Sound power level of road vehicles running on dense asphalt pavement at various sites in Japan

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Abstract: Road traffic noise is one of the major environmental issues in urban areas. In Japan, the road traffic noise prediction model “ASJ RTN-Model 2013,” which has been developed by the Research Committee in the Acoustical Society of Japan (ASJ), is used widely in environmental impact assessment. Several calculation formulas for the A-weighted sound power level, $L_W^A$, of each type of road vehicle are specified in this model. Among them, the formulas for $L_W^A$ of road vehicles on dense asphalt pavement have been derived using the measurement data acquired in 1991–1998. In this study, to improve the accuracy of $L_W^A$ for dense asphalt pavement, pass-by noise measurements were performed on 40 actual roads during the last decade. The results revealed that $L_W^A$ of passenger cars, including hybrid vehicles and mini-sized vehicles, was 1.1 dB lower than that adopted in ASJ RTN-Model 2013. Regarding the other vehicle types such as large-sized vehicles, the differences between $L_W^A$ obtained from field measurements and those in the model were 0.5 dB or less, and no marked changes in $L_W^A$ were found.

Keywords: Road traffic noise, Pass-by noise measurement, Empirical formula, Hybrid vehicles, ASJ RTN-Model 2018

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1. INTRODUCTION

The noise generated from running vehicles can be mainly divided into two sources: power-unit noise and tire/road noise. The contribution of each noise source depends on the vehicle type and running speed as well as the engine revolution speed [1–3]. The determination of these noise emission values is indispensable for precisely predicting road traffic noise in urban areas.

In Japan, the road traffic noise prediction model ASJ RTN-Model 2013 (hereinafter referred to as the RTN-Model) [4] is used widely in environmental impact assessment. In this model, several calculation formulas for the A-weighted sound power level, $L_W^A$, of each type of road vehicle on dense and porous asphalt pavement are given. The types of road vehicles are basically classified into four-category: passenger cars, small-, medium-, and large-sized vehicles. Among them, the calculation formulas for $L_W^A$ of road vehicles on dense asphalt pavement have been developed using the measurement data acquired in 1991–1998 [5,6].

From 2010 to 2018, to improve the accuracy of the calculation formulas for $L_W^A$, we accumulated new data on vehicle noise emission on dense asphalt pavement at 40 sites in Japan [7–9]. $L_W^A$ for each vehicle type derived from the newly acquired data were compared with those adopted in the RTN-Model. In addition, the variations in $L_W^A$ between measurement sites were examined using data obtained at actual roads.

Moreover, we focused on the noise reduction effect of
hybrid and electric vehicles (HVs/EVs) [10–12], which are becoming increasingly common, and the differences between \( L_{WA} \) for such low-emission vehicles and conventional gasoline engine vehicles (GEVs) were investigated.

2. NOISE MEASUREMENT

The power level \( L_{WA} \) of a vehicle running at a steady speed was calculated from the maximum value, \( L_{A,Fmax} \), of the A-weighted sound pressure level with the FAST time-weighting [13,14]. \( L_{A,Fmax} \) was measured at a flat roadside sufficiently away from signalized intersections or acoustical reflective surfaces such as building facades. Figure 1 shows the arrangement for pass-by noise measurement. In general, a microphone at 1.2 m height is set at a horizontal distance \( l_h \) of 7.5 m from the center of the running lane.

With this setup, we conducted noise measurements at 35 sites (one lane on one side) and five sites (two or three lanes on one side) paved with dense asphalt concrete. \( L_{A,Fmax} \) was measured at distances \( l_h \) of 3.0–9.4 m (35 sites: 6.0–7.5 m) and at heights of 1.2–1.5 m (two sites with guard pipes: 1.9, 2.1 m). Additionally, to determine the influence of background noise emitted by sound sources other than the object of measurement, all acoustic signals were recorded on PCM recorders. Then, \( L_{WA} \) was calculated only using data for which the difference between \( L_{A,Fmax} \) and background noise was 10 dB or more.

The vehicle speed was measured using a radar-type speed gun, and the type of each road vehicle (e.g., number plate of vehicle, HV or EV) was identified from the video image.

3. MEASUREMENT RESULTS

In the RTN-Model, the road vehicle is assumed to be an omni-directional point source located on the road surface, and the calculation formula for \( L_{WA} \) is given simply as a function of vehicle speed \( V \) [km/h] for practicality and convenience as follows:

\[
L_{WA} = a + b \log V,
\]

where \( a \) is varies with the vehicle type and \( b \) represents the speed dependence of \( L_{WA} \). The value of \( b \) has been determined using the various experimental results obtained on test tracks and actual roads by the Japan Automobile Research Institute (JARI), and is fixed at 30 for dense asphalt pavement regardless of the type of road vehicle [3,6,15]. Note that \( L_{WA} \) and \( a \) depend on the vehicle type; however, the subscript that defines the vehicle type is omitted from these symbols.

Firstly, in this study, to grasp \( L_{WA} \) for road vehicles at each measurement site, the coefficient \( b \) was fixed at 30, as in the RTN-Model, and then the coefficient \( a \) in Eq. (1) was derived from the measured \( L_{WA,j} \) and speed \( V_j \) for individual vehicle \( j \).

Specifically, the coefficient \( a_i \) at each site \( i \) was obtained as the mean energy level of the calculated \( a_j \) (= \( L_{WA,j} - 30 \log V_j \)) as

\[
a_i = 10 \log \left( \frac{1}{n_i} \sum_{j=1}^{n_i} 10^{\frac{L_{WA,j} - 30 \log V_j}{10}} \right),
\]

where \( n_i \) is the number of acquired data for each vehicle type at site \( i \). Table 1 shows the results of \( a_i \) calculated at each site (R1–R40), the arithmetic average of \( a_i \) and \( n_i \), and \( a \) adopted in the RTN-Model. Note that the sites are arranged in descending order on the basis of the sound power level \( (a) \) for passenger cars. In the pass-by measurements at 40 sites, the total number of newly accumulated data was 4,221 for passenger cars, 308 for small-, 688 for medium-, and 606 for large-sized vehicles.

Hereinafter, the representative \( a \) for each vehicle type derived from the new data measured at 40 sites is referred to as \( a_{new} \).

3.1. Passenger Cars

Figure 2 shows examples of the dependence of \( L_{WA} \) on the running speed for passenger cars at 21 measurement sites. The thick solid line indicates the calculation formula for \( L_{WA} \) of passenger cars in the RTN-Model, and the thin solid line indicates the empirical formula obtained from the measured data at each site.

On the whole, the empirical formula with the coefficient \( b \) of 30 corresponded well with the measured \( L_{WA,j} \) (almost all the correlation coefficients \( r \) are 0.60 or more), although low correlations between them were seen at a few sites where the measured data were distributed widely (e.g., R32: the standard error \( s \) and \( r \) were 2.85 and 0.15, respectively).

These results demonstrate that \( L_{WA} \) varies depending on the measurement site. The coefficient \( a_i \), which represents the magnitude of noise emission \( L_{WA} \), was from 49.4 to 40.2, and the maximum difference in \( L_{WA} \) among the sites was 9.2 dB. Several experimental studies on the effects of road roughness on tire/road noise have been
performed, and it has been reported that the magnitude of tire/road noise increases with increasing amplitude of roughness [8,16,17]. Hence, the variations in $L_{WA}$ between the measurement sites, as seen in Fig. 2, could be attributed to the roughness of the road surface.

In consideration of these differences in $L_{WA}$ among the sites, the coefficient $a_{new}$ was determined as the arithmetic average of $a_i$ obtained at 40 sites (Table 1). $a_{new}$ for passenger cars is 45.3, which is 1.1 dB lower than $a$ in the RTN-Model. The principal reason for this change in $L_{WA}$ is that the number of low-emission vehicles, such as HVs/EVs and mini-sized vehicles [18] (also referred to as K-cars), is increasing year by year. A discussion on the sound power levels of these road vehicles is given in Sect. 4.

Further examinations are necessary to quantify the relationship between tire/road noise and the road roughness for the evaluation of traffic noise at actual roads.

### 3.2. Small-, Medium-, and Large-Sized Vehicles

The mean number of passenger cars measured at each site was 106 (average of $n_i$), as presented in Table 1. On the other hand, those for small-, medium-, and large-sized vehicles (SML vehicles) were 8, 17, and 15, respectively. The amount of measured data for investigating $L_{WA}$ at each site was insufficient at actual roads. The coefficient $a_i$ for SML vehicles at each site (results in Table 1) depended strongly on $L_{WA}$ of individual measured vehicles. For example, the maximum $a_i$ of 59.6 dB for large-sized vehicles was determined from the measurement data for only two vehicles at site R33.

Thus, for SML vehicles, the representative $L_{WA}$ with reduced contribution of individual measured data was derived by the following three processes.

1. Using $L_{WA}$ for SML vehicles at the site where a certain amount of measurement data is acquired, check whether the difference in $L_{WA}$ among the sites has a tendency similar to that of passenger cars.

2. The 40 sites are divided into groups on the basis of $L_{WA}$ for passenger cars, and the measured $L_{WA}$ data for SML vehicles in these groups are gathered. Also, check the difference in $L_{WA}$ among the sites owing to the group (measurement site).

3. The representative $L_{WA}$ for SML vehicles is calculated using the mean $L_{WA}$ in each group.

First, the differences in $L_{WA}$ among the sites for SML vehicles were compared with those for passenger cars, as shown in Fig. 3. The x-axis indicates the differences between $a_i$ and $a$ ($= 46.4$) in the RTN-Model for passenger cars, and the y-axis indicates those for SML vehicles ($a$ for the three types of vehicles: 47.6, 51.5, and 54.4 in Table 1). The solid line in the figure represents a regression formula derived from the level differences at the sites with 10

### Table 1  Coefficient $a_i$ for $L_{WA}$ of each vehicle type at 40 measurement sites ($a$: coefficient in the RTN-Model, $n_i$: number of data, vehicle types: passenger cars, small-, medium-, and large-sized vehicles).

| Meas. Site | Passenger | Small | Medium | Large | Meas. Site | Passenger | Small | Medium | Large |
|------------|-----------|-------|--------|-------|------------|-----------|-------|--------|-------|
| R35        | 49.4      | 66    | —      | —     | R4         | 45.1      | 332   | 48.3   | 22    |
| R16        | 48.8      | 55    | 48.0   | 6     | R8         | 45.0      | 184   | 46.0   | 12    |
| R9         | 48.1      | 160   | 49.7   | 14    | R10        | 44.9      | 45    | 49.5   | 5     |
| R12        | 47.5      | 176   | 46.8   | 6     | R27        | 44.7      | 61    | —      | —     |
| R34        | 47.5      | 70    | 50.1   | 3     | R31        | 44.7      | 173   | 42.9   | 1     |
| R15        | 47.4      | 54    | 48.3   | 3     | R17        | 44.5      | 65    | 46.9   | 5     |
| R14        | 47.3      | 118   | 49.1   | 7     | R5         | 44.5      | 72    | 48.7   | 12    |
| R40        | 47.0      | 76    | 49.1   | 4     | R19        | 44.4      | 66    | 47.9   | 4     |
| R29        | 46.8      | 33    | 48.3   | 13    | R23        | 44.3      | 87    | 49.4   | 19    |
| R36        | 46.8      | 108   | 51.7   | 9     | R21        | 44.2      | 113   | 48.8   | 5     |
| R33        | 46.7      | 73    | 50.8   | 1     | R30        | 44.2      | 94    | 45.0   | 1     |
| R37        | 46.7      | 56    | 51.9   | 5     | R7         | 44.0      | 197   | 48.1   | 16    |
| R39        | 46.3      | 129   | 47.7   | 14    | R13        | 44.0      | 120   | 47.7   | 6     |
| R2         | 46.1      | 153   | 49.0   | 27    | R11        | 43.8      | 77    | 45.0   | 9     |
| R26        | 45.9      | 67    | —      | —     | R12        | 43.6      | 189   | 46.4   | 11    |
| R25        | 45.7      | 37    | 48.2   | 1     | R32        | 43.6      | 76    | 44.1   | 3     |
| R28        | 45.6      | 65    | 51.1   | 1     | R18        | 43.3      | 84    | 45.0   | 11    |
| R38        | 45.6      | 62    | 52.1   | 2     | R22        | 42.2      | 124   | 44.7   | 16    |
| R20        | 45.5      | 105   | 45.5   | 10    | R24        | 41.3      | 170   | 46.0   | 8     |
| R1         | 45.5      | 105   | 45.8   | 6     | R6         | 40.2      | 124   | 42.4   | 10    |

Note: Total number of $n_i$ is 5,823 (passenger: 4,221, small: 308, medium: 688, large: 606).
Fig. 2  Speed dependence of $L_{WA}$ for passenger cars at 21 measurement sites (—, —: formula for $L_{WA}$ derived from measured data and that in the RTN-Model, respectively; $n_i$: number of data, $r$: correlation coefficient, $s$: standard error).
or more measured data values (△: small-, □: medium-, ○: large-sized vehicles, number of data values: 66). The number of measured data values used for analysis was set to 10 under the assumption that the site had more than the average number of \( n_1 \) (= 8, in Table 1) for small-sized vehicles. From the slope of the regression line, it can be seen that \( L_{WA} \) for SML vehicles tends to increase with \( L_{WA} \) for passenger cars measured at each site. Thus, the tendency of the differences in \( L_{WA} \) among the sites is similar regardless of the type of road vehicle.

On the basis of the above results, 40 measurement sites were divided into groups in accordance with \( L_{WA} \) for passenger cars, and the coefficient \( a_k \) for each group \( k \) was calculated from the mean energy of \( L_{WA,j} \) for SML vehicles \( j \) contained in individual groups. Finally, \( a_{new} \) for each vehicle type was obtained as the arithmetic average value of \( a_k \) as

\[
a_k = 10 \log \left( \frac{1}{n_k} \sum_{j=1}^{n_k} 10^{(L_{WA,j} - 30 \log V_j)/10} \right),
\]

and

\[
a_{new} = \frac{1}{m} \sum_{k=1}^{m} G_k a_k,
\]

where \( a_k \) is obtained for each vehicle type, \( n_k \) and \( m \) are the numbers of measured data values and divided groups, respectively, and \( G_k \) is the proportion of the number of measurement sites in each group \( k \).

Figure 4 shows the results of dividing 40 measurement sites into eight groups on the basis of \( a_i \) for passenger cars. The data division was performed using an analysis of variance with multiple comparisons (significant difference at the \( p < 0.05 \) level). The mean differences of \( L_{WA} \) between each group were 0.8–1.7 dB (standard deviation: 1.6–2.2 dB), and the number of measurement sites in Group 3 was the largest and its \( G_k \) was 0.3.

Table 2 shows \( a_i \) and the arithmetic average \( a_{new} \) of them calculated using Eq. (4) for SML vehicles. Also, examples of the comparisons between the formulas for \( L_{WA} \) in Groups 2 and 5 and those adopted in the RTN-Model are shown in Fig. 5. Even when the measured data at 40 sites was divided into eight groups, the number of data values was not sufficient in a few cases. However, it can be seen that the values of \( a_k \) \( (L_{WA}) \) for SML vehicles in the eight groups have a descending trend similar to that for passenger cars. For SML vehicles, the maximum differences in \( a_k \) depending on the group (divided measurement site) were estimated to be almost 5 dB. By the above three processes, the representative \( a_{new} \) values for \( L_{WA} \) of
SML vehicles are given as 48.1, 51.4, and 54.4, respectively.

Regarding $L_{WA}$ for SML vehicles obtained from field measurements, the differences from that adopted in the RTN-Model are 0.5 dB or less, and no marked changes in noise emission levels are confirmed. Hence, low-noise technologies for not only passenger cars but also road vehicles such as trucks are desired for reducing road traffic noise in urban areas.

### 3.3. Light and Heavy Vehicles

In the RTN-Model, the two-category classification of road vehicles is adopted to enable wide use of this prediction model in environmental impact assessment. One of the categories is light vehicles including passenger cars and small-sized vehicles, and the other one is heavy vehicles including medium- and large-sized vehicles. In this section, $L_{WA}$ for light and heavy vehicles were calculated using the newly accumulated data.

According to market trend surveys, the number of registered small-sized vehicles relative to passenger cars has been almost 14% in the last five years [19,20]. Therefore, $L_{WA}$ of light vehicles was calculated, assuming the composition ratio of light vehicle types to be 7:1 (passenger cars:small-sized vehicles). In addition, $L_{WA}$ of heavy vehicles was calculated using the same composition ratio of 1:1 (medium-:large-sized vehicles) as in the previous study [21]. The calculated results are presented in Table 3. $a_{\text{new}}$ values for $L_{WA}$ of the two-category classification are 45.8 and 53.2. $L_{WA}$ for light vehicles is 0.9 dB lower than that in the RTN-Model. For heavy vehicles, both $L_{WA}$ values are equal, as mentioned in Sect. 3.2.

### 4. LOW-EMISSION VEHICLES

The numbers of registered mini-sized vehicles and...
HVs/EVs in Japan are shown in Fig. 6 [19]. As of the end of March 2017, the numbers of registered mini-sized vehicles and HVs/EVs contained in the category of passenger cars were about 22 million and 7.5 million, respectively. The percentages of these vehicle types have been about 35% and 12% of overall passenger cars over the last five years. In particular, the market share of HVs/EVs is expected to grow in the future.

As mentioned in the previous section, \(L_{WA}^{i}\) for passenger cars derived from the newly acquired data was revealed to be lower than that adopted in the RTN-Model. Therefore, the measured \(L_{WA}^{i}\) for passenger cars was divided into values for conventional GEVs, HVs/EVs, and mini-sized vehicles and compared with each other.

Firstly, values of \(a_i\) for \(L_{WA}^{i}\) obtained at each site \(i\) for conventional GEVs were compared with those for HVs (including two EVs) and mini-sized vehicles, as shown in Fig. 7. The solid line corresponds to a regression formula derived from \(a_i\) at sites with 10 or more measured data values (\(\wedge\): HVs, \(\vee\): mini-sized vehicles, number of data values: 60). On the whole, the sound power levels \(a_i\) for HVs and mini-sized vehicles were about 1 dB lower than those for GEVs at almost all measurement sites.

We subtracted the differences in \(L_{WA}^{i}\) among the sites \((a_i - a_{new})\) from all the measured \(L_{WA}^{i,j}\) values for each vehicle \(j\), and then from the mean energy values \(a_{pas}\) of these results, the formula for \(L_{WA}^{i}\) of three types of road vehicles was obtained as

\[
a_{pas} = 10 \log \left( \frac{1}{n} \sum_{i=1}^{M} \sum_{j=1}^{n_i} 10^{(L_{WA}^{i,j} - (a_{i} - a_{new}) - 30 \log V_j)/10} \right),
\]

where \(M\) and \(n\) are the numbers of measurement sites and acquired data, and \(a_i\) and \(a_{new}\) are values for passenger cars in Table 1 \((a_i = 49.4 - 40.2, a_{new} = 45.3)\).

Figure 8 shows the empirical formulas for \(L_{WA}^{i}\) calculated by Eq. (5), regarding GEVs, HVs, and mini-sized vehicles. The numbers of acquired data were 2,527 for GEVs, 451 for HVs, and 1,243 for mini-sized vehicles. The power levels \(L_{WA}^{i}\) for HVs and mini-sized vehicles were 0.6 and 1.5 dB lower than that of conventional GEVs, respectively. Hence, as mentioned in Sect. 3.1, the reasons for the decrease in \(L_{WA}^{i}\) for passenger cars may include the increase in the number of these low-emission vehicles.

In addition, the pass-by noise measurement was carried out at site R6 to compare the maximum values of A-
weighted sound pressure level $L_{A,F\text{max}}$ for HV and GEV under various running conditions [10]. The receiving points were set at distances of 130 m (Rec.1) and 50 m (Rec.2) from the starting line, as shown in Fig. 9. The test vehicles were controlled to reach a constant speed of 20–70 km/h in front of Rec.1. These points were located 7.5 m from the center of the running lane and 1.2 m above the road surface. In this experiment, road vehicles with the same engine type and displacement were used, and their weight and tire size were almost the same.

Figure 10 shows $L_{A,F\text{max}}$ for both vehicles under various speeds and running conditions. The regression formula $\Delta L$ at the bottom of the figure represents the differences between $L_{A,F\text{max}}$ for GEV and HV. $L_{A,F\text{max}}$ for HV at Rec.2 was almost 5 dB lower than that for GEV at a speed of 20 km/h. However, under steady running conditions at speeds higher than 50 km/h (at Rec.1), no significant difference in $L_{A,F\text{max}}$ between HV and GEV was found. Thus, the noise reduction effect of HVs can be expected in the vicinity of signalized intersections or expressway tollgates, which are dominated by the power-unit noise of vehicles. The accumulation of measured data of $L_{WA}$ for HVs/EVs and the examination of the noise reduction effect of low-emission vehicles will be necessary for assessing road traffic noise in future environments.

5. CONCLUSIONS

The RTN-Model is used widely in environmental impact assessment of road traffic noise in Japan. In this model, the calculation formulas for the A-weighted sound power levels $L_{WA}$ on dense asphalt pavement have been developed using data measured in 1991–1998. To improve the formulas for $L_{WA}$, pass-by noise measurements were conducted at 40 actual roads in Japan from 2010 to 2018. A formula for $L_{WA}$ of each vehicle type was derived using the measurement data of almost 5,800 road vehicles and compared with that in the RTN-Model. Additionally, the noise reduction effect of HVs/EVs running on actual roads was examined. From the results, the following conclusions were obtained.

1. $L_{WA}$ emitted from road vehicles depends on road surface conditions such as road roughness, and further examination of the relationship between road roughness and $L_{WA}$ is necessary to evaluate road traffic noise at actual roads.

2. $L_{WA}$ for passenger cars is 1.1 dB lower than that in the RTN-Model. The principal reason behind this change is the increasing number of low-emission vehicles such as HVs/EVs or mini-sized vehicles.

3. $L_{WA}$ for HVs is 0.6 dB lower than that for conventional GEVs under steady running conditions. On the other hand, from the results of the test experiment, the difference between them is almost 5 dB at speeds of 20 km/h or less.

4. Regarding small-, medium-, and large-sized vehicles, no marked changes in $L_{WA}$ are found. Low-noise technologies of these road vehicles are desired to reduce traffic noise in urban areas.

$L_{WA}$ for road vehicles was investigated using noise emission data measured at various actual roads. The change in $L_{WA}$ relative to the RTN-Model can be revealed under steady running conditions of 40 km/h or more, and it
should be examined under different running conditions (acceleration or low-speed flow) to enable widely applicable prediction.

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REFERENCES

[1] U. Sandberg, “Noise emissions of road vehicles effect of regulations: Final report 01-1 by I-INCE working party on noise emissions of road vehicles,” Noise News Int., 9, 147–203 (2001).

[2] Y. Oshino, T. Mikami, H. Ohnishi and H. Tachibana, “Investigation into road vehicle noise reduction by drainage asphalt pavement,” J. Acoust. Soc. Jpn. (E), 20, 75–84 (1999).

[3] K. Tsukui, Y. Oshino, G. Blokland and H. Tachibana, “Study of the road traffic noise prediction method applicable to low-noise road surfaces,” Acoust. Soc. & Tech., 31, 102–111 (2010).

[4] S. Sakamoto, “Road traffic noise prediction model “ASJ RTN-Model 2013”: Report of the Research Committee on Road Traffic Noise,” Acoust. Soc. & Tech., 36, 49–108 (2015).

[5] Research Committee of Road Traffic Noise in Acoustical Society of Japan, “ASJ Prediction Model 1998 for Road Traffic Noise: Report from Research Committee of Road Traffic Noise in Acoustical Society of Japan,” J. Acoust. Soc. Jpn. (J), 55, 281–324 (1999) (in Japanese).

[6] Y. Oshino, S. Kono, T. Iwase, H. Ohnishi, T. Sone and H. Tachibana, “Road traffic noise prediction model “ASJ Model 1998” proposed by the Acoustical Society of Japan — Part 2: Calculation model of sound power levels of road vehicles,” Proc. 29th Inter-noise 2000, pp. 3010–3018 (2000).

[7] T. Uemura, Y. Okada and K. Yoshihisa, “Experimental study on the sound power level of common vehicles running on dense asphalt and concrete pavements,” Tech. Rep. Noise and Vib. Acoust. Soc. Jpn., N-2017-17 (2017) (in Japanese).

[8] M. Yonemura, H. Lee and S. Sakamoto, “Field measurements of sound power levels of vehicles running on Japanese general roads,” Proc. 47th Inter-noise 2018, pp. 4947–4956 (2018).

[9] M. Yonemura, H. Lee and S. Sakamoto, “Sound power level and frequency characteristics of vehicles running on general roads measured at 20 sites nationwide,” J. Acoust. Soc. Jpn. (J), 75, 181–187 (2019) (in Japanese).

[10] Y. Okada, T. Tajika and S. Sakamoto, “Road traffic noise prediction model “ASJ RTN-Model 2013” proposed by the Acoustical Society of Japan — Part 2: Study on sound emission of road vehicles,” Proc. 43rd Inter-noise 2014, pp. 3634–3641 (2014).

[11] M. A. Pallas, M. Bérengier, R. Chatagnon, M. Czuka, M. Conter and M. Muirhead, “Towards a model for electric vehicle noise emission in the European prediction method CNOSSOS-EU,” Appl. Acoust., 113, 89–101 (2016).

[12] H. C. Vicente, R. P. Orts, N. C. Davo and E. V. Sanchez, “The effect of electric vehicles on urban noise maps,” Appl. Acoust., 116, 59–64 (2017).

[13] Acoustics—Measurement of the influence of road surfaces on traffic noise—Part 1: Statistical pass-by method, International Standard ISO 11819-1:1997, International Organization for Standardization, Geneva, Switzerland (1997).

[14] S. Sakamoto, “Road traffic noise prediction model “ASJ RTN-Model 2018”: Report of the Research Committee on Road Traffic Noise in the Acoustical Society of Japan,” J. Acoust. Soc. Jpn. (J), 75, 188–250 (2019) (in Japanese).

[15] T. Mikami, Y. Oshino and H. Tachibana, “Relationships between running speed and sound power levels on urban roads,” Proc. 27th Inter-noise 98, pp. 1169–1172 (1998).

[16] T. Fujikawa, H. Koike, Y. Oshino and H. Tachibana, “Definition of road roughness parameters for tire vibration noise control,” Appl. Acoust., 66, 501–512 (2005).

[17] T. Fujikawa, Y. Oshino and H. Tachibana, “Application of road-profile enveloping procedure to height-unevenness method for predicting tire/road noise,” Proc. 39th Inter-noise 2010, pp. 4318–4323 (2010).

[18] Y. Okada, K. Yamauchi and S. Sakamoto, “Road traffic noise prediction model “ASJ RTN-Model 2018” proposed by the Acoustical Society of Japan — Part 2: Calculation model of sound emission of road vehicles,” Proc. 23rd ICA 2019, pp. 3696–3703 (2019).

[19] Automobile Inspection and Registration Information Association, “Trends of registered road vehicles in Japan,” https://www.airia.or.jp/publish/statistics (accessed 30 May 2019) (in Japanese).

[20] Japan Automobile Manufacturers Association, “Survey of small and mini-sized truck market trends,” http://www.jama.or.jp/lib (accessed 30 May 2019) (in Japanese).

[21] T. Tajika, A. Fukushima, Y. Okada, T. Osafune and S. Sakamoto, “Study on the sound power spectral of common vehicles running on dense and drainage asphalt pavements,” Tech. Rep. Noise and Vib. Acoust. Soc. Jpn., N-2014-16 (2014) (in Japanese).