Estimation of combined annoyance due to Shinkansen railway noise and vibration using mean structure model

S. Yokoshima[1], T. Morihara[2], T. Yano[3], A. Ota[4], A. Tamura[5]

[1] Kanagawa Environmental Research Center, 1-3-39 Shinomiya, Hiratsuka, Kanagawa, 254-0014 JAPAN, yokoshima@k-erc.pref.kanagawa.jp

[2] Ishikawa National College of Technology, morihara@ishikawa-nct.ac.jp

[3] Kumamoto University, yano@gpo.kumamoto-u.ac.jp

[4] Yokohama National University, atota@ynu.ac.jp

[5] Yokohama National University, atamura@ynu.ac.jp

ABSTRACT

Shinkansen railway system has greatly increased its transportation capacity since it was first constructed. However, this has led to increased noise, ground vibration, and low frequency sound by running trains, which has annoyed inhabitants in areas along the railway line. For the purpose of preserving living environments and contributing to the protection of inhabitants' health, in 1975, Japanese government has notified "Environmental Quality Standards for Shinkansen Super-express Railway Noise". Next year, the Director of the Environmental Agency had recommended "Shinkansen railway vibration countermeasures to be urgently taken for environmental preservation". Over the past 40 years, social surveys on community response to Shinkansen railway noise and vibration in Japan have carried out. Lots of surveys suggested the presence of synergetic effects of the noise and vibration on each other's annoyance. The authors incorporated "combined annoyance" due to noise and vibration from Shinkansen railway as a latent variable and developed a causal model of the combined annoyance for structural equation modeling. Data used in analysis were obtained by social surveys and measurements in Kanagawa and Fukuoka Prefectures. Little difference in noise exposure was observed between the surveys; however, vibration exposure for the Kanagawa survey was higher than those for the Fukuoka survey. Comparison of the mean value of the combined annoyance among the surveys by using mean structure model indicated higher annoyance for the Kanagawa survey than those for the Fukuoka survey.

INTRODUCTION

Shinkansen railway system has greatly increased its transportation capacity since the Tokaido Shinkansen Line was operated in 1964. However, noise, ground vibration and low frequency sound due to running trains has annoyed inhabitants living in areas along the railway line. For the purpose of preserving living environments and contributing to the protection of inhabitants' health, in 1975, Japanese government has notified "Environmental Quality Standards for Shinkansen Super-express Railway Noise". Next year, the Director of the Environmental Agency had recommended "Shinkansen railway vibration countermeasures to be urgently taken for environmental preservation".

Enforcement of the environmental quality standards and recommendation has improved noise and vibration environments along the Shinkansen railway. However, not a few inhabitants along the railway have been still disturbed by the noise and vibration. In particular, many inhabitants tend to complain about not only noise but also vibration from Shinkansen railway.

Many social surveys on community response to Shinkansen noise and vibration have been carried out. Tamura indicated that Shinkansen was more negatively evaluated than ordinary railways in the areas where the railway noise was a major factor in the sound environment (Tamura 1994). Yokoshima et al released that community responses to Shinkansen railway noise was more severe than those to conventional railway or road traffic noise (Yokoshima & Tamura 2003). Yokoshima et al. reviewed metrics of Shinkansen railway noise by using separate three social surveys in Japan. When comparing noise metrics, maximum-based and energy-based sound pressure levels, the maximum-based index provided greater consistency than the energy-based index for the assessment of annoyance due to noise. The consistency of energy-based index can be partially explained by the synergetic effect of vibration (Yokoshima et al. 2009). Moreover, Yokoshima et al. clarified the synergetic effect of noise on annoyance due to vibration from Shinkansen railway using the aforementioned three datasets (Yokoshima et al. 2011).

Many studies mentioned interactive effects between noise and vibration on annoyance due to Shinkansen railway (Sato 2004; Yano 2005). Yokoshima and Tamura also verified the interaction and introduced a concept of “combined annoyance” due to noise and vibration induced-by Shinkansen railway. It was found that the effect of 5 dB in noise exposure on the combined annoyance is equal to that of 10 dB in vibration exposure for detached houses, using structural equation modeling (Yokoshima & Tamura 2005). Focusing on detached houses within 40m of the railway, vibration is found to have more serious effect than noise on the combined annoyance (Yokoshima & Tamura 2006).

Taking the construct of combined annoyance one step further, the authors try to estimate the mean value of the combined annoyance. We use datasets derived from the two surveys carried out in the Kanagawa and Fukuoka Prefectures (Yokoshima et al. 2008). Mean structure model, an approach by structural equation modeling, can estimate not only path coefficients by minimizing estimated error of each variance and covariance but also mean value of each latent variable. Therefore, we can to deduce the difference in the combined annoyance between the surveys by estimating the mean value.

SURVEYS

Kanagawa Survey

The Kanagawa Survey was conducted in residential areas along the Tokaido Shinkansen Line in the Kanagawa Prefecture, from 2001 to 2003. The survey used a distribution-by-mail method. Questionnaires for detached houses were distributed to inhabitants 18 years of age and over. By excluding respondents with survey site where ambient noises affect reaction to the target noise, the sample size for detached houses amounts to 872.

The questionnaire included activity disturbance and annoyance. For activity disturbances by unspecific sources the following items were evaluated: rattling, listening disturbance, sleep disturbance, rest disturbance and reluctance to open

windows. The answer format was multiple choices. Annoyance due to noise from Shinkansen railway was measured based on the ICBEN verbal scale. Likewise, annoyance due to the vibration was measured on the same scale.

After the social survey had been completed, measurement of noise and vibration was made to estimate the exposures associated with each of the respondents' dwellings on a site-by-site basis. Sound exposure level (L_{AE}) and maximum A-weighted and S-weighted sound pressure level (L_{ASmax}) of each passing train was measured at several points with different distance from the railway. Equivalent sound pressure level (L_{Aeq}) for 24 hours was determined based on the mean energy value of measured L_{AE} and the number of trains per day. Energy mean value among the top half of measured L_{ASmax} (L_{Amax}) was also calculated. By logarithmic regression analysis based on each value of noise metrics, we estimated noise exposures to each respondent.

Likewise, maximum value of vertical vibration level during a train passing was measured at the same point as the noise measuring. Vibration level was recorded at the surface on the ground. Vibration exposure (L_{vmax}) was calculated from the mean value of the top half among the measurements (re 10^{-5} m/s^2 in Japan). For the vibration exposure, the estimate was done in similar method as noise.

Fukuoka Survey

The Fukuoka Survey was conducted in 2003 in residential areas along the Sanyo Shinkansen Line in the Fukuoka Prefecture. Respondents aged between 20 and 75 years were randomly selected from a list of voters on a one-person-per-family basis. The questionnaires were distributed and collected either by the staff or by mail. In total, 724 responses were obtained.

The contents of the questionnaire were significantly different from those for the Kanagawa Survey. Annoyance due to each of noise and vibration from Shinkansen railway was measured with the ICBEN verbal scale. Activity disturbance was also evaluated on the same scale. Activity disturbance included the following items: disturbance in falling asleep, awaking, rest disturbance, listening disturbance, difficulty in opening windows, rattling, etc.

After the social survey had been carried out, noise measurements were made. L_{AE} and L_{ASmax} were recorded at least five times for each train type and track at the following points: reference point close to the Shinkansen line and points 5, 10, 20, 40 and 80 meters away from the reference point. Logarithmic regression equations between distance and noise reduction were formulated separately for the near and far tracks. Noise exposures to each respondent were obtained from the L_{Aeq} for 24 hours at the reference point and the noise reduction calculated using the formula.

Likewise, maximum value of vertical vibration level during a train passing was measured at points 12.5, 25, 50, 75, 100 and 150 meters from the closest track. Vibration level was recorded at the surface on the ground. Using the L_{vmax} as the logarithmic regression equation of the distance, we estimated vibration exposure for each respondent. Note that the number of respondents for which the L_{vmax} values were determined was 358.

STRUCTURAL EQUATION MODELING

Based on the previous studies, we construct a model for combined annoyance due to noise and vibration from Shinkansen railway as shown in Figure 1. This model is common to both surveys and hypothesizes that noise and vibration exposures have

not only direct effects but also indirect effects via "combined disturbance due to noise and vibration" on "combined annoyance due to noise and vibration". For noise exposure, we use the L_{Amax}, which indicates greater consistency than the L_{Aeq} for the assessment of annoyance due to noise (Yokoshima et al. 2009). Variables in square and oval represent observed and latent variables, respectively. Latent variable comprises a construct; ovals from e1 to e6 represent error variables affecting objective variables. Observed variables are responses and measurements associated with noise and vibration. We set correlation between the following parameters: L_{Aeq} and L_{vmax}, e1 and e4, and e2 and e5.

This model uses two latent variables. Combined annoyance has two indicators: noise and vibration annoyances. Each annoyance is measured by the ICBEN 5-point scale. Combined disturbance has also noise and vibration disturbances. Each disturbance is measured by the total number of "disturbed person". The scale with the Fukuoka survey is measured by the ICBEN 5-point scale; we regard the respondent with "very" and "extremely" as disturbed person according to each item. The distinction between noise and vibration disturbances is determined based on the matrix of correlation coefficient between exposure and response. Noise disturbance is defined as the sum of the responses with listening disturbance, reluctance to open windows and awaking; the vibration disturbance is defined as the sum of the responses with rattling, rest disturbance and disturbance in falling asleep. Note that response of the sleep disturbance for the Kanagawa survey was applied to both responses of awaking and disturbance in falling asleep.

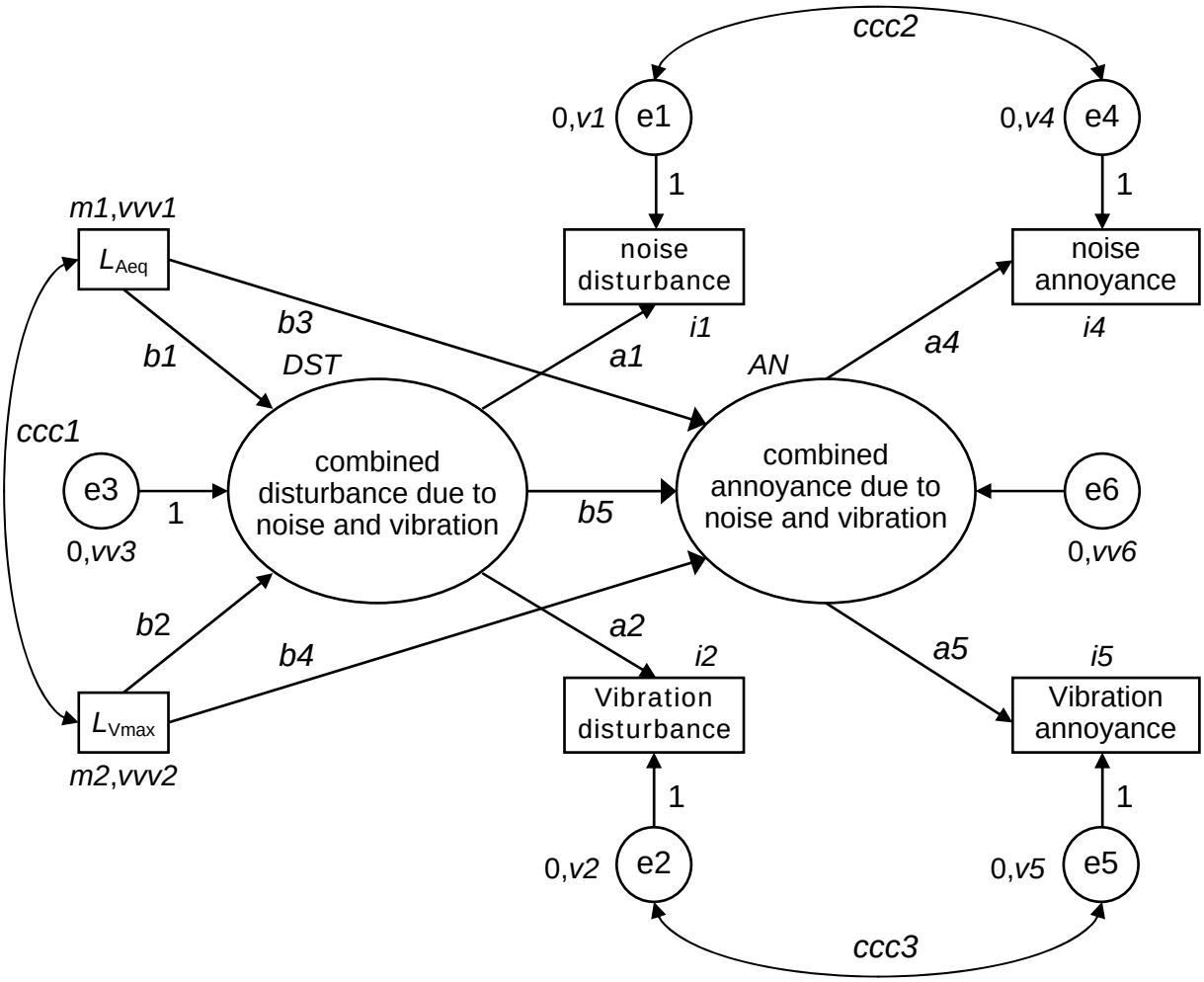

Figure 1: An initial structure equation model for combined annoyance due to noise and vibration.

Table1 explains details of each parameter used in this model. To discriminate the initial model, *a1*, coefficient from combined annoyance to noise annoyance was set to 1 in each group. Likewise, *a4*, coefficient from combined disturbance to noise disturbance was also set to 1. Moreover, mean value of each error variable was set to zero; coefficient from each error variable to observed one was also set to 1.

Table 1: Explanation of each parameter.

Parameter	Explanation
DST	intercept of combined disturbance
AN	intercept of combined annoyance
a1	coefficient from combined disturbance to noise disturbance
a2	coefficient from combined disturbance to vibration disturbance
a4	coefficient from combined annoyance to noise annoyance
a5	coefficient from combined annoyance to vibration annoyance
b1	coefficient from L_{Aeq} to combined disturbance
b2	coefficient from L_{vmax} to combined disturbance
b3	coefficient from L_{Aeq} to combined annoyance
b4	coefficient from L_{vmax} to combined annoyance
b5	coefficient from combined disturbance to combined annoyance
v1	variance of e1
v2	variance of e2
v4	variance of e4
v5	variance of e5
vv3	variance of combined disturbance
vv6	variance of combined annoyance
m1	mean value of L_{Aeq}
m2	mean value of L_{vmax}
vvv1	variance of L_{Aeq}
vvv2	variance of L_{vmax}
i1	intercept of noise disturbance
i2	intercept of vibration disturbance
i4	intercept of noise annoyance
i5	intercept of vibration annoyance
ccc1	covariance between L_{Aeq} and L_{vmax}
ccc2	covariance between noise disturbance and noise annoyance
ccc3	covariance between vibration disturbance and vibration annoyance

In order to apply multiple mean structure model, we imposed restrictions on some parameters. The first restriction was to equalize intercepts of *i1*, *i2*, *i4* and *i5* between the two surveys: to make the same value of *i1* for the Kanagawa survey and *i1* for the Fukuoka survey. We provided the same condition for intercepts of *i2*, *i4* and *i5*. The second was to set intercept of *i1* to zero. This means that the mean value of combined annoyance was equal to that of the noise annoyance. By this restriction, we can interpret combined annoyance through the scale of noise annoyance. Likewise intercept of *i4* was also set to zero. These constraints can estimate the mean values of combined disturbance and combined annoyance.

Under the above initial conditions, we made the first analysis. Comparing the estimated parameters between the surveys, it was found that there was no difference in the following parameters: *b2*, *v4*, *m1*, *ccc1* and *ccc2*. Therefore, imposing further restrictions, each of above 5 parameters with equal value among the surveys, we did the second analysis. The estimate value of each parameter was indicated in Table 2. In addition to non-standardized coefficients, values of *a1* to *a5* and *b1* to *b5* indicate also standardized coefficients. The values of the fit indices were 0.989 for CFI, 0.046 for RMSEA and 127.9 for AIC.

Table 2: Estimate values of parameters.

Parameter	Kanagawa survey		Fukuoka Survey	
	Non-standardized	Standardized	Non-standardized	Standardized
DST	-0.924		-3.530	
AN	0.849		-2.060	
a1	1.000	0.658	1.000	0.945
a2	1.482	0.919	0.818	0.803
a4	1.000	0.837	1.000	0.830
a5	1.251	0.999	1.031	0.835
b1	0.011	0.151	0.052	0.284
b2	0.012	0.181	0.012	0.094
b3	0.020	0.125	0.055	0.236
b4	0.008	0.056	0.028	0.119
b5	1.103	0.496	0.767	0.604
v1	0.275		0.073	
v2	0.086		0.225	
v4	0.446		0.446	
v5	0.004		0.456	
vv3	0.194		0.533	
vv6	0.715		0.317	
m1	66.286		66.286	
m2	55.263		41.651	
vvv1	0.000		17.971	
vvv2	-0.029		39.928	
i1	0.000		0.000	
i2	-0.029		-0.029	
i4	0.000		0.000	
i5	-0.749		-0.749	
ccc1	19.469		19.469	
ccc2	0.011		0.011	
ccc3	-0.025		0.109	

Assigning non-standardized coefficients into the following equation, we calculated the mean value of the combined annoyance:

$$\textit{Mean value} = (m1*b1+m2*b2+DST)*b5 + m1*b3+\mathrm{m2}*b4 + AN$$

The mean values were estimated to be 3.124 for the Kanagawa survey and 3.087 for the Fukuoka survey.

We calculated the total effects of L_{Amax} and L_{vmax} on combined annoyance. The direct effects of L_{Amax} and L_{vmax} are *b3* and *b4*, respectively. The indirect effects of L_{Amax} can be determined by multiplying *b1* and *b5*. Similar calculation can provide the indirect effect of L_{vmax}. The total effect is the sum of direct and indirect effects. The total effects are indicated in Table 3.

Table 3: Total effect of L_{Amax} and L_{vmax} on the combined annoyance.

Exposure	non-standardized total effect		standardized total effect	
	Kanagawa	Fukuoka	Kanagawa	Fukuoka
L_{Aeq}	0.032	0.095	0.200	0.408
L_{vmax}	0.021	0.037	0.146	0.176

DISCUSSION

Comparing the standardized total effects between the surveys, L_{Amax} for the Fukuoka survey indicates around double effect compared to the Kanagawa Survey. In contrast, little difference in L_{vmax} is found between the surveys. Although there is no difference in the mean value of L_{Amax} (*m1*), that of L_{vmax} (*m2*) for the Kanagawa survey is around

14 dB higher than that for the Fukuoka survey. This leads to a strong effect of vibration on inhabitant's annoyance. In particular, the indirect effect of L_{vmax} on combined annoyance for the Kanagawa survey is higher than that for the Fukuoka survey. This is probably caused by the difference in response to rattling between the surveys.

Then, for the mean value of combined annoyance, the Kanagawa survey (3.124) is slightly higher than the Fukuoka survey (3.087). Compared with exposures, the difference is smaller than expected. Here, we estimate the contribution of noise and vibration exposures to the mean value of combined annoyance. Regarding intercepts of combined annoyance and combined disturbance, we assume that each is divided according to the contribution ratios by L_{Amax} and L_{vmax}. For the Kanagawa survey, the respective contributions of L_{Amax} and L_{vmax} to the mean value are estimated to be 2.233 and 0.901: 72% and 28%. On the other hand, the Fukuoka survey estimates the following value: 2.376 (L_{Amax}) and 0.711 (L_{vmax}): 77% and 23%. These results indicate that vibration accounts for less than 30% of the mean value. This can lead to slight difference in combined annoyance despite large difference in vibration exposure.

CONCLUSION

Constructing combined annoyance due to noise and vibration from Shinkansen railway, we estimated the mean value of combined annoyance by mean structure model. The datasets derived from the two surveys carried out in Kanagawa and Fukuoka Prefectures are used for analysis. The difference in the estimated combined annoyance is found to be slight. Calculating the contribution of noise and vibration exposures to combined annoyance, respective noise and vibration exposures, on average, account for over 75% and 25% of the mean value of combined annoyance. The small proportion of vibration exposure to combined annoyance causes slight difference despite large difference in vibration exposure.

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