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Prediction of Traffic Noise from Trunk Roads and Access Roads in Urban Areas

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To protect residents in urban dwellings from unnecessary noise, land-use planning needs to be combined with a traffic-noise prediction method that includes the effect of trunk roads planned for urban areas along with the access road network. Accordingly, this study proposes a new prediction method based on a theory for an ideal homogeneous city. The results agreed with data from the Municipal Office in Kwang-Ju, South Korea

1. Introduction

As a result of town growth and the related increase in private car use, the construction of new roads and traffic flow have both increased. With the growth in traffic flow, road traffic noise has also increased. Currently, road traffic is clearly the main cause of outdoor noise pollution in urban areas, therefore, to protect residents in urban dwellings, land use planning should be combined with a traffic noise prediction method. Shaw and Olson established a theory for the steady-state urban noise of an ideal homogeneous city[1)], in which a city is treated as a plane surface with many identical sound sources randomly distributed throughout its area. The sound sources(motor vehicles) are treated as ideal point sources. By determining the probability of finding a source at a given position, the mean acoustic energy density can then be calculated at any observation point. Furthermore, if the contributions from all sources are integrated, excluding a single discrete "local" vehicle in a central cell, and then the effect of the single "local" vehicle is included, the total mean acoustic energy at the observation point can also be calculated. The inclusion of certain factors in the calculations is based on the assumptions that the attenuation of acoustic waves obeys an inverse square transmission, and that atmospheric absorption and shielding factors should both be included.[2)] Using these factors, Shaw and Olson then produced a simple theory for the steady-state urban noise of an ideal homogeneous city.

In a real city, prominent traffic streams form a trunk road network and these trunk roads are the main source of urban traffic noise. However, the theory of Shaw and Olson is unable to determine the effects of trunk roads cannot. The arrangement of trunk roads has been discussed in town planes by many researchers with considerable interest in treating such roads as noise sources.[3)] However, so far the treatment has only been qualitative.

Accordingly, this study proposes a new quantitative urban noise prediction method in which trunk roads are considered as line sources, constructed using homogeneously distributed point sources for traffic noise, and access roads as plane noise sources based on Shaw and Olson's theory for a homogeneous city.

2. Theoretical Considerations

It is assumed that roads can be divided into two types : trunk and access roads.

Effect of Access Roads. The theory covering access roads is the same as that developed by Shaw and Olson, in which a ground plane, which includes a network of roads, is treated as a homogeneous infinite plane with many identical noise sources randomly distributed over the area. However, in this study, the ground plane is divided into a large number of square planes with sides measuring 500m so as to incorporate the characteristics of each square plane. A city region is thus made up of finite planes, each with a land-zoning description. The planes are then divided into residential, commercial, and industrial zones. Taking into account all the access roads in the city, the acoustic energy density at an observer point can be written as;

$$E_o = \frac{1}{2\pi} W_o 10^{L_{pwl}/10} \int_s F \cdot N_{l,} / R^2 e^{\alpha l, R} ds \qquad (1)$$

where:

L_{PWL} is the average sound power level of each noise source obtained by weighing the ratio of the number of heavy vehicles to that of light vehicles (dB);

N_L is the source density (number of point sources/m^2);

W_o is the reference sound power. 10^{-12} watt;

F is the shielding factor; and

R is the distance to the observer.

Based on this elementary equation, the specific calculation procedure is then the same as that used in Shaw and Olson's theory.

The shielding factor F is particularly associated with the presence of obstacles in the transmission path yet also includes other properties of the transmission path which give rise to excess attenuation caused by the absortive properties of the ground plane. Therefore, the value of the shielding factor, F, used in the current calculations was identical to that estimated by Shaw and Olson, corresponding to a noise-level reduction of 15 dB.

The atmospheric absorption constant α_n is determined using the atmospheric temperature and relative humidity values typical during the measurement. The atmospheric absorption constant expressed in decibels per unit length, α, was determined to be roughly 5 dB/km($\alpha = 4.343 \alpha_n$).[1]

Vehicles are divided into two types : heavy and light. To combine the acoustic energy contributions from both classes of vehicle, the sound power-level of each kind of vehicle is used as it appears in the report by Ishii and averaged by weighing the ratio of the number of heavy vehicles to that of light vehicles.[4] The sound power-levels are given in the following equations:

$$L_w = 97 + 0.2\ V \text{ dB(A) for light vehicles}$$
$$L_w = 107 + 0.2\ V \text{ dB(A) for heavy vehicles} \qquad (2)$$

where V is the vehicle speed(km/hr).

For an area that includes an access road network, the traffic-flow volume per relatively large unit area of 20.2 hectares(ha), N_{fr}, does not exist. Therefore, to avoid the difficult task of measuring the traffic volume directly, a linear-regression model is used to estimate the traffic-flow volume. Therefore, N_{fr} is determined based on the result of the linear-regression equation. In this study, the equation was constructed using statistical data from 50 areas in Kwang-ju. The traffic flow volume, N_{fr}, which is the response variable, was measured by counting the vehicle numbers from aerial photographs of the city. The photographs were taken during weekday mornings and afternoons. The ratio of the number of heavy vehicles to that of light vehicles was also calculated by counting the vehicles. As explanatory variables, three input factors were selected as a result of a regression analysis: for example, the population P_L(persons/ 20.2 ha), and floor area ratio R_L(%), which is the ratio of the land area covered by the floor space of commercial buildings to the total land area. The traffic density in the area which includes access roads was calculated using the following regression equation:

$$N_{fr} = 0.798 P_L + 0.103 R_L + 0.347 S_L + 1.24 \qquad (3)$$

where;

N_{fr} is the traffic density of the access roads in the area (vehicles 20.2 ha);

P_L is the population (persons/20.2 ha);

R_L is the floor area ratio(%); and

S_L is the commercial area ratio(%).

The noise source density per unit area, N_L, is calculated from N_{fr} based on the following relation: $N_L = 5 \times 10^{-6} N_{fr}$. In practical calculations, the numerical integrations should be carried out, assuming a variety of land uses. The decibel notation of the result should be considered as a median level(L_{50})because the calculation method is essentially based on an ideal steady-state model.

Effect of Trunk Roads. The theory for trunk roads is treated as a line-source model of traffic noise. It is assumed that identical noise sources (moving vehicles) are randomly distributed over the center line of the trunk road.

The determination of the mean acoustic energy density from a trunk road is the same as in eq.(1). The integration is taken along the line source. The mean acoustic energy density is written as;

$$E_t = \frac{1}{2\pi} W_o 10^{L_{pwl}/10} \int_l F \cdot N_l / R^2 e^{-\alpha nR} ds \qquad (4)$$

where N_t is the source density(number of point sources/m). The source density, N_l, of a trunk road is determined based the traffic flow volume measured at the same time as the noise data.

3. Measurements

The environmental noise in Kwang-ju was measured by the Municipal Office of Kwang-ju during the daytime in the summer of 1999. Five hundred and nine locations were chosen as the measurement points distributed uniformly throughout the city area, about 170 km^2, the center of which coincided with the center of Kwang-ju. The positioning of buildings required additional measurement points. The median levels, L_{50}, were measured at intervals of 500 seconds using microphones placed 1.2 m above ground. The sampling rate was once every second. One hundred noise level values at each measuring point were analyzed to obtain the median level, L_{50}. Since the traffic volume during the measurement periods was relatively stable compared to that at rush hour or midnight, a 500 second measurement sample length was considered adequate. The traffic flow volume along the trunk roads was also measured at the same time.

4. Results

A comparison between the calculated and measured results was made based on the frequency distribution of the differences, see Fig. 1. Up to 60% of the predictions were within ±3 dB(A) of the measurements. This agreement was relatively good when considering the contrast in the macroscopic prediction method and the measurement approach. However, there seemed to be a shift of several decibels to the right in the frequency distribution as 40% of the model data was in error by more than 3 dB. In order to examine these points in more detail, noise level contours were drawn on the maps for each kind of zoned area. For example, in the case of residential areas (see Figs. 2 and 3), the values(numbers in black with white backgrounds) of the calculated contour lines and measured levels(numbers in white with black backgrounds) agreed quite well. Despite the fact that the calculated noise levels included the effects of the access roads, the contour pattern showed a reasonable tendency indicating a decline in the noise level in areas surrounding trunk roads.

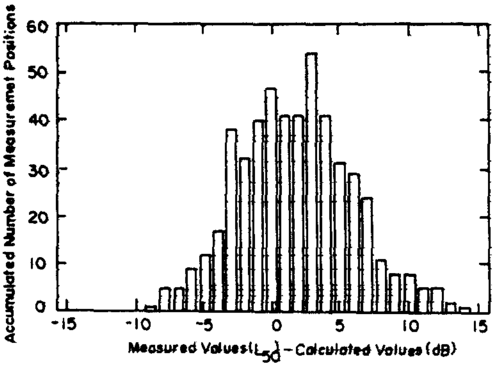

Fig. 1. Frequency distribution of differences between measured values[L_{50}dB(A)]and calculated values

In contrast, in the case of commercial areas(see Fig.4), the agreement was not good. A large error of more than 3 dB was found. This may have been due to noise produced by commercial activities in the area, thereby affecting the measured noise levels. Accordingly, since the characteristics related to the land zoning can be essential factors in a more microscopic analysis, the dependency of the shielding factor relative to the land-use zoning was examined.

Based on calculations in which each shielding factor F for each land-use zoning was set to reflect unity, the averaged values of the differences between the data and the calculated values were computed. Thereafter, new shielding factor F values for each land-use zoning were calculated to cancel the differences. The results including

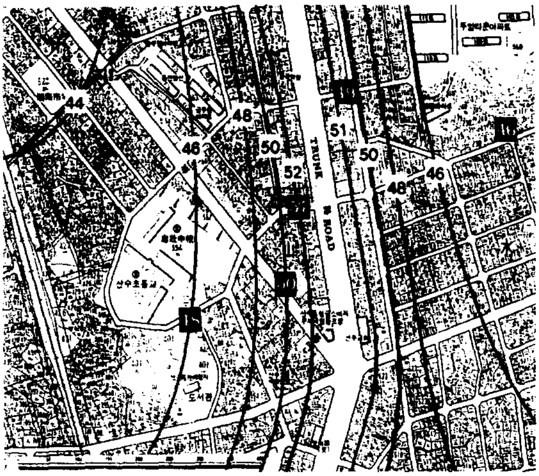

Fig. 2. Map of newly constructed residential area with one trunk road. Measured values[L_{50}dB(A)] are indicated by white figures with black background. Contour lines and levels are indicated in black.

the zoning characteristics are shown in Table 1. The shielding factors for the neighborhood commercial and residential areas were close to the value indicated by Shaw and Olson (F=0.032). This may mean that the density of private houses (number of houses per unit area) in Kwang-ju is similar to that in Ottawa where the factor used by Shaw and Olson was estimated. In contrast, the shielding factors for the commercial and residential areas were larger than the factor used by Shaw and Olson. This means that the measured data exceeded the calculated results. This may be due to the effect of noise from commercial and industrial activities which is not caused by traffic flow but rather by shop announcements, pedestrian voices, noise in factory noise, etc. However, since the shape and positioning of buildings also has an effect on the shielding factor, further detailed study is needed in this area.

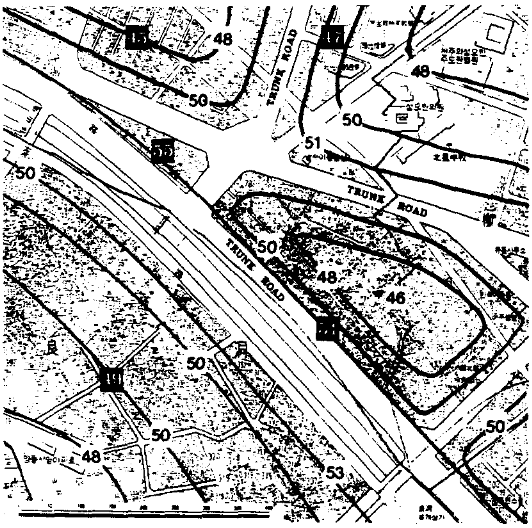

Fig. 3. Map of old residential area with three trunk roads. Measured values [L_{50}dB(A)] are indicated by white numbers with black background. Contour lines and levels are indicated in black.

Fig. 4. Map of commercial area. Measured values [L_{50}dB(A)]are indicated by white numbers with black background. Contour lines and levels are indicated in black.

Table 1. Relationship between land-use zoning and shielding factors

Relationship Between Land-Use Zoning And Shielding Factors	
Land-Use Zoning	Shielding Factors, F
Residential Area	0.042
Neighborhood Commercial Area	0.035
Commercial Area	0.065
Industrial Area	0.135

5. Conclusions

The results of this study confirmed that the proposed method can be used to predict environmental noise distribution in an urban area due to road traffic. The results may also be used to survey the distribution of citizens suffering from noise pollution.

Acknowledgements

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