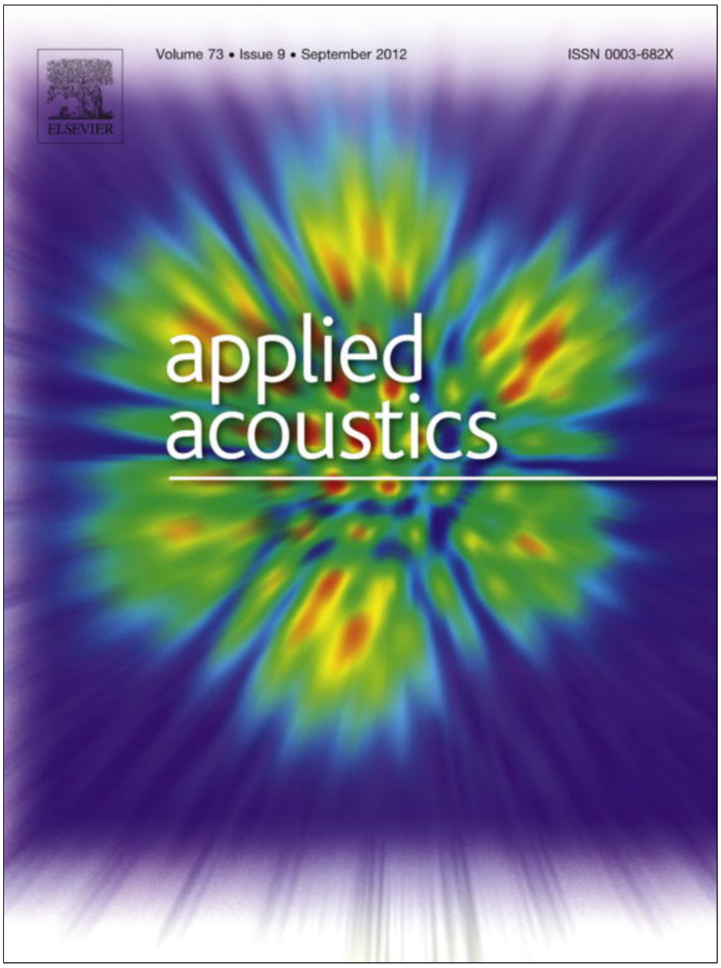
Volume 73 • Issue 9 • September 2012
ISSN 0003-682X
ELSEVIER
applied acoustics

Applied Acoustics 73 (2012) 952–959

Contents lists available at SciVerse ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Comparison of models to predict annoyance from combined noise in Ho Chi Minh City and Hanoi

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ARTICLE INFO

Article history:
Received 24 June 2011
Received in revised form 21 February 2012
Accepted 6 April 2012
Available online 30 April 2012

Keywords:
Annoyance
Road traffic noise
Aircraft noise
Combined noise models

ABSTRACT

Seven models were compared in terms of the ability to predict the annoyance due to the combination of aircraft and road traffic noises on the basis of data collected around airports in Ho Chi Minh City and Hanoi, Vietnam. The 24-h average sound levels $L_{Aeq,24h}$ and unweighted means of annoyance scores for aircraft, road traffic, and combined noise were used to solve the regression equations for the seven models. The results indicate that road traffic noise exposure and annoyance were more than those of aircraft noise at almost all sites in both Ho Chi Minh City and Hanoi. Among the considered models, the dominant source model yielded the highest coefficients of determination, with R^2 values of 0.82 and 0.90 for surveys in Ho Chi Minh City and Hanoi, respectively. These results suggest that the dominant source model is the most useful model in the vicinity of those airports in Vietnam where road traffic noise is more dominant than aircraft noise. This is convenient for situations in which dose-response curves are established separately for different noise sources.

1. Introduction

Various types of noise coexist within any living environment and induce annoyance in the community. Assessment of community annoyance with noise is very complex. Many studies have pointed out that the perception of noise by humans depends not only on its loudness, but also on its components, the source characteristics, and so on. Miedema and Vos [1] fitted a model of annoyance as a function of noise exposure to data from a very large set of social surveys and then presented curves for three types of noise sources: aircraft, road traffic, and railway. These relationships are valid in the range from 42 dB to 75 dB and point out that aircraft noise is more annoying than road traffic noise, which in turn is more annoying than railway noise, for a given noise level. Subsequently, these exposure–response relationships have been proved effective in assessing community responses to noise, and they have been widely used to draft noise-related policies and guidelines in many countries, especially in Europe.

However, it has been shown that many residential communities are exposed not to a single noise source but to multiple noise sources. Especially in the urban areas of densely populated cities, interference occurs among the many noises associated with the flow of a variety of vehicles. Recently, in addition to studies on the annoyance caused by a single noise source, a significant amount of research on the environmental effects of synthetic noise has been reported. The combined effects of road traffic and aircraft have been studied by Brink and Lercher [2] using the data from two surveys on aircraft noise annoyance in the vicinity of Zurich Airport. It was found that the aircraft noise annoyance was modified by additional road traffic noise, although the effect was not very strong. On the other hand, the exposure-effect curve for road traffic noise annoyance became flatter as aircraft noise exposure increased, and the trend was negative when aircraft noise exposure was more than 56.7 dB L_{Aeq}. A study of annoyance response to mixed noise from road traffic and railway was undertaken by Lam et al. [3] in Hong Kong and compared the determination of combined noise annoyance when the road traffic noise or railway noise is dominant. When the road traffic noise dominates, the annoyance is primarily determined by activity disturbance caused by the peaks in railway noise. When the railway noise dominates, the peaks in train events can induce annoyance response directly without causing activity disturbance.

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0003-682X/$ - see front matter
http://dx.doi.org/10.1016/j.apacoust.2012.04.005

This paper was inspired by the work of Taylor [4], which compared the abilities of five models to predict annoyance reaction to mixed sources using data from the vicinity of Toronto International Airport. The results indicated that the energy difference model is the best predictor of mean total annoyance and the simple energy summation model is the worst. This finding confirmed the importance of absolute level differences between sources. Taylor also emphasized the need for studies adding to the evidence provided by his analysis.

The socio-acoustic surveys were conducted in the vicinities of the airports of the two largest cities in Vietnam, where busy highways and roads concentrate. The residents are exposed to not only aircraft noise, but also road traffic noise [5]. Therefore, the impact of aircraft noise in Vietnam should be assessed in association with the impact of road traffic noise. It is noteworthy that all sites exposed to aircraft noise around the main airports in Vietnam were also exposed to heavy road traffic noise and that the characteristics of the noise around the airports in Vietnam are different from those around the Toronto International Airport, investigated by Taylor. Hence, the social survey on the combined noise of aircraft and road traffic in Vietnam can provide the material to conduct further analysis in order to extend the discussion on a valid rating model for combined noise sources. In addition to the five models reviewed by Taylor, the present study takes into consideration two other models: the "annoyance equivalents model" [6] and the "dominant source model" developed by Rice and Izumi [7].

The purpose of this study is to find the best model for rating the annoyance caused by the combined noise sources in Vietnam from the policy-oriented viewpoint because a sufficient number of combined noise models have been proposed.

2. Combined noise models

In this study, seven models are compared in terms of the ability to predict the annoyance due to the combination of aircraft and road traffic noises. This section gives an overview of the seven models that have so far been proposed to evaluate the annoyance due to a combined noise source. The first is the energy summation model, whereby the total annoyance is predicted from the total noise level calculated as an energy sum of the separate sources. The second is the independent effects model, in which the separate sources are assumed to make independent contributions to the total annoyance. The next three models are energy summation models with different correction factors to account for interactions between the separate sources. The sixth model is the annoyance equivalents model, which translates the noises from the individual sources into equally annoying sound energy levels of a reference source and then sums these levels to calculate the total noise level. The last model is the dominant source model, in which the total annoyance is equal to the maximum of the single source annoyances.

2.1. Energy summation model

In the energy summation model, the total annoyance is expressed as

$$A = f(L_{\mathrm{T}})$$

where A is the annoyance response to the combined sources, and L_T is the total noise level calculated as an energy sum of separate sources L_i.

$$L_{\mathrm{T}} = 10\log\sum_{i=1}^{n}10^{L_i/10}$$

This model is based on the assumption that the annoyance caused by combined noise sources can be predicted by the total energy.

2.2. Independent effects model

In the independent effects model, the total annoyance is expressed as

$$A = f_1(L_1) + f_2(L_2) + \cdots + f_n(L_n)$$

where A is the annoyance response to the combined sources, while $L_1, L_2, \ldots, L_n$ are separate source L_{Aeq} values and $f_1(L_1), \ldots, f_n(L_n)$ are functions determined for each source. This model is based on the assumption that the separate sources make independent contributions to the total annoyance.

2.3. Energy difference model

In the energy difference model, the total annoyance is expressed as

$$A = f_1(L_{\mathrm{T}}) - f_2(|L_1 - L_2|)$$

where A is the annoyance response to the combined sources, L_T is the total L_{Aeq} from the combined sources, L_1 is the L_{Aeq} from the first source, L_2 is the L_{Aeq} from the second source, $f_1(L_T)$ is the function determined for the total L_{Aeq} from the combined sources, and $f_2(|L_1 - L_2|)$ is the function determined for the absolute difference between the source L_{Aeq} values. The model includes a correction factor to take account of the absolute difference between the L_{Aeq} values of the separate sources. The application of this model is limited to situations involving only two types of contributing sources.

2.4. Response-summation model [8]

In the response-summation model, the total annoyance is expressed as

$$A = f(L_{\mathrm{T}} + \sum_{i=1}^{n}D_i 10^{(L_i - L_{\mathrm{T}})/10})$$

where A is the annoyance response to the combined sources and L_T is the total L_{Aeq} from the combined sources. In this model, the expression for the annoyance includes a correction factor in addition to the total L_{Aeq}. The model is guided by the condition that if the component source L_i dominates the combined level L_T, the total annoyance response A must equal the response to the single source i.

2.5. Summation and inhibition model [9]

In the summation and inhibition model, the total annoyance is expressed as

$$A = f(L_{\mathrm{T}} + E)$$

where A is the annoyance response to the combined sources, L_T is the total L_{Aeq} from the combined sources, and E is a correction factor for the summation and inhibition effects among the sources. A graph was provided by Powell [5] to obtain values of E for the level difference D between two sources with the same annoyance (Fig. 1). In this study, the value of D is 12 for Ho Chi Minh data, 7 for Hanoi data, and 12 for the synthesized data of both cities. The model is based on the assumption that a total annoyance reaction to combined sources is a sum of the inhibited subjective magnitudes of the component noise sources.

2.6. Annoyance equivalents model [6]

In the annoyance equivalents model, the total annoyance is expressed as

$$A = f(L).$$

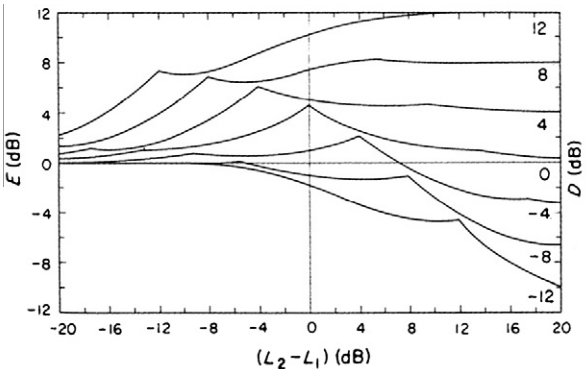

Fig. 1. Correction factor to account for summation and inhibition [4].

This model translates the noises from the individual sources into equally annoying sound energy levels of a reference source and then sums these levels. Fig. 2 illustrates this for two different sources (A and B). The level L_B of source B is transformed into the equally annoying level of source A. Then, L_A is added to the level of the reference source on the basis of an energy summation, giving L. The corresponding annoyance from the combined sources is found by using the exposure-annoyance relationship expressed in the previous equation.

2.7. Dominant source model [7]

In the dominant source model, the total annoyance is expressed as

$$A = f(A_D)$$

where A is the annoyance response to the combined sources, $A_D = \max\ [h_j\ (L_j)_j]$, and h_j is the exposure-annoyance function for source j. This model is based on the assumption that the total annoyance is equal to the maximum of the single source annoyances.

3. Data collection

3.1. Site selection

Tan Son Nhat Airport in Ho Chi Minh City and Noi Bai Airport in Hanoi are the two largest international airports in Vietnam. However, their handling capacities were considerably different. The average number of flights per day in Noi Bai Airport was 154, while this figure for Tan Son Nhat Airports was 225 during the measurement periods. Ten residential sites around Tan Son Nhat Airport were selected, consisting of eight sites under the approach and departure paths of aircraft and two sites to the north and south of the runway. Nine sites around Noi Bai airport were selected, consisting of seven sites under the approach and departure paths of aircraft and two sites to the south of the runway. The site selection was intended to reflect the aircraft noise exposure by including locations at various distances and directions relative to the airport. All houses selected from the combined noise areas at each site were facing the road, with various traffic volumes in the vicinities of the airports. Tan Son Nhat Airport is located in a crowded residential area of Ho Chi Minh City and is surrounded by busy commercial streets. Noi Bai Airport is located in a scattered rural area 45 km away from downtown Hanoi, but right at the hub of many national arterial roads and industrial zones. Since the situations in the vicinities of the two airports were quite different, the validity of the models will be examined for the data of each airport separately.

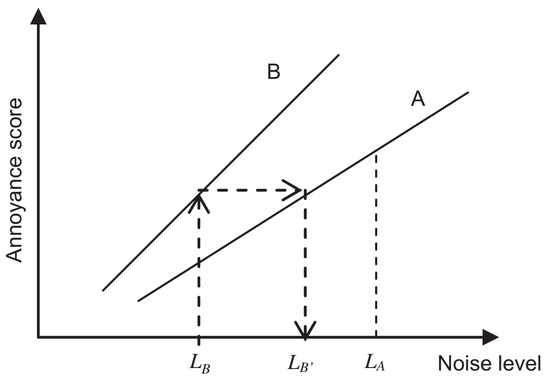

Fig. 2. Illustration of the annoyance equivalents model.

3.2. Social surveys

Social surveys on the community response to aircraft noise and combined noise from aircraft and road traffic were conducted around Tan Son Nhat Airport in Ho Chi Minh City from August to September of 2008 and then around Noi Bai Airport in Hanoi from August to September of 2009. Community responses were obtained through an interview questionnaire presented as a social survey on the living environment. The responses to combined noise sources were collected from residents of the houses that faced the roads and were presumably exposed to noise from both aircraft and road traffic.

In the questionnaire, a 5-point verbal scale and an 11-point numeric scale were used to evaluate the noise annoyance of each respondent. These two scales were constructed according to the method of the International Commission on Biological Effects of Noise (ICBEN) [10]. The respondents were asked to evaluate their annoyance with all three types of noise sources: aircraft, road traffic, and the combination of both. In this paper, the data from the 11-point numeric questionnaire are considered. The wording of the numeric questionnaire is shown in Appendix A.

Ho Chi Minh City and Hanoi have different climatic and social conditions. Fig. 3 compares the house ownership status of the respondents in Ho Chi Minh City and Hanoi. This reveals that the percentage of respondents living in their own houses was higher in Hanoi than in Ho Chi Minh City. The percentage of respondents who had lived in their houses for over 20 years was also higher in Hanoi than in Ho Chi Minh City (Fig. 4). Both cities are major economic centers in Vietnam and thus attract great numbers of migrants from the neighboring areas. This assertion is consistent with the findings of Douglass et al. 2002 that the migration rates of interprovincial migrants are 23% and 8% for Ho Chi Minh City and Hanoi, respectively. Ho Chi Minh City has a tropical climate with consistently high temperatures. Hanoi lies in the north and has a monsoonal climate with heavy rainfall during a hot summer and scant rainfall during a cold winter. This might cause a different habituation in the population of each city.

3.3. Noise measurements

Noise measurements were performed in Ho Chi Minh City from September 22–29, 2008, and in Hanoi from September 10–17, 2009, with the same method. The combined noise of aircraft and road traffic was measured on the road shoulder every 1 s for 24 h. Aircraft noise exposure was measured every 1 s for seven successive days by using sound level meters (RION NL-21 and NL-22) on the rooftop of the house, away from the road, and thus, mainly exposed to aircraft noise. Flight numbers and conditions were

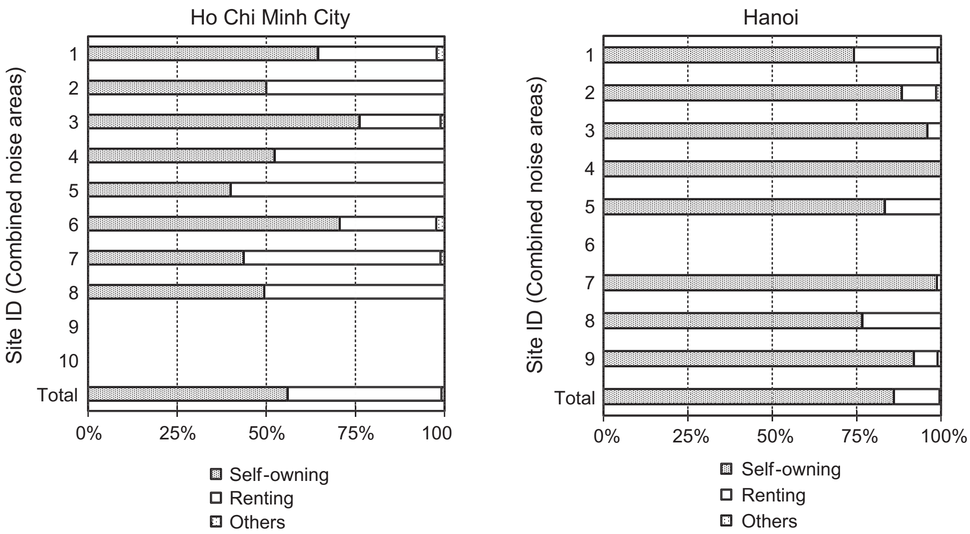

Fig. 3. Distributions of respondents by house ownership status.

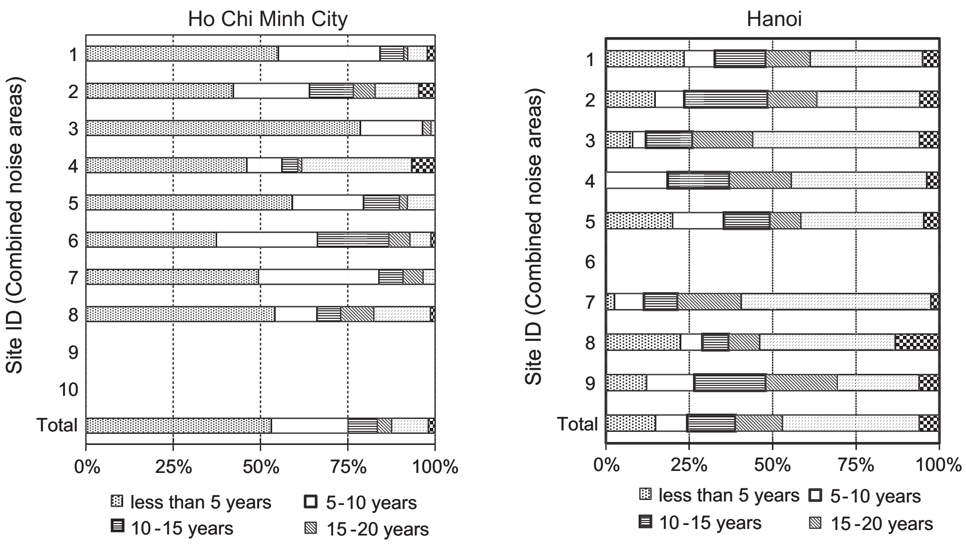

Fig. 4. Distributions of respondents by length of residence.

obtained from the home page of the airport offices (Fig. 5). Table 1 summarizes some of noise indexes calculated for aircraft noise exposure in Ho Chi Minh City and Hanoi.

Road traffic noise metrics were calculated by energy subtraction of aircraft noise metrics from combined noise metrics. The aircraft and combined noise exposures in Ho Chi Minh City ranged from 53.2 to 70.6 dB and from 73.4 to 82.5 dB in L_{den} (from 49.4 to 65.8 dB and from 69.4 to 76.9 dB in $L_{Aeq,24h}$) and those in Hanoi ranged from 48.0 to 61.1 dB and from 70.1 to 81.8 dB in L_{den} (from 44.2 to 56.8 dB and from 68.8 to 77.9 dB in $L_{Aeq,24h}$), respectively. $L_{Aeq,1h}$ at all sites in Ho Chi Minh City and Hanoi are shown Figs. 6 and 7, respectively.

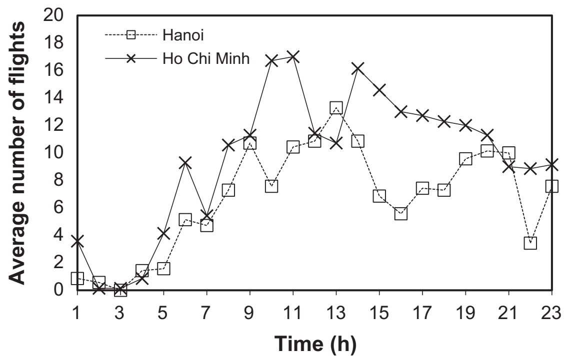

Fig. 5. Number of flights in Ho Chi Minh City and Hanoi.

4. Results and discussion

4.1. Statistical analysis

In this section, the data are used to examine the validity of the combined noise models. The annoyance at each site was calculated from the unweighted mean of the individual annoyance scores. The 24-h average sound level $L_{Aeq,24h}$ and the average annoyance scores for aircraft, road traffic, and combined noise that were obtained from the surveys in Ho Chi Minh City and Hanoi are summarized in Tables 2 and 3, respectively. In Ho Chi Minh City, aircraft noise

Table 1
Noise indexes of aircraft noise exposure in Ho Chi Minh City and Hanoi.

Noise index (dB)	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8	Site9	Site10
Ho Chi Minh										
$L_{Aeq,day}$ (07:00–19:00)	55.8	51.2	50.1	53.1	66.7	59.6	60.1	57.4	56.8	55.0
$L_{Aeq,evening}$ (19:00–22:00)	54.9	47.3	48.2	52.7	67.7	60.9	61.7	58.4	57.8	55.2
$L_{Aeq,night}$ (22:00–07:00)	51.5	44.7	48	49.2	61.7	55.8	57.7	54.8	54.2	52.6
L_{den}	59.3	53.2	55.1	57.2	70.6	64.2	65.6	62.3	61.7	60
Hanoi										
$L_{Aeq,day}$ (07:00–19:00)	50.6	52.1	58.0	53.9	45.9	46.6	54.3	57.3	48.6	
$L_{Aeq,evening}$ (19:00–22:00)	52	51.7	59.3	53.9	44.2	44.1	53.5	55.3	45.1	
$L_{Aeq,night}$ (22:00–07:00)	46.7	48.8	51.3	44.2	39.5	41.2	48.3	53.8	45.2	
L_{den}	54.7	56.2	60.9	56.3	48	49.2	56.8	61.1	52.4	

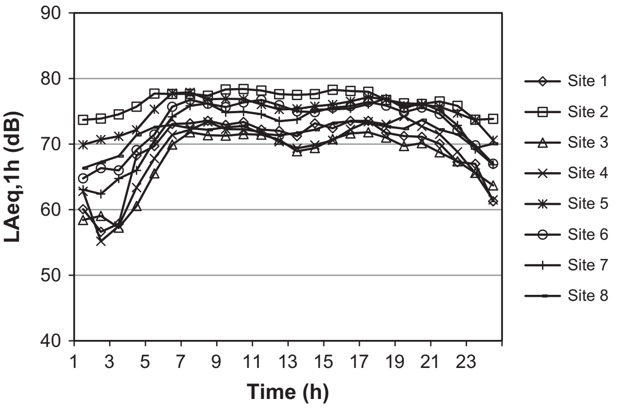

Fig. 6. Average road traffic noise exposure for every hour at all sites in Ho Chi Minh City.

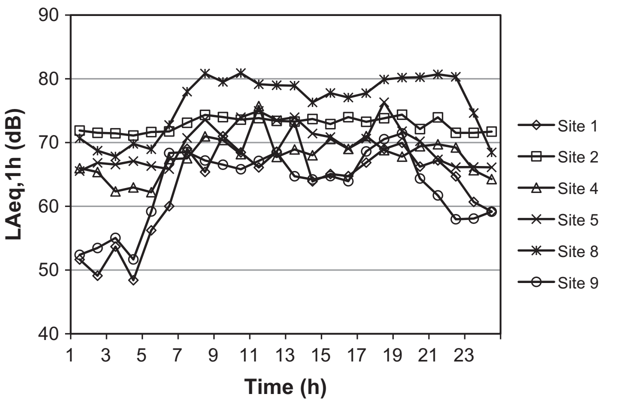

Fig. 7. Average road traffic noise exposure for every hour at all sites in Hanoi.

Table 2
Noise exposure and annoyance data for Ho Chi Minh City.

Site ID	Noise level L_{Aeq} (dB)			Mean annoyance score			*N*
	Aircraft	Road	Combined	Aircraft	Road	Total	
1	54.2	71.1	71.2	3.2	4.3	4.4	59
2	49.4	76.9	76.9	0.5	8.9	8.9	57
3	49.4	69.3	69.4	7.7	3.8	5.9	54
4	52.0	70.7	70.7	2.7	4.1	3.5	88
5	65.8	75.1	75.6	7.0	7.8	8.2	87
6	59.0	74.3	74.5	5.4	6.6	5.7	84
7	59.8	73.8	74.0	6.3	4.2	4.9	85
8	56.8	71.8	71.9	5.9	7.1	7.0	85

N is the number of respondents.

Table 3
Noise exposure and annoyance data for Hanoi.

Site ID	Noise level L_{Aeq} (dB)			Mean annoyance score			*N*
	Aircraft	Road	Combined	Aircraft	Road	Total	
1	49.8	66.5	66.6	1.6	4.7	4.0	94
2	51.0	72.9	73.0	3.3	8.4	7.7	67
3	56.8	72.8	73.0	7.9	8.4	8.6	51
4	52.5	68.9	69.0	7.7	7.9	8.0	26
5	44.2	71.1	71.1	3.3	7.8	6.8	67
7	52.7	71.0	71.1	2.7	7.5	7.3	73
8	56.1	77.9	77.9	4.5	8.0	7.8	59
9	47.2	65.7	65.8	3.1	6.4	5.0	92

N is the number of respondents.

exposure ranged from 49.4 to 65.8 dB while road traffic noise exposure ranged from 69.3 to 76.9 dB. The average annoyance scores ranged from 0.5 to 7.7 for aircraft noise and from 3.8 to 8.9 for road traffic noise. In Hanoi, aircraft noise exposure ranged from 44.2 to 56.8 dB while road traffic noise exposure ranged from 65.7 to 77.9 dB. The average annoyance scores ranged from 1.6 to 7.9 for aircraft noise and from 4.7 to 8.4 for road traffic noise. Road traffic noise exposure and annoyance were more than those of aircraft noise, except at Sites 3 and 7 in Ho Chi Minh City.

The situation of the sites surveyed by Taylor was quite different [4]. The noise levels obtained in that study were from 55.6 to 71.1 dB for aircraft noise and from 52.2 to 69.9 dB for road traffic noise. The average annoyance scores were from 2.17 to 6.46 for aircraft noise and from 0.13 to 4.33 for road traffic noise. The aircraft noise and road traffic noise were physically comparable but the aircraft noise was psychologically dominant. Such data indicate the different combinations of aircraft and road traffic noises in the two studies. Moreover, even though an 11-point numeric scale (0–10) was used in both surveys, the end point was labeled "extremely annoyed" in our study but "unbearably disturbed" in Taylor's.

A linear regression analysis was applied to estimate the effects of aircraft and road traffic noise exposure on annoyance. The individual annoyance scores and noise data are used to formulate the regression equations, in which the aircraft $L_{Aeq,24h}$ (L_{AC}), the road traffic $L_{Aeq,24h}$ (L_{RT}), and the cross product of L_{AC} with L_{RT} ($L_{AC} \times L_{RT}$) are used as independent variables to explore the contributions to the total, aircraft, and road traffic annoyances. The results are listed in Table 4. The aircraft $L_{Aeq,24h}$ had an effect on total annoyance at significance levels of $p < 0.05$ and $p < 0.01$ in Ho Chi Minh City and Hanoi, respectively. Total annoyance in Hanoi was influenced by road traffic $L_{Aeq,24h}$ at the significance level of $p < 0.01$. The influences of both aircraft and road traffic noises are opposite for the two cities; that is, negative for Ho Chi Minh City and positive for Hanoi. By contrast, the interference of two sources has a positive effect on total annoyance in Ho Chi Minh City but a negative one in Hanoi. These findings emphasize the difference in the composition of total annoyance between the two cities. It is noteworthy that, while aircraft annoyance has opposite mechanisms, road traffic annoyance shows the same composition in both cities. Moreover, no factor other than road traffic $L_{Aeq,24h}$ significantly affects road traffic annoyance. In other words, road traffic annoyance is independent of the effect of aircraft noise as well as the cross product of aircraft and road traffic noises. These findings imply that the road traffic noise has a dominant role in the mixed noise environments of all the surveyed sites around the Tan Son Nhat and Noi Bai Airports, which are exposed to very heavy road traffic.

Next, a multiple regression analysis was applied to compare how well the seven models predict the data observed in Ho Chi Minh City and Hanoi (Table 5). The regression equations are calculated by fitting a model to the data such that the sum of the squared differences between the fitted line and the data points is minimized. The coefficient of determination R^2 indicates the percentage to which the model accounts for the variability in the total noise annoyance. The standard error of the estimate is the amount of variability in the points around the regression line.

The coefficient of determination R^2 of the regression equations for the Ho Chi Minh City data indicated that the energy difference model ($R^2 = 0.49$) estimated the total annoyance better than the energy summation, independent effects, response summation, summation and inhibition, and annoyance equivalents models ($R^2 = 0.25$–0.48). This result is consistent with the study of Toronto International Airport by Taylor. The regression equations of the seven models for the Hanoi data indicated that the energy difference model ($R^2 = 0.58$) estimated the total annoyance slightly better than the energy summation ($R^2 = 0.53$), independent effects ($R^2 = 0.53$), or annoyance equivalents ($R^2 = 0.54$) models, but less effectively than the response summation ($R^2 = 0.62$) and summation and inhibition ($R^2 = 0.62$) models. This result is somewhat different from those of Taylor. These results again confirm the importance of absolute level differences between sources in their effects on total annoyance.

However, the coefficients of determination R^2 of the dominant source model are 0.82 and 0.90 for the surveys in Ho Chi Minh City and Hanoi, respectively. These are also the highest among those of all models. The dominant source model implies that the overall annoyance is always equal to the greatest single source annoyance. Miedema criticized the dominant source model for its failure to describe the empirical data correctly, in that the total annoyance increases when the annoyance level of a non-dominant source approaches that of the dominant source [7]. Nevertheless, R^2 of the dominant source model is greatest for the surveys in both Ho Chi Minh City and Hanoi, suggesting that it is the most useful for rating the total noise annoyance. Table 5 shows that the annoyance predicted by the dominant source model was significantly correlated with the total annoyance score at the 0.01 level in both surveys, while those predicted by other models were not significantly correlated or only significantly correlated at the 0.05 level. Finally, the regression equations were calculated to fit the seven combined noise models to data synthesized for Ho Chi Minh City and Hanoi. Results of the regression analysis are shown in Table 6. Except for the dominant source model, the coefficients of determination R^2 for the other models decreased considerably and are rather low ($R^2 = 0.22$–0.32). In other words, these models are highly correlated with the pattern of the dataset. The change in the composition of the combined noise source might have lowered the predictive ability of these models. However, the coefficient of determination remained high for the dominant source models ($R^2 = 0.86$).

4.2. Limitation and policy implication

The findings of this study can be explained by the situation in the vicinities of the airports in Vietnam, where the difference in noise level between two sources is rather large (as shown in Tables 2 and 3). This finding also confirms the aforementioned dominant role of road traffic noise in the mixed noise environments around airports in Vietnam. However, a question arises as to whether this finding is also applicable to other areas where road traffic is less dominant. The results from a railway noise survey in Hanoi in August 2010 showed that the total annoyance was determined by the dominant source when road traffic noise exposure was more or less than railway noise exposure [11]. Furthermore, the dominant source model was found to have the most predictive ability among all seven models in rating the annoyance caused by the combination of railway and road traffic noises. Railway and road traffic noise exposures were quite comparable at all sites ranging from 55 to 81 dB $L_{Aeq,24h}$ and from 66 to 79 dB $L_{Aeq,24h}$, respectively [12]. This result confirms the above finding that the dominant source model is superior in rating total noise annoyance in Vietnam. The dominant source model explains the total annoyance by a subjectively dominant source-specific annoyance, while the other models explain the total annoyance by objective noise levels. Thus, the ability of the dominant source model cannot be directly compared with that of the other models. In addition, even if the dominant source model is superior to the situation of mixed noises sources with comparable railway and road traffic noise exposure, it may not be applicable to the combined situation of comparable aircraft and road traffic noise exposures. Further investigation is required to clarify this issue.

The exposure–response relationships for three transportation noise sources, road traffic, aircraft, and railway, have been separately presented and reflected on the basis of EU noise regulation as well as noise policies of many countries, including both EU and non-EU countries. Among the seven models, only annoyance

Table 4
Total, aircraft, and road traffic annoyances as functions of source L_{Aeq}.

Equation	R^2	Standard error
Ho Chi Minh City		
$A_T = 80.948 - 2.220\ L_{AC}^{*} - 0.983\ L_{RT} + 0\ 0.030\ L_{AC} \times L_{RT}^{*}$	0.200	2.465
$A_{AC} = 301.464 - 5.106\ L_{AC}^{**} - 4.231\ L_{RT}^{**} + 0.073\ L_{AC} \times L_{RT}^{**}$	0.351	2.294
$A_{RT} = -128.191 + 1.709\ L_{AC} + 1.81\ L_{RT}^{*} - 0.023\ L_{AC} \times L_{RT}$	0.262	2.423
Hanoi		
$A_T = -160.129 + 2.851\ L_{AC}^{**} + 2.296\ L_{RT}^{**} - 0.039\ L_{AC} \times L_{RT}^{**}$	0.280	2.191
$A_{AC} = -49.723 + 0.960\ L_{AC} + 0.583\ L_{RT} - 0.010\ L_{AC} \times L_{RT}$	0.134	2.729
$A_{RT} = -72.247 + 1.156\ L_{AC} + 1.152\ L_{RT}^{*} - 0.017\ L_{AC} \times L_{RT}$	0.152	2.402

$L_{AC} = L_{Aeq,24h}$ of aircraft noise (dB), $L_{RT} = L_{Aeq,24h}$ of road traffic noise (dB), A_T = Individual total annoyance score, A_{AC} = Individual aircraft annoyance score, A_{RT} = Individual road traffic annoyance score.
* $p < 0.05$.
** $p < 0.01$.

Table 5
Regression equations for combined noise source models.

Model		R^2	Standard error
Ho Chi Minh City			
Energy summation	$A_T = -29.97 + 0.49\ L_T$	0.47	1.47
Independent effects	$A_T = -30.41 + 0.53\ L_{RT} - 0.03\ L_{AC}$	0.47	1.61
Energy difference	$A_T = -30.48 + 0.49\ L_T + 0.05\ L_{DIFF}$	0.49	1.58
Response summation	$A_T = -28.53 + 0.47(L_T + 10.25 \times 10^{(L_{AC}-L_T)/10})$	0.48	1.60
Summation and inhibition	$A_T = -13.26 + 0.25\ L_{T(CORR)}\ (D = 12)$	0.25	1.75
Annoyance equivalents	$A_T = -40.75 + 0.62\ L$	0.44	1.51
Dominant source	$A_T = -0.52 + 1.00\ A_D$	0.82**	0.85
Hanoi			
Energy summation	$A_T = -14.30 + 0.30\ L_T$	0.53*	1.17
Independent effects	$A_T = -14.65 + 0.23 L_{RT} + 0.098\ L_{AC}$	0.57*	1.23
Energy difference	$A_T = -14.86 + 0.33\ L_T - 0.095\ L_{DIFF}$	0.58*	1.23
Response summation	$A_T = -18.88 + 0.35(L_T + 171.906 \times 10^{(L_{AC}-L_T)/10})$	0.62*	1.17
Summation and inhibition	$A_T = -16.18 + 0.32 L_{T(CORR)}\ (D = 7)$	0.62*	1.06
Annoyance equivalents	$A_T = -14.77 + 0.31\ L$	0.54*	1.17
Dominant source	$A_T = -1.99 + 1.20\ A_D$	0.90**	0.53

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 6
Regression equations for combined noise source models using data synthesized from Ho Chi Minh City and Hanoi.

Model		R^2	Standard error
Energy summation	$A_T = -13.86 + 0.28\ L_T$	0.30*	1.50
Independent effects	$A_T = -14.09 + 0.32\ L_{RT} - 0.05\ L_{AC}$	0.31*	1.54
Energy difference	$A_T = -14.34 + 0.28\ L_T + 0.05\ L_{DIFF}$	0.32*	1.53
Response summation	$A_T = -13.85 + 0.28(L_T + 0.41 \times 10^{(L_{AC}-L_T)/10})$	0.30*	1.56
Summation and inhibition	$A_T = -8.91 + 0.20\ L_{T(CORR)}\ (D = 12)$	0.22	1.58
Annoyance equivalents	$A_T = -9.79 + 0.22\ L$	0.25	1.56
Dominant source	$A_T = -0.99 + 1.07\ A_D$	0.86**	0.67

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

equivalents and dominant source models are capable of interpreting the total annoyance caused by the effects of synthetic noise by applying the established curve of the corresponding individual noise source. It is noteworthy that the elaborate "annoyance equivalents model" is not applicable to the situation in which road traffic noise is dominant. Finally, only the dominant source model is the most valid of the seven. In other words, the policy implication of the dominant source model is that the effects of combined noise source can be assessed through the dose-response relationships of the corresponding dominant noise source.

5. Conclusions

The validity of the dominant source model in rating the total noise annoyance was confirmed by surveys conducted around airports in Vietnam, where road traffic noise was more dominant than aircraft noise. From the policy-oriented viewpoint, the dominant source model is found to be the most practically appropriate model because it is useful in the situation in which the dose-response curve is established for every single noise source.

Acknowledgments

The authors are grateful to Ms. T.B.N. Nguyen from Ho Chi Minh City University of Architecture and Prof. D.N. Pham and Dr. T.H. Nguyen from the National University of Civil Engineering for their help in conducting the surveys in Ho Chi Minh City and Hanoi. We also appreciate the enthusiastic assistance of the students from both universities, who participated in the interviews and noise measurements.

Appendix A

A.1. Numeric annoyance question

Thinking about the last 12 months or so, what number from 0 to 10 best shows how much you are bothered, disturbed, or annoyed by aircraft noise, road traffic noise, and combined noise of aircraft and road traffic?

(Aircraft noise)

0	1	2	3	4	5	6	7	8	9	10
Not at all										Extremely

(Road traffic noise)

0	1	2	3	4	5	6	7	8	9	10
Not at all										Extremely

(Combined noise of aircraft and road traffic)

0	1	2	3	4	5	6	7	8	9	10
Not at all										Extremely

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