Abstract
In predicting road traffic noise by using the ASJ Model, calculation of the sound emission of a vehicle is one of the important factors. The calculation model was published in 1998 on the basis of the data at that time. Since then, however, the Technical Committee of the ASJ has been accumulating new data about vehicle noise emission included are the increase in noise level while climbing a slope; the directivity of vehicle noise emission; and noise level variation due to road surface conditions.

The present paper describes a revised calculation of the sound emission from road vehicles using the newly acquired data.

1. Introduction
The sound power levels of road vehicles vary with vehicle type and running conditions, including velocity and road surface condition. The calculation of sound power level was described for these conditions in ASJ Model of 1998. The new ASJ RTN-Model 2003 basic calculation formula for sound power level has not changed but correction terms for drainage asphalt pavement, road gradient and sound directivity have been introduced. In particularly, corrections for road surface condition and the number of years of road operation after relaying are taken into consideration. In addition, a sound power spectrum of drainage asphalt pavement is described by a mathematical formula.

2. Classification of road vehicles
Road vehicles are classified into four types: passenger cars, small-, medium- and large-sized vehicles. Motorcycles are classified as small-sized vehicles. Two subdivisions are also adopted for simplicity: which is light vehicles (passenger cars and small-sized vehicles) and heavy vehicles (medium- and large-sized vehicles). These classifications are the same as those used in ASJ Model 1998 [1].

3. Sound power levels of road vehicles
3.1. Basic formula for sound power level
A-weighted sound power level of road vehicle is given by the formula

\[ L_{WA} = a + b \log_{10} V + C \]  

where \( a \) and \( b \) are regression coefficients, \( V \) is velocity in [km/h], and \( C \) is a correction term against the normal value of sound power level for dense asphalt pavement laid recently.

\[ C = \Delta L_{\text{surf}} + \Delta L_{\text{grad}} + \Delta L_{\text{dir}} + \Delta L_{\text{etc}} \]  

\( \Delta L_{\text{surf}} \) : Correction term for drainage asphalt pavement

\( \Delta L_{\text{grad}} \) : Correction term for road gradient

\( \Delta L_{\text{dir}} \) : Correction term for sound directivity

\( \Delta L_{\text{etc}} \) : Correction term for miscellaneous factors
3.2. Factors for steady and unsteady running condition

On freeways and urban roads under steady running conditions, a value of 30 is adopted for $b$ at velocities above 40 km/h. For accelerating and decelerating vehicles on urban roads, a value of 10 is adopted for $b$ at velocities lower than 60 km/h. Values for $a$ are listed in Tables 1 and 2.

![Illustration of calculations for sound power level of road vehicle (1)](image)

Figure 1: Illustration of calculations for sound power level of road vehicle (1)

### Table 1: Constant values “a” for the four-level classification (1)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transient running condition</th>
<th>Steady running condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{WA} = a + 10\log_{10}V$</td>
<td>$L_{WA} = a + 30\log_{10}V$</td>
</tr>
<tr>
<td></td>
<td>(10 km/h ≤ $V$ ≤ 60 km/h)</td>
<td>(40 km/h ≤ $V$ ≤ 140 km/h)</td>
</tr>
<tr>
<td>Passenger car</td>
<td>82.0</td>
<td>46.4</td>
</tr>
<tr>
<td>Small-sized</td>
<td>83.2</td>
<td>47.6</td>
</tr>
<tr>
<td>Medium-sized</td>
<td>87.1</td>
<td>51.5</td>
</tr>
<tr>
<td>Large-sized</td>
<td>90.0</td>
<td>54.4</td>
</tr>
</tbody>
</table>

### Table 2: Constant values “a” for the two-level classification (2)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transient running condition</th>
<th>Steady running condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{WA} = a + 10\log_{10}V$</td>
<td>$L_{WA} = a + 30\log_{10}V$</td>
</tr>
<tr>
<td></td>
<td>(10 km/h ≤ $V$ ≤ 60 km/h)</td>
<td>(40 km/h ≤ $V$ ≤ 140 km/h)</td>
</tr>
<tr>
<td>Light vehicle</td>
<td>82.3</td>
<td>46.7</td>
</tr>
<tr>
<td>Heavy vehicle</td>
<td>88.8</td>
<td>53.2</td>
</tr>
</tbody>
</table>

3.3. Factors for the area around an interchange

Near an interchange, the running conditions of vehicles include acceleration, deceleration and stop. Under these conditions, at accelerations up to 80 km/h from 10 km/h, the regression coefficient $b$ is 10, and for deceleration from 140 km/h to 10 km/h $b$ is 30. For power levels under 10 km/h, the level at 10 km/h is adopted. Values for $a$ are shown in Tables 3 and 4.

![Illustration of calculation formulas for sound power level of road vehicle (2)](image)

Figure 2: Illustration of calculation formulas for sound power level of road vehicle (2)

### Table 3: Constant values “a” for the four-level classification (3)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Accelerating condition</th>
<th>Decelerating condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{WA} = a + 10\log_{10}V$</td>
<td>$L_{WA} = a + 30\log_{10}V$</td>
</tr>
<tr>
<td></td>
<td>(10 km/h ≤ $V$ ≤ 80 km/h)</td>
<td>(10 km/h ≤ $V$ ≤ 140 km/h)</td>
</tr>
<tr>
<td>Passenger car</td>
<td>84.5</td>
<td>46.4</td>
</tr>
<tr>
<td>Small-sized</td>
<td>85.7</td>
<td>47.6</td>
</tr>
<tr>
<td>Medium-sized</td>
<td>89.6</td>
<td>51.5</td>
</tr>
<tr>
<td>Large-sized</td>
<td>92.5</td>
<td>54.4</td>
</tr>
</tbody>
</table>

### Table 4: Constant values “a” for the two-level classification (4)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Accelerating condition</th>
<th>Decelerating condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{WA} = a + 10\log_{10}V$</td>
<td>$L_{WA} = a + 30\log_{10}V$</td>
</tr>
<tr>
<td></td>
<td>(10 km/h ≤ $V$ ≤ 80 km/h)</td>
<td>(10 km/h ≤ $V$ ≤ 140 km/h)</td>
</tr>
<tr>
<td>Light vehicle</td>
<td>82.3</td>
<td>46.7</td>
</tr>
<tr>
<td>Heavy vehicle</td>
<td>88.8</td>
<td>53.2</td>
</tr>
</tbody>
</table>

3.4. Correction terms against basic formula

The basic formula for sound power level of a vehicle is based on the assumption that it is an omni-directional point source running on flat, dense, asphalt pavement. However, power levels depend on the condition of the road surface, the vertical gradient of the road, the sound...
directivity of the vehicle and miscellaneous factors. Changes of sound power levels are expressed according to the corresponding correction factor.

3.4.1 Correction term for drainage asphalt pavement
In the new ASJ RTN-Model 2003, the reduction effect of drainage asphalt pavement changes depending on the type of vehicle[2]. It also depends on the number of years after paving. Correction terms expressed for urban road and freeway are as follows.

**Urban Road**

Light Vehicles \[ \Delta L_{surf} = -6 \log_{10} V + 5.7 + 1.0y \] (3)

Heavy Vehicles \[ \Delta L_{surf} = -10 \log_{10} V + 14.9 + 0.3y \] (4)

**Freeway**

Light Vehicles \[ \Delta L_{surf} = -6 \log_{10} V + 5.7 + 0.5y \] (5)

Heavy Vehicles \[ \Delta L_{surf} = -10 \log_{10} V + 14.9 + 0.3y \] (6)

3.4.2 Correction for road gradient
The correction term for a vertical gradient of road is expressed as follows,

\[ \Delta L_{grad} = 0.05 \cdot i^2 + 0.14 \cdot i, \quad 0 \leq i \leq i_{\text{max}} \] (7)

where \( i \) is vertical gradient [%] and \( i_{\text{max}} \) is the applicable maximum gradient. This formula is derived from the relationship between gradient load and noise emission of a vehicle. This correction is applied to heavy vehicles only, on ascending roads only[3].

**Table 5: Applicable maximum vertical gradients for different velocities of a heavy vehicle**

<table>
<thead>
<tr>
<th>( i_{\text{max}} ) [%]</th>
<th>Velocity [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
</tr>
</tbody>
</table>

3.4.3 Correction term for sound directivity
In the ASJ Model 1998, a vehicle is treated as an omnidirectional point source. In the new model, the correction term is adopted in order to predict the noise level at the top of high residential buildings, and also at the site of a double-deck viaduct.

\[ \Delta L_{\text{dir}} = \begin{cases} 
(a + b \cdot \cos \varphi + c \cdot \cos 2\varphi) \cos \theta, & \varphi < 75^\circ \\
0, & \varphi \geq 75^\circ 
\end{cases} \] (8)

\[ \theta = \tan^{-1}(\sin \varphi \tan \Theta), \quad \varphi \neq 0 \] (9)

Where, \( \Theta \) is the projection angle of \( \theta \) on the horizontal plane. The relationship of both angles is expressed above. This correction is applied for velocities of more than 40km/h, and also for dense and drainage asphalt pavement[4],[5].

![Figure 3: Expression of the coordinate for each point](image)

**Table 6: Coefficient of the correction term**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light vehicles</td>
<td>-1.8 -0.9 -2.3</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>-2.6 -1.1 -3.4</td>
</tr>
</tbody>
</table>

3.4.4 Correction for miscellaneous factors
To predict and assess road traffic noise in the future, account must be taken of the laws governing vehicle noise emission limits, because the number of low noise vehicles will increase in the near future. On the other hand, some cars with remodeled mufflers have been found to be noisier. These cases are calculated from the model using the correction term \( \Delta L_{\text{etc}} \).

4. Sound power spectrum of road vehicle

4.1. Representative shape of the power spectrum

For both of steady and transient running conditions, the same sound power spectrum characteristic is given by Eq. (10). The frequency range for the calculation is 63Hz to 4kHz for octave bands or 50Hz to 5kHz for 1/3 octave bands. This spectrum is expressed by the solid line in **Fig. 3**. Details of these relationships have been published in reference [6].

\[ \Delta L_{f}(f) = -10 \log_{10} \left( 1 + \left( \frac{f}{2000} \right)^2 \right) \] (10)

\( \Delta L_{f}(f) \) : relative sound power level for the center frequency at \( f \) (Hz) of each objective band.
When the vehicle velocity on an objective road is known, a correction, expressed below, is added. Two correction terms are expressed by the dotted lines in Fig. 3.

\[
V < 80 \text{ km/h} \quad \Delta K(f) = -\left(\frac{10}{4}\right) \log_{10}\left(\frac{f}{1000}\right)
\]

(11)

\[
V \geq 80 \text{ km/h} \quad \Delta K(f) = \left(\frac{10}{4}\right) \log_{10}\left(\frac{f}{1000}\right)
\]

(12)

For convenience of numerical calculation, these correction values are given by the following expression.

\[
\Delta K_{\text{drain}}(f) = D_1 + D_2
\]

(13)

where \(D_1\) is the reduction effect of the suppression and absorption for pumping noise centered at 2kHz, and \(D_2\) is the addition term for road noise under 1kHz derived from rough road.

\[
D_1 = \begin{cases} 
0.13(x^4 - 6x^2 - 500), & -5 < x \leq 4 \ (630 < f < 5000) \\
0, & x > 5
\end{cases}
\]

(14)

\[
D_2 = \begin{cases} 
0.42x^3 + 3.6x^2 + 9.5x + 5.4, & -5 < x \leq -1 \ (630 < f < 5000) \\
0, & x > -5
\end{cases}
\]

(15)

where, \(x = 10\log_{10}\left(\frac{f}{2000}\right)\)

5. Conclusion

New formulas have been introduced for sound power levels of road vehicles adopted in the ASJ RTN-Model 2003. This new Model is a revised version of Model 1998. There is little difference between these models in basic formulas but the new formula extends the range of the model’s applicability.

6. Reference


