Can et al. 2010). The progress analytic models make lies in the fact that they attempt to account for single vehicle dynamics, although the TNM model only calculates the entrance and exit speed and converts them to the

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segment average speed (Arnaud Can et al. 2008). This analytic model is suitable in the freeway scenario, which has relatively continuous traffic flow and less traffic characteristic variation.

In recent years, many researchers have focused on dynamic models (Ruffin Makarewicz et al. 2011), which can output not only hourly equivalent sound level, but also instantaneous noise emission. Dynamic models such as MOBILEE and ROTRANOMO (Volkmar, H. 2005) are based on different microsimulation methods, which can give position, speed and acceleration of each vehicle. When the values of these variables are substituted into a noise emission law and sound propagation algorithm, instantaneous sound pressure can be calculated. Microsimulation models are well suited for complex traffic situations such as cross intersections and roundabouts, where traffic characteristics are quite variable. However the massive amounts of data involved necessitate large amounts of computing power and calculation time.

This paper offers a refined classic noise prediction method (analytic model) based on the classic FHWA noise prediction model and using the VISSIM traffic microsimulator to analyze the sound level contributed by the traffic on the Nanjing Lukou airport connecting freeway before and after its widening. The aim of this research is to (i) assess the traffic noise impact on the Nanjing University of Aeronautics and Astronautics (NUAA) campus before and after freeway widening, (ii) compare the prediction results with the field data to test the accuracy of this method, and (iii) analyze the relationship between traffic characteristics and sound level.

The organization of this paper is as follows: (i) the first part describes the geometric layout of the experimentation site, then discusses the traffic microsimulation and noise prediction model selected, and (ii) the second part demonstrates the results and analyzes different traffic characteristics and their impact on noise level.

# 2 METHODOLOGY

## 2.1 Case Study

### 2.1.1 Geometric Design

The selected study site is located on the Nanjing airport connecting freeway, in a suburban district of the city. It contains three lanes in the North to South direction as well as in the opposite direction before widening (current scenario). After widening, lane number will be doubled in each direction, with the new lanes being located in the middle of the origin site (space was pre-reserved). The detailed geometric design is shown in Figure1: (i) the overall length of the studied freeway section is 400m, including a 3.5m high barrier on the side where noise levels are of interest; (ii) the width of the traffic lanes is 3.75m, while the shoulder width is 3.3m; (iii) the tree zones after widening have two different widths: 2.7m and 6.5m.

### 2.1.2 Field Data Collection

The experiment included traffic and acoustic measurements, which were carried out before the widening in two one-hour periods (7:30-8:30, 9:30-10:30) on a weekday. The two time periods cover peak and normal traffic flows respectively. The recorded traffic accounts for all traffic flow in the freeway section as there are no access ramps or intersections. Overall peak hour traffic flow (7:30-8:30) was 6401 veh/h, comprised of 3376 veh/h in the north to south direction and 3025 veh/h in the opposite direction. Normal traffic flow was 4833 veh/h, comprised of 2579 veh/h travelling north to south and 2254 veh/h travelling in the other direction. Three vehicle categories were recorded: cars (including light trucks), heavy goods vehicles, and buses (including mid-size trucks). The detailed traffic composition is given in Table 1.

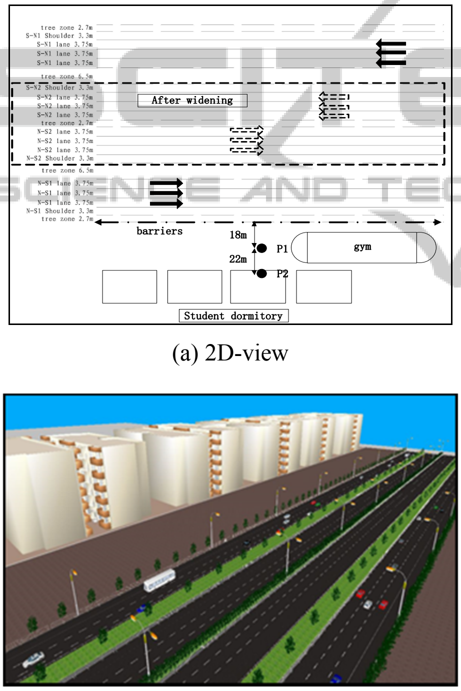
Acoustic recordings are $L_{Aeq,1s}$ (A-weighted equivalent sound level for 1 second) for the points P1, P2 (Figure 1) selected for sound pressure level estimation. P1 was near the NUAA gym, and P2 was in front of the student dormitory. Both were in the barrier-contained section at the same cross section, with receivers set 1.5m high.

## 2.2 Traffic Microsimulation

In this paper, the chosen traffic microsimulator VISSIM (PTV. Ltd. 2007) was used to refine dynamic speed calculation of the FHWA noise prediction model. VISSIM is a microscopic, time step and behavior based simulation model developed to be applied in a variety of transportation problem settings. The essential elements of traffic modeling is the car following and lane change model which directly affects vehicle interaction, especially

Table 1: Traffic composition (Before widening) (veh/h).

| Time | Direction | Cars(LT) | Bus(MT) | HGV | Total |
|---|---|---|---|---|---|
| Peak | North-South | 3114 | 169 | 93 | 3376 |
| | (composition) | 0.922 | 0.050 | 0.028 | 1.000 |
| | South-North | 2852 | 107 | 66 | 3025 |
| | (composition) | 0.943 | 0.035 | 0.022 | 1.000 |
| normal | North-South | 2434 | 61 | 84 | 2579 |
| | (composition) | 0.944 | 0.023 | 0.033 | 1.000 |
| | South-North | 2101 | 65 | 88 | 2254 |
| | (composition) | 0.932 | 0.029 | 0.039 | 1.000 |



(a) 2D-view

(b) 3D-view

Figure 1: Geometric design.

dynamic speed at different cross sections. Thus we used a psycho-physical car following model based on the work of Wiedemann (PTV. Ltd. 2007).

(i) Input the traffic composition figures collected from the field experiment before the freeway widening and later input the assumed data after widening, in order to analyze the impact of widening on noise level.

(ii) Select the appropriate speeds for all the vehicle types based on the field observations and empirical data from Chinese freeways. The speeds set for Car (LT), Bus (MT) and HGV were respectively 90km/h, 70km/h, and 60km/h (For convenience, the speeds are set to integer based on the observations).

(iii) Set the data collector at selected cross section to collect instantaneous speed information. Dynamic speed was used to calculate vehicle noise emission and traffic adjustments (see next section) for the noise prediction model.

## 2.3 Noise Level Estimation Process

The selected Federal Highway Administration Traffic Noise Model (FHWA) predicts sound level by adding a series of adjustments to a reference noise level. It can also be used to aid in the design of highway noise barriers. The FHWA model calculation process includes vehicle noise emission and noise propagation estimation. The general sound level calculation is as follows:

### 2.3.1 Vehicle Noise Emission

The FHWA model contains noise-emission equations for the five built-in vehicle types, but in order to reduce complexity the medium trucks and buses are regarded as Bus (MT) for convenience and to be consistent with the vehicle type split in VISSIM.

The vehicle noise emission calculation is based on the FHWA noise emission database (Christopher W. Menger et al. 1998). The maximum A-weighted reference sound level as a single vehicle passes by a receiver 15 meters to the side and 1.5m high is considered to represent the entire vehicle's noise-emission level. For each vehicle type defined above for use in VISSIM, the emission level is:

$$\overline{L_{ocar}} = 38.1\log_{10} S_{car} \text{-}2.4(\text{dBA}) \quad (1)$$

$$\overline{L_{obus(\text{MT})}} = 33.9\log_{10} S_{bus(\text{MT})} +16.4(\text{dBA}) \quad (2)$$

$$\overline{L_{0HGV}} = 24.6\log_{10} S_{HGV} +38.5(\text{dBA}) \quad (3)$$

Si represents the average speed of each vehicle type.

### 2.3.2 Traffic and Distance Adjustment for Free Field Conditions

Free field sound conditions are first assumed, such that the sound is assumed to travel without boundaries (the effects of a barrier are addressed in the next section). Based on the basic assumption that the A-weighted reference sound level reaches its peak value when a vehicle passes by the location perpendicular to the receiver, we can derive a single car's free field noise level at any time by considering only the distance attenuation:

$$L_t = \overline{L_0}\text{-}20\log_{10}\frac{R}{D_0} = \overline{L_0}\text{-}20\log_{10}\frac{D_0^2}{D^2+(st)^2}(\text{dBA}) \quad (4)$$

Where $(st)$ refers to the distance a single car travels during time period $t$ , $D$ refers to the distance between the car and the receiver.

And for a continuous time period $t_1 \sim t_2$ (usually 1h), the equivalent sound level is:

$$\begin{aligned} L_{Aeq}(T) &= 10\log_{10}\frac{1}{t_2\text{-}t_1}\int_{t_1}^{t_2} 10^{L_t/10}\text{dt} \\ &= \overline{L_0} + 10\log_{10}\frac{1}{T}\int_{t_1}^{t_2}\frac{D_0^2}{D^2+(st)^2}\text{dt}(\text{dBA}) \end{aligned} \quad (5)$$

For convenience, it is assumed that the short time period during which a car passes by the receiver contributes the greatest proportion of sound energy, thus the equation can be rewritten:

$$\begin{aligned} &L_{Aeq}(T) \\ &\approx \overline{L_0} + 10\log_{10}\frac{1}{T}\int_{-\infty}^{+\infty}\frac{D_0^2}{D^2+(st)^2}\text{dt} \\ &\approx \overline{L_0} + 10\log_{10}\left(\frac{\pi D_0}{sT}\right) + 10\log_{10}\left(\frac{D_0}{D}\right)(\text{dBA}) \end{aligned} \quad (6)$$

Thus, given traffic volume $N_i$ for each vehicle type $i$:

$$\begin{aligned} L_{Aeq}(N_{i,j}T) &\approx 10\log_{10}\left[\sum_{j=1}^{N_{i,j}} 10^{L_{Aeq}(T)/10}\right] \\ &= 10\log_{10}\left[\frac{1}{N_i}\sum_{j=1}^{N_{i,j}}\left(10^{\overline{L_{0j}}/10} \times \frac{\pi D_0}{s_j T} \times \frac{D_0}{D}\right)\right](\text{dBA}) \end{aligned} \quad (7)$$

Note that in the classic FHWA model, the vehicle speed for a single car of a specified type is always defined as a constant value, which does not reflect reality. Thus to improve the accuracy of the noise level calculation, the data collector at the studied cross section collected the instantaneous speed profile, and with VB programming the hourly equivalent free field sound level for each vehicle type can be calculated.

### 2.3.3 Barrier Insertion Loss

Barriers are structures that are fixed vertically and have a height and a base. The barrier insertion loss estimation algorithm is based upon the Fresnel diffraction theory, as described by De Jong, Moerkerken, and Van der Toorn (Christopher W. Menger et al.1998).

In the general scenario, barriers have diffracting points at the bottom of the left face, the top, and the bottom of the right face and for simplicity, a sound barrier is usually defined as a thin material of a particular height. The insertion loss equation for sound barriers can be defined as follows:

$$A_{bar} = \text{-}10\log_{10}\left[\frac{1}{3+20N_1} + \frac{1}{3+20N_2} + \frac{1}{3+20N_3}\right](\text{dBA}) \quad (8)$$

$N_i$ refers to the Fresnel number which can be calculated from the equation $N_i = 2\delta_i / \lambda$ , $\delta_i$ refers to three kinds of sound propagation path differences respectively , which are defined at the top, bottom left and right face diffracting points. $\lambda$ is sound wavelength computed from the center frequency 500 HZ for traffic and sound speed 340 m/s.

At the studied site, the sound barrier between the receiver and the traffic is relatively infinite (the total barrier length is approximately thousands of meters), thus the attenuation equation can be simplified as follows:

$$A_{bar} = \text{-}10\log_{10}\left[\frac{1}{3+20N_1}\right](\text{dBA}) \quad (9)$$

The diffracting points at the bottom of the right and left face are irrelevant due to the barriers' "infinite" length.

#### 2.3.4 Hourly Equivalent a-weighted Sound Level for a Receiver

By adding the insertion loss to equation (Kurze U.J et al. 1971), for a particular vehicle type, the hourly equivalent A-weighted sound level for a receiver is:

$$L_{Aeq}\left(N_{i,j}TA_{bar}\right) = 10\log_{10}\left[\frac{1}{N_i}\sum_{j=1}^{N_{i,j}}\left(10^{\overline{L_{0j}}/10}\times\frac{\pi D_0}{s_j T}\times\frac{D_0}{D}\right)\right] - 10\log_{10}\left[\frac{1}{3+20N_1}\right](\text{dBA}) \tag{10}$$

Considering three input vehicle types and traffic composition collected from field data or assumed ones, the equation for overall noise level before and after widening will be:

$$L_{Aeq}(N,T,A_{bar},\text{Total}) = 10\log_{10}\left[\sum_{alldirectioin}10^{\left[10\log_{10}\left(\sum_i 10^{L_{Aeq}(N_{i,j},T,A_{bar})/10}\right)\right]/10}\right](\text{dBA}) \tag{11}$$

## 3 RESULTS

### 3.1 Model Verification

This part of paper provides a comparison of refined FHWA model with field measurements in order to evaluate the accuracy of the model. The comparisons are made at two different selected points which are set to evaluate the noise impact on the campus. The hourly equivalent A-weighted noise level is computed based on the VB (Microsoft Visual Basic) programming using the instantaneous speed profile generated by VISSIM simulation. The field measurements $L_{Aeq,1h}$ can be obtained from the statistic noise levels $L_{90}$ and $L_{10}$, which are derived from initial collected descriptor $L_{Aeq,1s}$. The results before the widening are shown in Table 2.

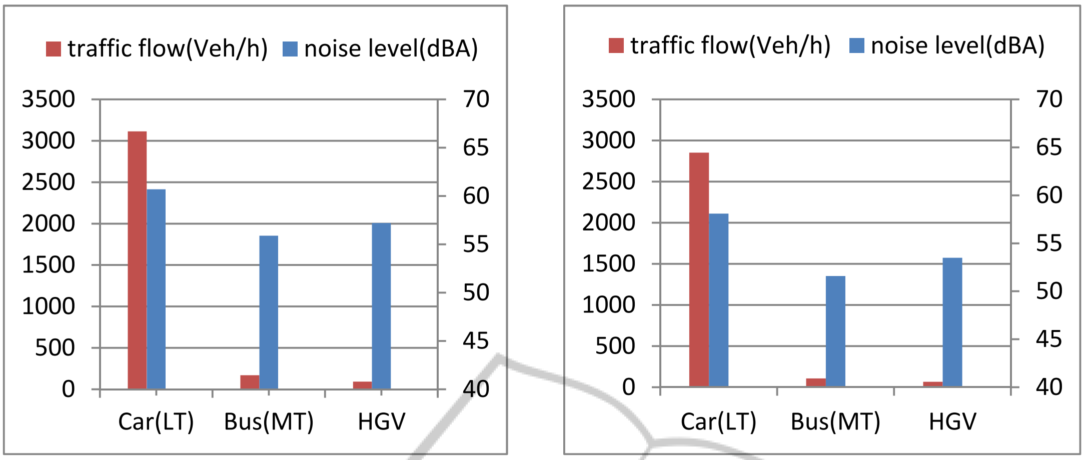
As can be seen in Table 2, both the prediction results and field data exceed the recommended standard of noise level in China (the accepted level on campus is 55dBA), even before the impact of widening is taken into account. The refined model gives estimates that are on average 2.6 dBA higher than the field results, an apparent improvement on noise estimation using the classic model (usually a 3 dBA or more mean error is accepted). The reasons for the overestimation could include: (i) the application of the American standard to the current scenario, (ii) elimination of ground attenuation, which is hard to assess because of the geometric complexity, (iii) simplification of the distance between vehicle and receiver in the calculation to compute $L_{Aeq}\left(N_{i,j}TA_{bar}\right)$ using the VB program, or (iv) underestimation of the effect of the noise barrier by using a less complicated algorithm.

### 3.2 Traffic Composition Impact

Although the Car (LT) category contributes the most sound energy for all time and direction combinations, it is unwise to conclude that buses (MT) and HGV have a minor impact on the noise level without also considering the traffic flow for each type. For example, the traffic flow for cars in the North to South direction is 3114 veh/h, which contributes 60.7 dBA at receiver P1, while the HGV flow of only 93 veh/h adds 57.2 dBA to the total sound level, which is only 2.5 dBA less than car contribution,. Thus, despite the relatively higher traffic attenuation (adjustment) for Bus (MT) and HGV, their contribution to overall noise cannot be ignored. Figure 2 shows the selected traffic flow for each type of vehicle and their related $L_{Aeq}\left(N_{i,j}TA_{bar}\right)$.

Table 2: Noise level comparison of refined model with field measurements (dBA).

| Receiver | Time period | Sum (direction) | Field data |
|---|---|---|---|
| P1 | Peak | 64.3 | 61.6 |
| | Normal | 63.3 | 60.5 |
| P2 | Peak | 62.2 | 59.8 |
| | Normal | 61.5 | 58.9 |




(a) North to South, peak hour, P1

(b) South to North, peak hour, P1

Figure 2: Selected traffic flow and noise contribution for each vehicle type.



## 3.3 Speed Analysis

Speed is also an important factor in analyzing the traffic and noise level. As discussed above, the speed profile generated by the VISSIM simulation result was used to calculate the vehicle noise emission and traffic adjustment for free field conditions. The instantaneous speed of every vehicle passing by the collector was extracted to estimate the average speed for each direction and time period. The results show a small increase in speed for cars from peak to normal flow. For instance, the average car speed in peak hour in the North to South direction was 94.1 km/h, while in a normal hour for the same direction, the speed increased to 95.4 km/h. The fact that this increase is relatively low, in spite of the decrease in traffic flow, suggests that the freeway is far from over-saturated during peak hour. Thus, combined with the fact the HGV category contributes a lot to the noise level (and, as shown in Table 1, the amount of HGV does not vary much during different hours), suggests that the minor difference in sound level between peak and normal hours may be accounted for by the modest increase in speed being insufficient to fully offset the noise reduction due to the drop in traffic flow.

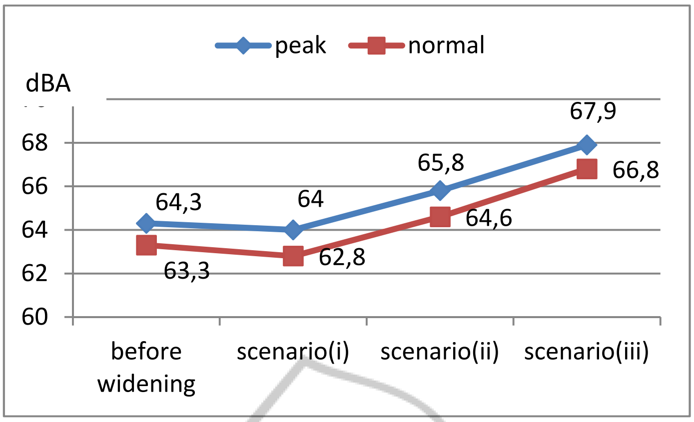
## 3.4 Noise Level Prediction after Widening

After the widening of the freeway, the lane number for each direction will double. The new lanes will be located in the middle of the original lanes as shown in Figure 1. Due to the lack of estimates of traffic flow after widening, this paper considers three scenarios regarding possible vehicle numbers during each split time period: (i) the traffic flow in each direction remains the same, (ii) the traffic flow increases by 50%, (iii) the traffic flow doubles. For convenience, it is assumed that the traffic composition (vehicle proportion) remains the same and that half of the traffic flow takes place in the new lanes for each scenario. Note that a scenario involving a decrease in traffic has not been included as it is considered highly unlikely. The calculation results are shown in Figure 3.

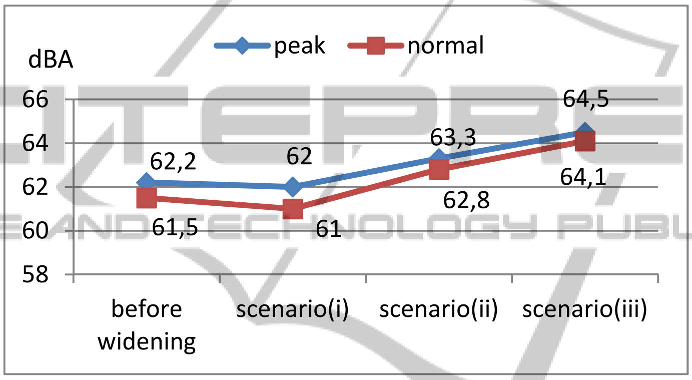
Table 3: Average speed for different time period before widening.

| Direction | Vehicle type | Vehicle speed (km/h) | |
|---|---|---|---|
| | | Peak hour | Normal hour |
| North to South | Car(LT) | 94.1 | 95.4 |
| | Bus(MT) | 72.7 | 73.1 |
| | HGV | 63.0 | 62.6 |
| South to North | Car(LT) | 94.2 | 95.5 |
| | Bus(MT) | 72.8 | 72.7 |
| | HGV | 63.5 | 63.7 |

The noise level of the first scenario drops slightly despite traffic flow being the same as before widening, after which noise level increases at a high rate with increasing traffic, such that a 50% growth in traffic is associated with approximate 1.2-1.5 dBA increase in noise level. Thus, given that there is already an unacceptable noise level at the campus




(a) Noise level at P1




(b) Noise level at P2

Figure 3: Noise level at receivers based on the three traffic flow scenarios.

under current conditions, the simple conclusion can be drawn that, assuming that the widening will attract higher levels of traffic, noise pollution on campus will be worse than at present. This suggests that consideration should be given to providing additional noise barriers in the freeway section adjacent to the campus.

## 4 CONCLUSIONS

In this paper, the author provides a refined classic noise prediction model to estimate the noise level in the campus of NUAA, which is caused by the traffic in the Nanjing airport connecting freeway. The refined method consists of a traffic microsimulation and a classic noise estimation model, and VISSIM is used to simulate the dynamic vehicle operation condition (especially speed) to refine the noise calculation process in the selected noise prediction model. After thorough analysis of the estimation results and traffic characteristics, conclusions can be drawn as follows:

(i) Sound levels predicted by the model exceed field measurements by a more or less acceptable level (2.6 dBA). The error could be reduced by refining the vehicle emission level assumptions, considering the ground diffraction and reflection effect, and using a more complex method to evaluate the sound barrier attenuation (BEM/FEM methodology).

(ii) Although they have a much lower traffic volume than the Car (LT) category, the Bus (MT) and HGV categories contribute significant amounts of sound power which should not be ignored. In addition, the relatively low increase in speeds in the normal traffic flow period explains why the increase in noise due to the higher speed is largely offset by the decrease in traffic flow.

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