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Analysis of Traffic Noise Propagation around Main Roads in Kwang-ju City

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This paper describes an analysis of various factors affecting traffic noise propagation, including the distance from the road, existence of a direct path of noise propagation, density and height of buildings, and procedure for predicting the attenuation of noise levels from roads. The analysis is based on a multiple number of regression models, utilizing the quantification theory of the first kind. This study incorporates a large amount of survey data concerning traffic noise propagation. The survey of the traffic noise propagation around main roads was carried out in several residential areas, mainly in Kwangju. The attenuation of noise levels measured provided 691 usable data samples. A multiple regression analysis demonstrated that the distance from the road makes the most significant contribution to the attenuation of the noise level. The second contributor was found to be the existence of a direct path of noise propagation. The building density and average height of the buildings also affected the attenuation of the noise level considerably. Other factors, such as the height of the building behind the receiver microphone and the number of traffic lanes on the noise-source roads, did not contribute as much to the attenuation of the noise level as the factors mentioned above.

Key words : traffic noise, propagation, attenuation, microphone.

1. Introduction

To plan countermeasures to reduce the traffic noise propagating into residential areas, the characteristics of the propagation must be investigated, accordingly, the establishment of a method for predicting the propagation of traffic noise is necessary. Currently, there are several methods of predicting the propagation of traffic noise, such as the scale model technique, mathematical models based on numerical calculations, and computational methods based on field survey data[1-5]. Other methods of calculating the attenuation of the noise level by barriers, which use the diffraction theory, can also be applied to calculate traffic noise propagation in urban areas[6]. In a macroscopic method, for instance, a real city is replaced by a cell model of an ideally homogeneous city where propagation laws of steady state noise are established[7]. However, in reality, the prediction of traffic noise propagation in densely populated areas is more complicated because the buildings cause multiple reflections and diffractions while also acting as noise barriers. Simply stated, the characteristics of traffic noise propagation are extremely complex, therefore, an accurate prediction of the propagation requires the consideration of a combination of factors.

This paper describes an analysis of various factors affecting traffic noise propagation. The analysis is based on a regression model utilizing the quantification theory of the first kind, that is, a method of multiple regression analysis[8-10]. This study incorporates a large amount of survey data concerning traffic noise propagation.

2. Traffic Noise Propagation Survey

To accumulate basic data for the multiple regression analysis, a survey of traffic noise propagation was carried out near main roads in several residential areas in and around Kwang-ju. Fig. 1

is a photograph of one of these areas. Each survey area was limited to 100meters from the road. The purpose of this study was to investigate the propagation of traffic noise rather than changes in the absolute noise level due to traffic-related factors. Therefore, only survey areas where the road was flat, as is common in most Korean cities, and where the traffic volume and speed were relatively constant were chosen. This helped to eliminate any variations due to road structures, traffic volume, and driving speed. On all the roads in the noise survey areas, the traffic volume was estimated at above 2500 automobiles per hour. Accordingly, the effect of traffic volume on noise propagation was considered as only slight.

The survey consisted of noise measurements and investigations which took into consideration the location, size, and height of the buildings in a given survey area.

2.1. Noise Measurement

The attenuation of the noise levels from the road was calculated as the difference between the A-weighted sound level at the edge of the road and the A-weighted sound level at the receiver in the built-up area. This is represented as

$$\triangle L_{50} = L_{50(1)} - L_{50(2)} \qquad (1)$$

where $\triangle L_{50}$ is the attenuation of the noise level ; $L_{50(1)}$ is the A-weighted statistical sound level at the edge of the road which is exceeded for just 50% of the sample period, regarded as the power level of the noise source ; and $L_{50(2)}$ is the A-weighted statistical sound level at the receiver, which is the level of the propagated traffic noise. The expression L_{50} was used because it represents the standard for evaluating environmental noise in Korea, including traffic noise.

Each pair of L_{50} values, like those previously discussed, was simultaneously measured for 500 seconds by a pair of Rion Type noise level analyzers placed at a height of 1.2 meters. This is the standard height used in Korea to measure environmental noise. A total of 691 usable data samples of $\triangle L_{50}$ were accumulated. In fact, approximately 900 data samples were collected ; immediately after measuring, however, some 200 samples were disqualified because they were considered to be too highly influenced by noise from sources other than the road under consideration. This extraneous noise came from such sources as factories and construction sites, as well as automobiles and pedestrians in the immediate area of the receiver microphone.

2.2. Investigations of Buildings

To investigate the properties of the buildings that affected the traffic noise propagation, considerable data were obtained. These data included the size, height, and location of all the buildings in the survey area, in addition to the existence or non-existence of a direct path of noise propagation, which was determined by whether or not there was an unobstructed visual path between the receiver microphone and the noise source. Detailed building maps were compiled based on residential maps, however, confined and small barriers around the buildings were ignored because their effects were considered slight in comparison with those of the buildings themselves.

2.3. Survey Data

Fig. 1 shows the relation between $\triangle L_{50}$ and the distance from the road. The distance from the road was measured using the building map. Fig. 1 shows the difference between the $\triangle L_{50}$ values from where a direct path of noise propagation existed and the $\triangle L_{50}$ values from where there was no path. Note that where there was a direct path of noise propagation, the $\triangle L_{50}$ values were smaller on average than where there was no path. In the figure, as expected, there was also a strong correlation observed between $\triangle L_{50}$ and the distance from the road.

3. Correlation Analysis

Before the multiple regression analysis, two kinds of correlation analysis were carried out to select the predictors for the multiple regression model.

3.1. Calculation of Predictors

Many factors that potentially affect noise propagation were considered prior to the statistical analysis ; these factors are shown in Fig. 2. The following factors were considered for use in the

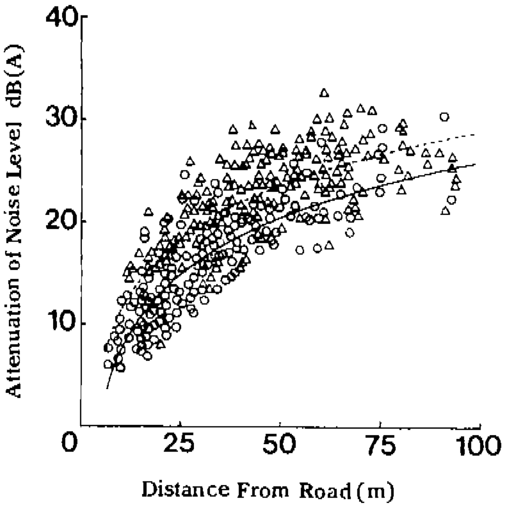
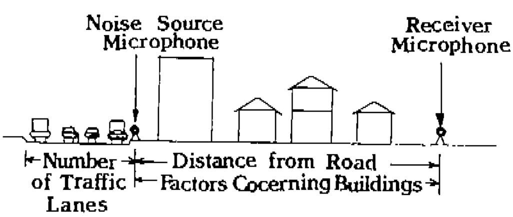


Fig. 1. Relationship between attenuation of noise level and distance from road.
-- ○ = existence of direct path of noise propagation
-- △ = no direct path

multiple regression analysis and were calculated as follows :

(a) *Distance from the Road.* Using building maps, the distance from the road was measured as the shortest distance from the receiver in the built-up area to the road.

(b) *Building Density.* This was calculated as a percentage of the total survey area affecting the propagation of the traffic noise. The building density was calculated using the following equation :



· Building Density
· Average Height of Buildings
· Density and Average Height of Buildings Adjacent to the noise-Source Road
· Height and Size of Buildings Around the Receiver Microphone
· Existence of a Direct Path of Noise Propagation

Fig. 2. Factors affecting propagation of traffic noise.

$$K=\frac{B}{A}\times 100 \quad (2)$$

where K is the building density, A is the total survey area which affects the propagation of the traffic noise, and B is the total area of the buildings in the given area.

In defining the appropriate size and shape of the area to be used for calculating the building density in the multiple regression analysis, several possibilities were considered, as illustrated in Fig. 3. Some of the more viable possibilities considered included a 90° triangle originating at each individual receiver microphone, as well as similar 60° and 30° triangular areas.

(c) *Height of Buildings.* Two kinds of factors were considered concerning the height of the buildings. One was the average height of the buildings in the area. This average height was calculated using the following equation :

$$H=\frac{\sum_{i=1}^{N}(Si\times i)}{\sum_{i=1}^{N}} \quad (3)$$

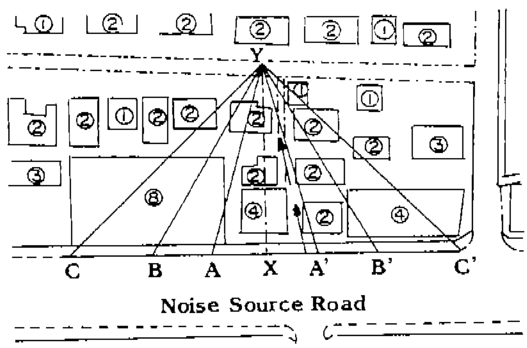


Fig. 3. Determination of appropriate size and shape of survey area.
X = noise source microphone, $L_{50(1)}$
Y = receiver microphone, $L_{50(2)}$
$\triangle AYA'$ = 30° triangular area
$\triangle BYB'$ = 60° triangular area
$\triangle CYC'$ = 90° triangular area
←← = a direct path of noise propagation
circle numbers = number of stories of each building

where H is the average height, in stories, of the buildings ; N is the number of stories of the highest buildings in the given area ; and Si is the total area of *i* story buildings. In Korea, the average height of one story is approximately 3 meters, however, for simplicity, the number of stories was used instead of meters. The other factor was the height, in stories, of the highest buildings in the given area. The average height and height of the highest buildings were calculated for each triangular area.

(d) *Factors Concerning First Row of Buildings Adjacent to the Road.* The first row of buildings adjacent to the road was considered to greatly influence the traffic noise propagation. Accordingly, two factors concerning the first row of buildings adjacent to the road were calculated. One was the building density of the first row only, and the other was the average height of the buildings in the first row only.

(e) *Factors Concerning Buildings Around the Receiver.* These factors were considered with regard to the buildings around the receiver. The first was the height of the building directly behind the receiver ; the second was the height of the building directly in front of the receiver between the receiver and the road which is the source of the noise ; and the third was the distance of the receiver to the building directly in front of it, which was calculated using the following equation :

$$G=\frac{D}{R} \tag{4}$$

where G is the non-dimensional value resulting from the division of D by R, D is the distance from the receiver to the building directly in front of the receiver, and R is the distance from the road to the receiver.

(f) *Existence of Direct Path of Noise Propagation.* Four kinds of factors were selected. One was based on the survey data obtained by visual investigation, and the other three were identified using the building maps for each triangular area.

(g) *Factor Related to the Road.* This factor was determined by the width of the road, measured based on the number of traffic lanes at the noise source.

All of the above factors were considered as predictors for the correlation analysis.

3.2. Correlation Between $\triangle L_{50}$ and Predictors

Table 1 shows the correlation coefficient between $\triangle L_{50}$ and the factors affecting the noise propagation. In the table, the building density and average height factors used a 30o triangular area when there was no significant difference between the results for the 30°, 60°, and 90° triangular areas. Also, the determination of a direct path of noise propagation was based on the survey data. The correlation coefficient of Table 1 indicated the following :

(a) The distance from the road had the highest correlation with $\triangle L_{50}$.

(b) The next highest correlation factor was how near the receiver was to the building directly in front of the receiver and the existence of a direct path of noise propagation.

(c) The third factor was the building density as well as the building density of the first row only.

(d) The number of traffic lanes only exhibited a slight correlation to $\triangle L_{50}$.

3.3. Correlation Among Predictors.

Table 2 shows the correlation coefficient between one of the predictors and the other predictors. As in Table 1, the density and height of the buildings were used for a 30° triangular area. The correlation coefficient of Table 2 indicated the following :

(a) The correlation coefficient between the building density of the first row only and the building density of the total given area was high.

(b) The factors related to building height had a high correlation with each other. One example of this was the relationship between the building height of the first row, the average height of the area, and the highest building, which exhibited a high correlation coefficient.

(c) The existence of a direct path of noise propagation had a high correlation with the nearness of the receiver to the building directly in front of it.

(d) The correlation coefficient between the average height of the buildings in the area and the height of the building directly in front of the receiver was relatively high.

From the results of these two correlation analyses, six factors were selected as predictors for the multiple regression analysis, including the distance from the road, the building density, the average height of the buildings, the height of the building directly behind the receiver, the existence of a direct path of noise propagation, and the number of traffic lanes at the noise source.

The five factors that were considered yet not included were the height and density of only the first row of buildings adjacent to the road, the height of the highest building in the area, the height of the building directly in front of the receiver, and the distance of the receiver to the building directly in front of it. These factors had a high correlation with those chosen above.

4. Multiple Regression Analysis Using Quantification Theory of the First Kind

4.1. Analysis Method

The prediction of a quantitative variable from plural quantitative predictors was accomplished using a multiple regression analysis.

In this study, the quantification theory of the first kind was used for the multiple regression analysis. The quantification theory of the first kind was improved by Dr. Chikio Hayashi of the Institute of Statistical Mathematics in Japan. The quantification theory of the first kind is one type of multiple regression analysis. It is used in cases where the dependent variable is quantitative and the predictors are qualitative. In this case the

Table 1. Correlation Coefficient Between Attenuation in Noise Level and Predictors

Correlation Coefficient Between Attenuation in Noise Level and Predictors	
Predictors	Correlation Coefficient
Distance from Road	0.78
Building Density	0.36
Average Height of Buildings	0.13
Height of Highest Building	0.19
Building Density of First Row Only	0.35
Average Height of Buildings of First Row Only	0.10
Height of Building Directly Behind Receiver	0.20
Height of Building Directly in Front of Receiver	0.25
Nearness of Receiver to Building Directly in Front of Receiver	-0.57
Existence of a Direct Path of Noise Propagation	0.57
Number of Traffic Lanes	0.07

Table 2. Correlation Coefficient among Predictors

CORRELATION COEFFICIENT AMONG PREDICTORS											
Predictors	*R*	*K*	*H*	*MH*	*KI*	*HI*	*B*	*F*	*G*	*C*	*L*
R	1.00										
K	0.15	1.00									
H	0.13	0.42	1.00								
MH	0.23	0.39	0.88	1.00							
KI	0.15	0.78	0.42	0.37	1.00						
HI	0.14	0.32	0.91	0.90	0.32	1.00					
B	0.18	0.23	-0.02	-0.02	0.21	-0.05	1.00				
F	0.17	0.54	0.60	0.50	0.52	0.47	0.24	1.00			
G	-0.34	-0.59	-0.14	-0.15	-0.54	-0.07	-0.45	-0.55	1.00		
C	0.36	0.41	0.17	0.20	0.41	0.12	0.40	0.43	-0.70	1.00	
L	0.16	0.08	0.04	0.05	0.05	0.05	0.02	0.05	0.03	0.02	1.00

(R=distance from road ; K=building density ; H=average height of buildings ; MH=height of highest building ; KI=building density of first row only ; HI=average height of buildings of first row only ; B=height of building directly behind receiver ; F=height of building directly in front of receiver ; G=nearness of receiver to building directly in front of receiver ; C=existence of a direct path of noise propagation ; L=number of traffic lanes) predictors are the various factors affecting traffic noise propagation and the dependent variable is the attenuation of the noise level. The predictors may also include non-quantitative variables, in this case, the existence of a direct path of noise propagation. This theory can be used in much the same way as a multiple regression analysis by converting the quantitative data into categorized data. The quantification theory of the first kind is equal to a multiple regression equation utilizing dummy variables, expressed in this paper by the symbol δ, which have a value of 0 or 1.

In the quantification theory of the first kind, the numerical score is given by the method of least squares, namely, the numerical score makes a maximum correlation coefficient between the measured value and the estimated value. The numerical scores of the quantification theory of the first kind have almost the same meaning as the partial regression coefficient of the multiple regression equation. The numerical score of each category indicates the contribution to the dependent variable, in this case, the attenuation of the noise level measured. As the numerical score pattern of each predictor indicates the relationship between the predictor and the dependent variable, this theory is useful for investigating the special relationship between the predictor and the dependent variable, such as a nonlinear relationship.

4.2. Multiple Regression Model

A multiple regression analysis using the quantification theory of the first kind was performed several times by substituting three of the six factors mentioned above into triangular areas with apex angles of 30°, 60°, and 90°. After investigating the different possibilities, the average height of the buildings and building density, calculated using a 60o triangle originating at each individual receiver microphone, were determined as the predictors of the multiple regression model since they resulted in the highest multiple correlation coefficient. For this same reason, the existence of a direct path of noise propagation was determined using the survey data gathered by visual inspection.

The multiple regression model obtained by the quantification theory of the first kind can be expressed as followed :

$$\triangle L_{50} = f(R.\ C.K.H.B.L) = \sum_{j=1}^{6} \sum_{k=1}^{kj} \delta(jK) XjK + \triangle L_{50} \qquad (5)$$

where R is the distance from the road ; C is the existence of a direct path of noise propagation ; K is the building density ; H is the average height of the buildings ; B is the height of the building directly behind the receiver ; L is the number of traffic lanes at the noise source ; kj is the number of categories in the j-th predictor ; if δ (jk) is equal to 1, the data falls in the k-th category of the j-th predictor ; if δ (jk) is equal to 0, it does not ; Xjk is the numerical score in the k-th category of the j-th predictor ; and $\triangle L50$ is the mean of the $\triangle L50$ values measured. Concerning δ (jk) in the j-th predictor, the following relation holds :

$$\sum_{K=1}^{Ki} \delta(jK) = 1 \qquad (6)$$

4.3. Numerical Score and Partial Correlation Coefficient

The results of the multiple regression analysis using this quantification theory of the first kind produced numerical scores for all the categories along with the partial correlation coefficient between each predictor and the attenuation of the noise level, as shown in Table 3. The numerical scores in each category indicate the magnitude of the effect on the noise propagation. The multiple correlation coefficient of the multiple regression model was evaluated as 0.876. This value is high enough for this multiple regression model to be used to explain $\triangle L_{50}$.

Fig. 4 shows the close relationship between the values estimated by the multiple regression model and the actual data.

4.4. Relationship Between Number of Predictors and Multiple Correlation Coefficient

Fig. 5 shows the increase in the multiple correlation coefficient relative to the number of predictors. This figure demonstrates that the distance from the road made the greatest contribution to increasing the multiple correlation coefficient. The second and third contributors were the existence of a direct path of noise propagation and the building density, respectively. The multiple correlation coefficient was evaluated to be 0.85 based on these three predictors.

4.5. Contribution of Factors Affecting Noise Propagation

In the quantification theory of the first kind, the partial correlation coefficient and range between the maximum and minimum numerical scores in each predictor can generally be used as an index of contribution thereby explaining the dependent variable, in this case, the attenuation of the noise level $\triangle L_{50}$.

Fig. 6 shows the range of scores and contribution to the attenuation of the noise level for each predictor. Using the partial correlation coefficient and score pattern in Table 3 and the increase in the multiple correlation coefficient and range of scores in Fig. 6, the contribution of each predictor in the analysis of $\triangle L_{50}$ can be described as follows :

(A) The distance from the road made the most significant contribution to the value of $\triangle L_{50}$. Its range was 11.5dB(A) and accounted for 49% of $\triangle L_{50}$. As expected, $\triangle L_{50}$ increased with distance.

(b) The second contributors was the existence

Table 3. Multiple regression model using the quantification theory of the first kind(all partial correlation coefficients were statistically significant, the uncertainty limit[11] was 0.098, $P < 0.01$)

PREDICTORS	CATEGORIES	% OF DATA SAMPLE	NUMERICAL SCORE	PARTIAL CORRELATION COEFFICIENT
DISTANCE FROM ROAD[m]	0-20	18	-6.2	0.77
	20-40	40	-1.4	
	40-60	29	2.9	
	60-80	10	4.6	
	80-	3	5.3	
EXISTENCE OF A DIRECT PATH OF NOISE PROPAGATION	EXISTENCE	54	-2.2	0.48
	NONEXISTENCE	46	1.3	
BUILDING DENSITY[%]	0-10	9	-2.0	0.28
	10-20	13	-0.9	
	20-30	24	-0.3	
	30-40	26	0.5	
	40-50	17	0.8	
	50-	11	1.0	
AVERAGE HEIGHT OF BUILDINGS [NUMBER OF STORIES]	0	2	-1.0	0.26
	1.0-1.5	14	-0.2	
	1.5-2.5	58	0.4	
	2.5-3.5	14	0.3	
	3.5-4.5	4	0.3	
	4.5-5.5	3	-1.1	
	5.5-6.5	2	-1.5	
	6.5-	3	-3.0	
HEIGHT OF BUILDING DIRECTLY BEHIND RECEIVER[NUMBER OF STORIES]	0	42	0.3	0.13
	2	12	0.3	
	2	44	-0.4	
	3	2	-1.1	
NUMBER OF TRAFFIC LANES	2	30	0.1	0.11
	4	40	0.3	
	6	30	-0.5	
MEAN VALUE OF MEASURING ATTENUATION OF NOISE LEVEL ; $\triangle L_{50}$ =19.3dB(A)			MULTIPLE CORRELATION COEFFICIENT ; 0.876	

of a direct path of noise propagation. This predictor had a range of 3.5dB(A), accounting for 15% of $\triangle L_{50}$.

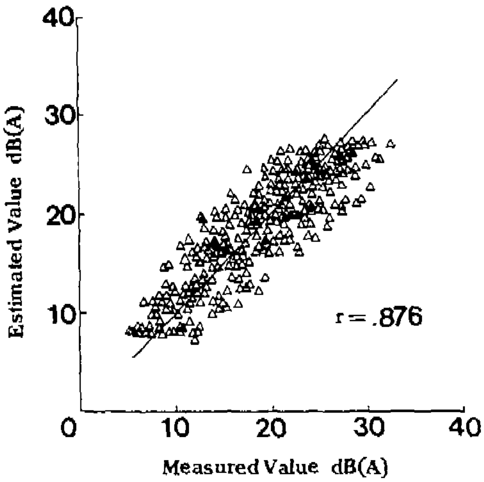


Fig. 4. Relationship between measured and estimated values ; r equals the correlation coefficient between the measured and estimated values.

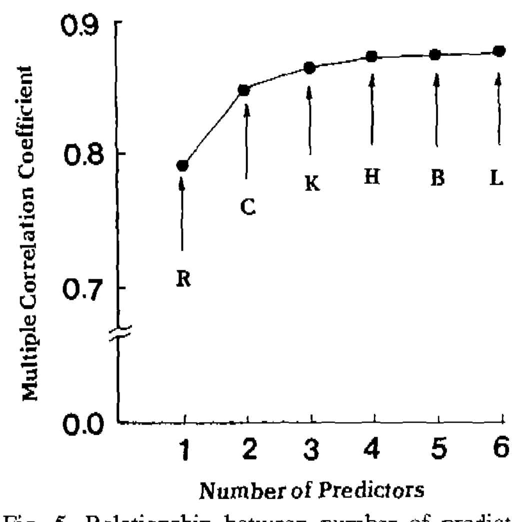


Fig. 5. Relationship between number of predictors and multiple correlation coefficients.
R = distance from road
C = existence of a direct path of noise propagation
K = building density
H = average height of buildings
B = Height of building directly behind receiver
L = number of traffic lanes

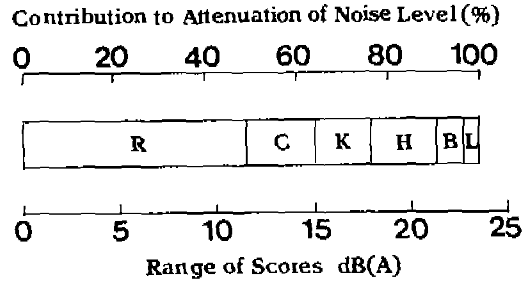


Fig. 6. Range of sources and contribution to attenuation of noise level for each predictor.
R = distance from road
C = existence of a direct path of noise propagation
K = building density
H = average height of buildings
B = height of building directly behind receiver
L = number of traffic lanes

(c) The building density affected $\triangle L_{50}$ considerably. The range for the building density was 3.0dB(A), which accounted for 13% of $\triangle L_{50}$. As the building density increased, so did $\triangle L_{50}$.

(d) The average height of the buildings also affected $\triangle L_{50}$ considerably. The range for the average building height was 3.4dB(A) and this accounted for 15% of $\triangle L_{50}$. When the average height of the buildings was higher than four stories, $\triangle L_{50}$ decreased. At this point, this tendency cannot be fully explained, because the quantification theory of the first kind requires an number of data samples in each predictor category, however, in this study, the volume of the survey data for an average building height of over four stories was relatively small. This is a subject for future study.

(e) As the height of the building behind the receiver increased, $\triangle L_{50}$ decreased. This tendency seemed to be caused by the reflection of the building. Its range was 1.4dB(A) and accounted for 6% of $\triangle L_{50}$. It should be noted that in the calculations there was no significant difference between the reflection of a one-story building and no building. However, this is difficult to explain. Perhaps, since the effect was nominal the calculation did not show the expected results.

(f) The number of traffic lanes had a range of 0.7dB(A), accounting for only 3% of $\triangle L_{50}$, a very limited contribution.

5. Conclusions

In conclusion, as a result of an analysis using the quantification theory of the first kind, three major factors that affect traffic noise propagation were identified. The results in order of their significance are as follows :

(a) The distance from the road is the chief factor in noise propagation.
(b) The second major contributor is the existence of a direct path of noise propagation.
(c) The building density and average height of all the buildings in the given area have a considerable affect on noise propagation .

As the relative contribution of each factor in traffic noise propagation was accounted for in this paper, it would seem likely that a considerable noise reduction would result from controlling these factors. It is hoped that through the proper control of the factors outlined in this paper, traffic noise pollution can be reduced, especially in urban areas.

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References

[1] M. E. Delany., A. J. Rennie and K. M. Collines., 1978, A Scale Model Technique for Investigation Traffic Noise Propagation, Journal of Sound and Vibration, 56(3), 325 ~ 340.

[2] H. W. Jones., D. C. Stredulinsky and P. J. Vermeulen., 1980, An Experimental and Theoretical Study of the Modelling of Road Traffic Noise and its Transmission in the Urban Environment, Applied Acoustics, 13(3), 251 ~ 265.

[3] H. Kuttruff., 1982, A Mathematical Model for Noise Propagation between Buildings, Journal of Sound and Vibration, 85(1), 115 ~ 128.

[4] J. S. Bradley., A Study of Traffic Noise Attenuation Around Buildings, ACUSTICA, 38(4), 247 ~ 252.

[5] A. Lawrence and M. Burgess., 1980, Measurement of Traffic Noise Shielding Provided by Buildings, Applied Acoustics, 13(3), 211 ~ 225.

[6] Z. Maeka., 1962, Experimental Study on Acoustical Designing of a Screen for Noise Reduction, Journal of Acoustical Society of Japan, 18(4), 187 ~ 196.

[7] E. A. G. Shaw and N. T. Olson, 1972, Theory of Steady State Urban Noise for an Ideal Homogeneous City, Journal of the Acoustical Society of America, 51, 1781 ~ 1793.

[8] C. Hayashi., 1952, On Prediction of Phenomena from Qualitative Data and Quantification of Qualitative Data from the Mathematical-Statistical Point of View, Annals of the Institute of Statistical Mathematics, 3(2), 69 ~ 98.

[9] C. Hayashi., 1954, Multidimensional Quantification with the Applications to Analysis of Social Phenomena, Annals of the Institute of Statistical Mathematics, 5(2), 121 ~ 143.

[10] S. Yasuda and M. Umino., 1977, Shakai Tokeigaku, Social Statistical, Maruzen Co. Tokyo.

[11] R. A. Fisher., 1963, Statistical Methods for Research Workers, Oliver and Boyd Ltd., London.