ARCHIVES OF ACOUSTICS
32, 2, 351–360 (2007)

MEASUREMENTS OF EXPOSURE SOUND LEVEL L_{AE} GENERATED BY PASSING VEHICLES FOR DIFFERENT ROAD SURFACE TYPES

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(*received March 30, 2007; accepted April 24, 2007*)

The influence of the road surface types on the noise emission level is a significant source of uncertainty of road noise maps drawn up using computational methods. In such methods the influence of the road surface type is taken into account through a correction to the noise emission level determined for the so-called reference surface. Depending on the kind of carriageway surface and its condition the road noise emission level may vary by several dB, which significantly affects the determined road noise propagation range. The paper presents the results of pass-by noise measurements for vehicles moving in the real city traffic. The investigations were carried out for 11 road with different pavements typical for city streets in Poland, including asphalt, asphalt concrete, stone mastic asphalt and cobblestones pavements. Also the results of comparative analyses of measurements and NMPB calculations for the investigated are be presented.

Keywords: road noise, pass-by measurements, road surface.

1. Introduction

The level of noise emitted by vehicles moving in a traffic stream is the resultant of engine and exhaust system noise, aerodynamic noise and tyre/road surface interaction noise. The engine and exhaust system noise depends on the type of vehicle and the engine speed. The tyre/road noise is determined by the type of tyres, the type of road surface as well as by the type of vehicle and its travelling speed. As travelling speed increases so does the share of tyre/road noise in the resultant noise emission level and at high travelling speeds it may become dominant [8, 10].

In methods of calculating road noise for noise mapping or environmental impact assessments the type of road surface is one of the noise source model input parameters which affect the noise emission level. In the French calculation method NMPB recommended by the European Noise Directive (END) for constructing strategic noise maps one can choose from 6 types of road surface: from "quiet" porous surfaces to "loud" stone-paved surfaces [5]. The Good Practice Guide developed by the EC Working Group for the Assessment of Environmental Noise in order to provide help to the Member States in the first round of noise mapping in accordance with END proposes road surface type corrections from -3.5 dB to $+4.8$ dB [4]. In Poland because of the lack of relevant data, the type of road surface and its condition are usually determined through visual inspection. If this is so, the effect of road surface can be a major source of uncertainty of road noise maps constructed using calculation methods. For this reason investigations of the level of noise emitted by cars moving in real urban traffic on roadways with different surfaces were undertaken.

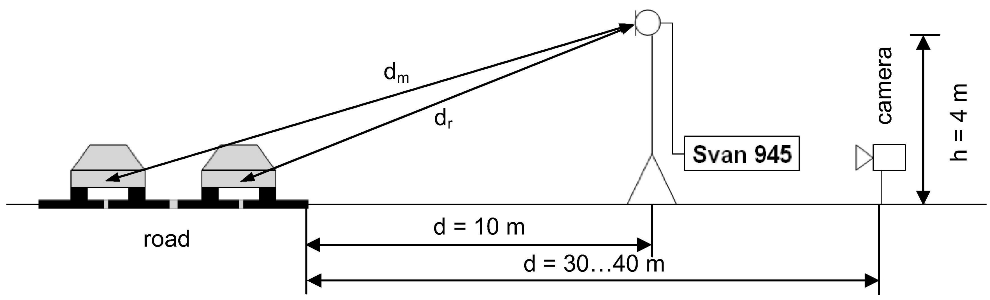


Fig. 1. A diagram of the measuring system.

2. Measuring method

Several measuring methods are used to evaluate the acoustic properties of road surfaces. The most popular among them are the Statistical Pass-By (SPB) method [6]. In this method the measurements are taken at specific location and driving conditions, a microphone is placed at 7.5 m from the center of the lane, at a height of 1.2 m. In view of the aim of the investigations, a method consisting in measuring the noise emitted by passing single vehicles moving in a real traffic stream in urban conditions was adopted in this research. The measuring microphone was located in accordance with the guidelines for locating the reference point for measurements of road noise emission, i.e. at distance $d_o = 10$ m from the roadway's edge at height $h_o = 4$ m (Fig. 1) [8]. The passage of a car is considered as an acoustic event for which exposure sound level L_{AE} and maximum sound level $L_{\mathrm{A\,max}}$ are measured. Acoustic events were classified according to the type of vehicles, the traffic lane and the speed. A two-class division into types of vehicles: a light vehicles class and a heavy vehicles class was assumed [8, 9]. A major problem, besides noise level measurement, is vehicle identification which would allow the explicit classification of the measured acoustic events.

The sound level L_{A} was recorded at every 100 ms, stored in the memory of the digital sound level meter and subsequently analyzed in order to determine the values of $L_{\mathrm{AE}i}$ and $L_{\mathrm{A\,max}\,i}$ for the particular acoustic events. A digital camera was used to identify vehicles and determine their travelling speed. The camera set up at a right angle to the roadway records the passage of a vehicle along road section S visible in the camera frame, being a function of the distance of the camera from the traffic line and the camera's shooting angle α. The distance of the camera from the roadway was determined from an analysis of the speed (V) estimation error, which took into account the variable distance of the traffic line of vehicles moving on the same traffic lane and the error in reading the time of vehicle passage across the camera frame. For urban conditions, the camera distance was set at $d = 30...40$ m at which the error in reading speed V is ± 4 km/h for thr speed about 70 km/h and the camera illumination at night is sufficient [10].

3. Selection of road surface and measuring points

The main types of road surface which occur on urban roads in Poland, i.e. standard asphalt road surfaces in good and bad condition, an asphalt concrete, stone mastic asphalt and stone-paved surfaces with different types of paver, were selected for the investigations. Measurements were carried out mainly at exit roads where the traffic can be regarded as approximately continuous. The location of the measuring points was such that the influence of the surrounding could be regarded as negligibly small. Because of the low traffic volume required to measure single acoustic events, the measurements were performed mainly in the evening and at night. The measurements were carried out for 11 streets with different roadway surfaces. The investigated situations are described in Table 1.

Table 1. Measured type of road surfaces.

Point No	Type or road surfaces	Road surface condition	Symbol
P1	Smooth asphalt	Good	SA-1
P2	Smooth asphalt	Good	SA-2
P3	Asphalt concrete	Good	AC-1
P4	Asphalt concrete	Good	AC-2
P5	Stone mastic asphalt	Good	SMA
P6	Asphalt	Rather bad	AP-1
P7	Asphalt	Bad, ruts	AP-2
P8	Asphalt	Bad, patch	AP-3
P9	Even large cobblestones	Rather good	LCS
P10	Convex small cobblestones	Rather good	SCS
P11	Mixed: large cobblestones and Asphalt	Bad	MIX

4. Measurement and analysis results

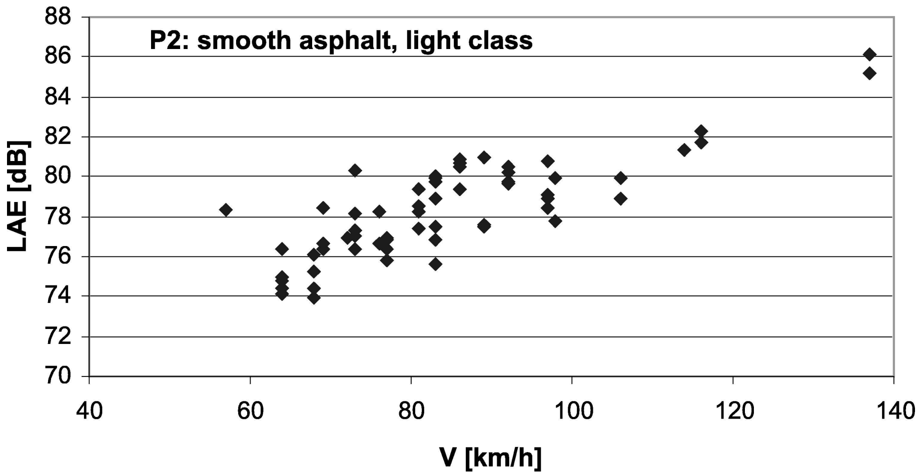
In total 1040 single vehicle passage, including 456 heavy-class vehicles, measurements were carried out [3, 10]. Sample results of direct measurements for smooth asphalt road surface are illustrated in Fig. 2. At first step the analysis covered:

- The normalization of measurement results of sound exposere level, L_{AE}, obtained for vehicles moving on traffic lanes situated at a larger distance (d_m) than the reference one (d_r – first lane), according to relation (Fig. 1):

$$L_{\mathrm{AE}r} = L_{\mathrm{AE}m} - 10\log(d_m/d_r) \quad \mathrm{dB}, \tag{1}$$

where: $L_{\mathrm{AE}m}$ – measured pass-by sound exposure level, d_m – distance between traffic lane and observation point, d_r – distance between 1-st traffic lane and observation point.

a)



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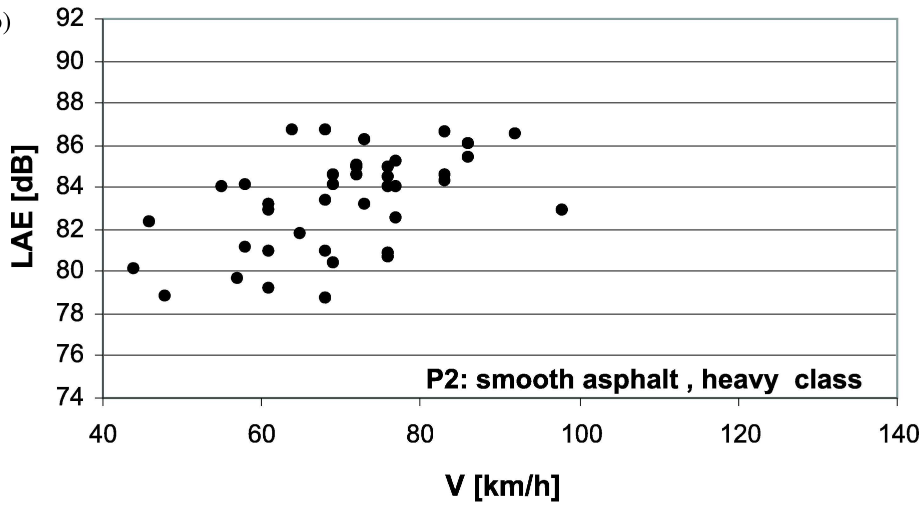


Fig. 2. Results of $L_{\mathrm{AE}i}$ measurement for smooth ashalt road surface – point P2; a) light vehicles $(N = 62)$, b) heavy vehicles $(N = 41)$ ($L_{\mathrm{AE}i}$ – normalised to 1-st lane).

- The determination of the sound power level, L_{WA}, for each pass-by vehicle according to:

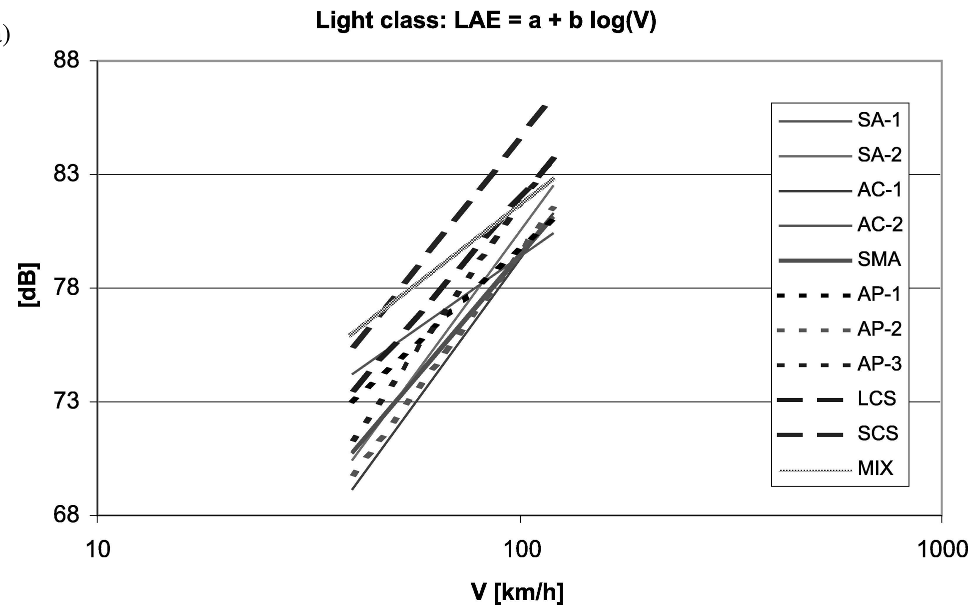
$$L_{\mathrm{WA}} = L_{\mathrm{A\,max}} + 10\log\left(2\pi + 20\log(d_m/d_o)\right) \quad \mathrm{dB}, \tag{2}$$

where $L_{\mathrm{A\,max}}$ – maximum A-weighted pass-by sound level, d_m – distance between traffic lane and observation point (for 1-st lane $d_m = d_r$), $d_o = 1$ m.

Table 2. Results of regression analysis: $L_{\mathrm{AE}} = a + b\log(V)$, N – number of measured pass-by, Δa and Δb – errors, R – correlation coeffcient.

Point No	Symbol	N	a [dB]	Δa [dB]	b [dB]	Δb [dB]	R^2	Speed range v [km/h]
a) light class of vehicles								
P1	SA-1	56	35.6	3.0	22.0	3	0.50	50–120
P2	SA-2	62	29.9	4.1	25.3	2.1	0.70	40–160
P3	AC-1	45	28.1	5.8	25.6	3	0.62	50–130
P4	AC-2	47	53.2	7.1	13.1	3.6	0.23	60–130
P5	SMA	49	35.8	3.6	21.8	2.1	0.74	40–140
P6	AP-1	54	45.2	6.2	17.3	3.5	0.32	30–110
P7	AP-2	47	31.1	5.6	24.2	3.2	0.57	40–100
P8	AP-3	46	30.2	5.3	25.7	2.7	0.67	50–150
P9	LCS	70	40.1	4.6	20.9	2.5	0.57	30–120
P10	SCS	52	39.1	5.8	22.7	3.2	0.50	30–130
P11	MIX	55	52.7	6.8	14.5	3.8	0.20	30–130
b) heavy class of vehicles								
P1	SA-1	46	46.2	9.0	20.3	5.1	0.27	40–90
P2	SA-2	41	54.4	7.5	15.7	4.1	0.27	40–100
P3	AC-1	36	76.1	10.5	3.5	5.8	0.01	40–100
P4	AC-2	39	63.7	9.9	10.4	5.3	0.95	50–100
P5	SMA	38	71.8	7.9	5.3	4.4	0.38	40–90
P6	AP-1	39	80.2	8.8	0.9	5.2	0.00	30–80
P7	AP-2	50	69.3	5.5	7.4	3.3	0.07	20–70
P8	AP-3	49	39.4	10.8	23.5	5.8	0.33	40–100
P9	LCS	35	54.2	11	15.9	6.5	0.15	30–80
P10	SCS	43	73.1	9.1	6.3	5.3	0.06	30–80
P11	MIX	39	65.8	7.2	10.8	4.5	0.14	20–80

a)



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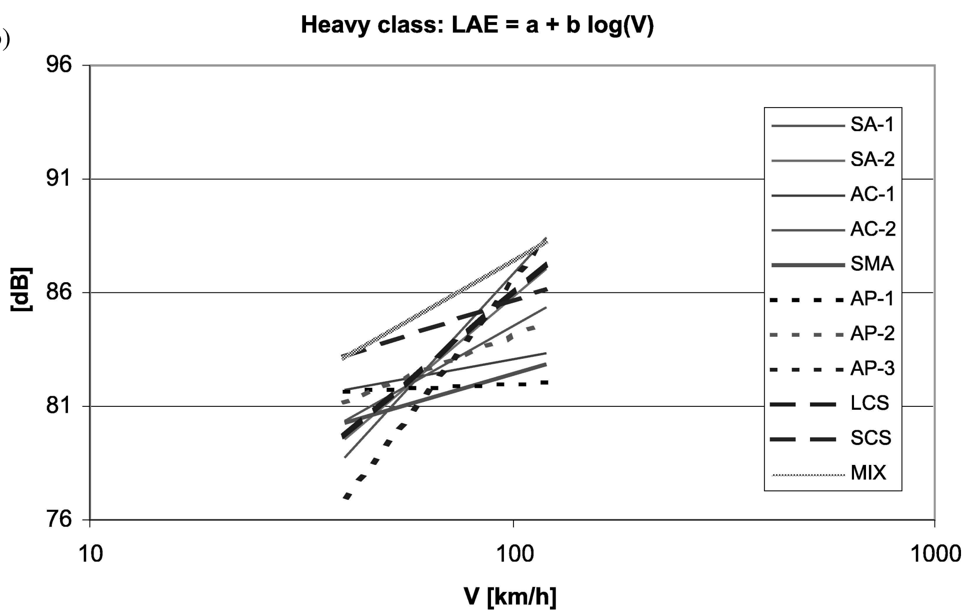

Fig. 3. Results of regression analysis: $L_{\mathrm{AE}} = a + b\log(V)$ for investigated road situations; legends – as in Table 2.

The data collected for each measuring situations and each vehicles class is used as input to linear regression analysis. The tyre/road and power unit noise have a strong relationship with vehicle speed. The tyre/road noise level increases approximately logarithmically with speed. So, for each measuring point (i) and each vehicle class (j) the best fitting linear function was determined according to:

$$\begin{aligned} L_{\mathrm{AE}ij} &= a_{ij} + b_{ij}\log(V) \quad \mathrm{dB}, \\ L_{\mathrm{WA}ij} &= a_{wij} + b_{wij}\log(V) \quad \mathrm{dB}. \end{aligned} \tag{3}$$

The correlation coefficient between sound exposure level L_{AE} and velocity V as well between sound power level L_{WA} and velocity V were estimated. The errors of determined values of a_{ij} and b_{ij} were calculated too. The obtained result are given in Tables 2, 3 and showed in Fig. 3.

Table 3. Results of regression analysis: $L_{\mathrm{WA}} = a_w + b_w \log(V)$.

		Light class			Heavy class		
Point No	Symbol	a_w [dB]	b_w [dB]	R_w^2	a_w [dB]	b_w [dB]	R_w^2
P1	SA-1	51.2	28.3	0.6	60.2	27.6	0.34
P2	SA-2	37.6	35.7	0.79	73	20.8	0.33
P3	AC-1	43.9	31.7	0.77	92.1	9.7	0.07
P4	AC-2	66.9	20.2	0.42	83.8	14.4	0.14
P5	SMA	50.1	28.5	0.84	85.7	12.7	0.16
P6	AP-1	59.5	24.4	0.45	90.6	10.5	0.08
P7	AP-2	46	30.4	0.66	84	13.3	0.18
P8	AP-3	47.8	31.2	0.75	54.1	30.4	0.34
P9	LCS	52.1	29.2	0.61	67.9	23.3	0.28
P10	SCS	52.7	30.6	0.61	83.4	16.1	0.20
P11	MIX	65.3	22.8	0.38	80.4	18.3	0.25

5. Corrections for surface type

For the investigated situations the surface type correction $\Delta L_{\mathrm{A\,surf}}$ was determined by comparing the measured and calculated equivalent sound level $\mathrm{L}_{\mathrm{Aeq}T}$ at the reference point for the same traffic conditions. It was assumed that the NMPB method correctly estimates the engine and exhaust system noise emission level and any differences between measurements and calculations are mainly due to the influence of the road surface. The measured noise level $L_{\mathrm{Aeq}Tm}$ was calculated from relations (4) and (5).

The equivalent sound level $L_{\mathrm{Aeq}Tij}$ for given vehicles class (i) and given trafffic lane (j) is:

$$L_{\mathrm{Aeq}Tij} = L_{\mathrm{AE}ir}(V) + 10\log(Q_i) + 10\log(1/T) + 10\log(d_r/d_{m_j}) \quad \mathrm{dB}, \tag{4}$$

where $L_{\mathrm{AE}ir}$ – sound exposure level calculated acc. to (3) for coefficients a and b given in Table 2, Q_i – traffic volume, d_r and d_{mj} – distances acc. to Fig. 1.

The total equivalent sound level $L_{\mathrm{Aeq}T}$ is:

$$L_{\mathrm{Aeq}T} = \sum_{ij} 10^{0.1 L_{\mathrm{Aeq}Tij}} \quad \mathrm{dB}, \tag{5}$$

where $L_{\mathrm{Aeq}Tij}$ – acc. to. (4).

The calculations were done using the NMPB method and software Cadna A. Noise level $L_{\mathrm{Aeq}Tc}$ was calculated for open space conditions assuming:

- the roadway cross section based on the inventory of the existing state,
- road srface type – smooth asphalt (the reference road surface, the correction for the road surface type – 0 dB),
- total traffic volume – $Q = 1000$ veh./h.

The influence of the traffic speed and the vehicle stream composition on the value of correction $\Delta L_{\mathrm{A\,surf}}$ was analyzed. Levels $L_{\mathrm{Aeq}Tm}$ and $L_{\mathrm{Aeq}Tc}$ were determined for traffic speeds in a range of $V = 50 \ldots 120$ km/h for different traffic stream compositions. A typical and extreme percentage of heavy-class vehicles: $p_c = 0$; 0.15 and 100% were assumed. Table 4 shows road estimated surface type corrections $\Delta L_{\mathrm{A\,surf}}$ in comparison to corrections assumed according to [4] on the basis of the visual inspection.

Table 4. Road surface correction $\Delta L_{\mathrm{A\,surf}}$.

		$\Delta L_{\mathrm{A\,surf}} = L_{\mathrm{Aeq}Tm} - L_{\mathrm{Aeq}Tc}$, dB.										
Point		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
p_c [%]	V [km/h]	SA-1	SA-2	AC-1	AC-2	SMA	AP-1	AP-2	AP-3	LCS	SCS	MIX
0	50	1.9	1.8	0.1	3.6	1.8	3.6	1.2	2.8	4.4	6.5	5.6
	70	2.0	2.4	0.7	2.4	1.9	3.0	1.6	3.5	4.4	6.7	4.6
	90	2.1	2.8	1.2	1.5	2.0	2.6	1.9	4.0	4.3	6.9	3.9
15	50	0.2	0.3	0.0	1.1	0.2	1.6	−0.2	0.1	1.8	6.7	3.4
	70	1.2	1.2	−0.2	0.7	0.2	1.0	0.1	1.6	2.4	6.6	3.2
	90	1.3	1.3	−0.6	−0.2	−0.2	0.2	−0.1	2.1	2.3	6.1	2.4
100	50	−2.6	−2.2	−1.6	−2.7	−2.4	−2.6	−2.2	−1.6	−2.7	−2.4	0.1
	70	0.4	0.1	−1.1	−1.2	−1.6	0.4	0.1	−1.1	−1.2	−1.6	1.7
	90	0.6	−0.2	−2.7	−2.0	−3.1	0.6	−0.2	−2.7	−2.0	−3.1	0.8
Surface type [4]		Ref.	Ref.	Ref.	Ref.	Ref.	Ror.	Ror.	Ror.	PS even	PS uneven	PS uneven
$\Delta L_{\mathrm{A\,surf}}$ acc. [4]		0.0	0.0	0.0	0.0	0.0	1.1	1.1	1.1	3.1	4.8	4.8

Ref. – smooth asphalt (reference), Ror – rough asphalt,
PS even – even pavement stones,
PS uneven – uneven pavement stones [ ].

6. Conclusion

The measurement results show a trend consistent with the data reported in the literature [2, 4]. Stone-paved road surfaces have been found to be the loudest – causing an increase in noise emission for mixed traffic stream by $2\ldots7$ dB. For light vehicles the differences in the measured noise emission levels for the asphalt, asphalt concrete and stone mastic asphalt road surfaces are so small (compare to estimated errors) that all the investigated surfaces of this type can be considered as reference surfaces.

A regards the average acoustic properties, the new asphalt road surfaces in Poland are similar to the ones in other EU countries. For the investigated road surfaces the differences in average corrections for the road surface type, experimentally determined for a typical traffic stream composition ($p_c = 15\%$) amount to -0.6–1.3 dB.

The experimentally estimated corrections for the asphalt road surface depend on the traffic speed and the traffic vehicle composition. For light-class vehicles ($p_c = 0$) $L_{\mathrm{Aeq}T}$ determined from measurements is higher than the one calculated using the NMPB method whereas for heavy-class vehicles ($p_c = 100\%$) the measured noise level is lower than the calculated one. This indicates that the influence of the road surface type is not the only source of the differences between calculation and measurement results.

The disadvantages of assumed measuring method is the influence of the variability of noise emission from different vehicles within each type and class.

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