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EVALUATION OF TRANSPORTATION NOISE IN URBANISED AREAS

A case study

Alfredo CALIXTO, Cristiane PULSIDES, Paulo Henrique Trombetta ZANNIN

Laboratório de Acústica Ambiental – Industrial e Conforto Acústico
Departamento de Engenharia Mecânica, Universidade Federal do Paraná, Centro Politécnico
CEP: 81.540-420, Curitiba, Paraná, Brasil
e-mail: paulo.zannin@pesquisador.cnpq.br

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The paper describes a study of noise emission levels by roads inside an urban setting. For this purpose simultaneous measurements were performed: a) noise levels L_{eq}, L_{10} and L_{90}, b) vehicle flow and c) traffic composition. Vehicle flow and traffic composition have been used to estimate sound emission levels using mathematical models. Models were developed for two different situations, either as a function of a single variable (vehicle flow, VF), or as a function of two variables (VF and percentage of heavy vehicles, HV). Results of the prediction models agreed well with measured noise levels, especially for the model considering the two independent variables, VF and HV.

Keywords: emission noise levels: road traffic noise: noise in urbanised areas: urban noise: environmental noise.

1. Introduction

Noise is especially annoying in urban areas. It interferes with sleep and relaxation and destroys the privacy of citizens. While noise has invariably accompanied people throughout the ages, the types of noise and human perception of it have changed over time. Noise in large urban agglomerations is now seen as a factor that greatly impairs the quality of life, similarly to air or water pollution [1]. Noise is considered by the World Health Organization to be the 3-rd most hazardous type of pollution – air, water, noise.

Traffic noise is a major environmental source of pollution in the whole planet, both in developed and underdeveloped nations. Noise pollution in small, medium and large cities is an ever growing problem due to the fact that the urban environment is becoming increasingly crowded and busy. Many field surveys were conducted to evaluate the outdoor noise environment in several countries [2–16].

A survey carried out in a large Brazilian city, Curitiba ($\sim$1.7 million inhabitants), by [13, 17], showed that noise generated by traffic of vehicles is the most annoying noise type followed by noise due to neighbors. For 73% of the 860 participants of the survey, road traffic was the main noise source.

In Brazil, traffic occurs basically exclusively through highways. This choice was made in the Fifties (last century). Railroad traffic is essentially non-existent, and the sparse railroads are dedicated to charge transportation, for example to harbours.

The general goal of this study was to evaluate noise emission levels generated by road traffic in Brazil. The highway chosen for the study was the BR 416, a highway that connects the two most developed and heavily populated regions of the country: the Southeastern and the Southern regions. This highway travels across a large Brazilian city, Curitiba. Locally, the BR 416 was originally intended to serve the traffic that arrives to or departs from the city. Nowadays, this road connects downtown Curitiba to surrounding satellite cities. After intense growth and occupation of peripheral areas surrounding the original area occupied by the city, this highway has suffered a functional change as the years went by. It is now also an important city avenue with intense traffic. In conclusion, this road presents peculiar characteristics with respect to its traffic. It displays intense traffic by different vehicle types (trucks, buses, automobiles, motorcycles), and the average speed and distance between traffic lights are untypical both of highways and of regular urban avenues or streets.

The aim of this study was: 1) to measure the equivalent continuous sound levels L_{eq} and the statistic sound levels L_{10} and L_{90} emitted by the road traffic through BR 416 inside Curitiba, and 2) to estimate the noise levels from the traffic through mathematical models. The mathematical models were developed both as a function of one variable, vehicle flow (VF), or as a function of two variables, VF and percentage of heavy vehicles (HV).

2. Methodology

Different strategies for evaluating environmental noise in a city can be employed, such as: 1) measuring the noise levels in several points organized in an approximately regular grid, 2) measuring the noise levels according to a previous classification of the urban noise according to the usage of the area, demographic density or the relevance of the urban streets [4]. In this research, the second strategy was applied since as the goal was to evaluate the traffic noise generated by the road (BR-416) previously classified as the main road used as a big avenue inside an urban setting [8, 18]. In order to evaluate the noise descriptors (L_{eq}, L_{10} and L_{90}), several points along the road were chosen and analyzed. A total of 100 samples was considered, as can be seen in Table 1.

The following parameters were simultaneously assessed: 1) the duration of each measurement; 2) the number of cars, motorcycles, trucks and buses passed by the observer during the time interval of each measurement; 3) the equivalent and statistical levels in dB(A): L_{eq}, L_{10} and L_{90}. A sound pressure level meter BK 2238 was used for the sound measurements. Since there are no updated standards in Brazil for the assessment of noise in highways, the German Standard RLS 90 was employed as the reference – Directions for the control of noise in highways [19, 20].

Table 1. Measurements of vehicle flow and noise descriptors.

Sample N^o	Time (s)	Emission						
		Trucks	Bus	Cars	Total	L_{10} dB (A)	L_{90} dB (A)	L_{eq} dB (A)
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	120	20	0	40	60	73.8	63.8	71.5
2	71	18	0	26	45	75.6	68.1	73.1
3	73	14	0	27	43	76.4	68.2	73.4
4	77	19	0	31	50	75.7	64.5	72.2
5	77	19	1	22	44	76.4	65.3	73.4
6	66	21	0	27	48	77.9	65.6	75.1
7	67	16	0	32	50	77.6	66.9	74.6
8	70	12	0	28	40	78.4	63.2	74
9	80	13	0	36	49	76.9	65.6	73.1
10	74	16	0	52	69	77.5	65.8	74.7
11	71	17	0	30	49	76.7	67.1	74
12	80	16	0	41	60	76.8	67.1	73.7
13	88	15	0	38	54	76	59.3	72.3
14	165	20	0	30	52	76.3	63.1	73.1
15	54	21	0	16	38	79	68.6	75.7
16	70	14	0	19	35	77.2	66.1	74.1
17	76	20	0	25	49	77.4	66.8	74.3
18	79	20	0	32	56	78	67.6	74.8
19	70	17	1	36	56	76.8	66	73.7
20	79	25	0	27	57	77.7	69	76
21	78	16	0	41	61	75.9	67.7	72.8
22	72	17	0	41	60	79.2	65.9	75.5
23	60	12	0	12	27	74.8	61.8	70.9
24	59	16	0	22	38	76.6	67.2	73.7
25	65	17	1	26	47	77.4	66.6	73.7
26	49	11	0	26	37	76.9	68.6	73.9
27	79	19	0	33	53	78.2	65.9	75.1
28	72	16	1	29	48	76.3	66.3	73.2
29	85	17	0	50	70	75.8	67.3	73.2
30	62	21	0	25	48	77.1	66.4	73.7
31	65	27	0	35	63	79.6	71.4	77.5
32	80	20	0	39	61	76.8	69.1	73.9

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
33	65	15	0	33	49	75.3	67.4	72.8
34	90	14	0	46	63	75.3	61.3	72.2
35	45	14	0	30	46	77.2	67.1	74.2
36	34	10	0	3	13	77	70.2	74
37	96	18	0	45	67	75.9	63.4	72.1
38	75	16	0	36	55	75.4	64.6	72.1
39	70	19	0	29	53	78.1	64.9	74.6
40	92	16	1	50	70	75.9	65.7	72.5
41	63	13	0	32	49	77.4	65.7	74.4
42	54	9	1	25	36	75.9	65.9	73.2
43	98	19	0	35	56	76.9	64.1	73.4
44	59	10	0	26	36	76.9	66.2	73.6
45	87	16	0	33	53	76.7	66.6	73.4
46	85	25	0	34	62	78.3	66.3	76.1
47	84	15	1	30	50	77	65.8	73.5
48	88	17	0	28	50	76	64.7	72.5
49	79	12	0	35	49	75.7	63.8	72.1
50	80	19	0	37	58	76.5	64.6	73.4
51	98	22	0	44	68	77.5	64.7	73.7
52	86	19	0	37	59	77.3	65.2	73.6
53	90	20	1	30	57	78.2	67	74.3
54	87	17	0	36	53	76.8	66.9	73.4
55	84	21	0	34	56	76.1	63.5	72.8
56	90	22	1	42	66	77.1	65.5	73.8
57	69	14	2	35	56	76.5	66.6	73.4
58	83	21	3	40	65	76.8	67.1	75.7
59	83	23	0	37	63	77.1	62.7	74.5
60	85	16	0	39	55	76.9	66	73.8
61	75	15	0	41	56	78.2	62.9	74.9
62	84	16	0	34	50	77.8	66.5	74.1
63	75	15	0	44	60	75.5	68.4	73
64	76	20	0	28	51	78.2	63.7	75
65	93	15	1	36	53	76.8	66.6	73.5
66	85	17	1	37	56	77.6	65.5	74.7
67	80	17	2	42	62	76.4	66.5	73.3
68	81	22	0	34	60	76.4	68.3	73.7
69	81	22	1	29	58	76.9	66.1	73.7
70	82	23	1	25	51	76.5	63.7	74.3
71	80	12	0	41	55	77.3	64.6	73.2

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
72	86	17	0	32	54	76.4	64.5	73
73	92	24	0	40	64	77.5	63.5	74.2
74	79	15	1	44	67	76.2	65.4	73.4
75	98	17	0	29	51	76.2	58.6	72.9
76	333	23	0	65	90	74.5	60.5	71.1
77	584	61	2	128	198	75	63.5	71.5
78	367	35	0	115	153	74.5	61	70.8
79	471	41	4	130	178	74.5	64	71.6
80	324	26	5	120	154	75.5	64	72.5
81	161	6	0	74	87	74.5	64	70.8
82	307	48	4	120	174	76.5	69	74.1
83	316	19	3	120	147	76.5	67	73.7
84	376	26	2	120	152	75.5	64	72.5
85	302	23	3	94	125	74	61	70.7
86	409	28	2	120	156	74.2	60.8	71.1
87	386	31	6	120	169	73.1	60.5	69.9
88	388	22	1	120	154	73	60	68.6
89	451	30	4	119	161	73.4	60.3	69.7
90	406	17	6	120	155	73.2	60.2	69.4
91	362	26	5	120	152	74.8	61.4	69.5
92	327	20	2	120	149	73.3	63.5	69.5
93	371	36	1	120	166	74.5	64.3	70.7
94	392	28	7	120	168	75.5	64.2	71.2
95	398	31	4	120	158	73.8	60.2	70.4
96	384	27	7	120	163	74.7	63	70
97	358	56	2	118	186	77	68	74
98	420	64	2	100	172	76.5	66	73
99	81	13	0	29	42	75.5	68.5	72.7
100	622	106	4	215	341	77	67.5	74.3

The German Standard RLS 90 considers as emission noise level that one measured at a distance of 25 m from the center of the road as can be seen in Fig. 1.

In order to group the results obtained for the several measurement points in a single data matrix, some variables of the process were fixed. Sites with similar paving conditions, traffic characteristics, longitudinal inclination, and topographical parameters were selected, so that these could be considered non-variable. Each measurement site had the following characteristics:

1. Roads paved with smooth asphalt and in good conservation.
2. Approximately constant speed with average of 55 km/h, pondered by a multiplying factor for the heavy vehicles.

3. Longitudinal inclination less than 5%, which can be considered as a flat stretch.
4. Straight stretch.
5. Flat nearby terrain characterizing an open field with no reflecting objects.

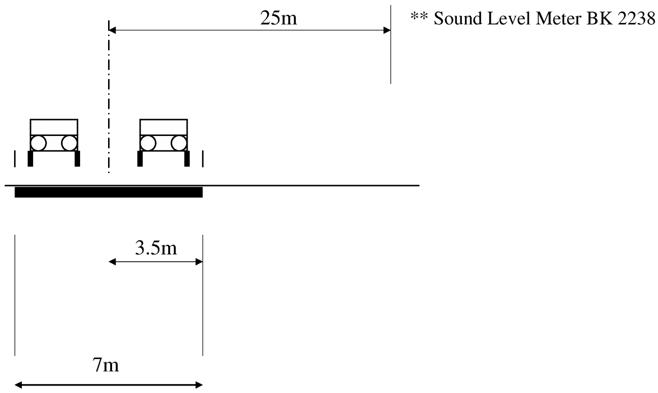

Fig. 1. Illustration of the road (BR 416) and the positioning of the sound level meter.

With this simplification, the input data of the model could be reduced to vehicle flow and traffic composition and the output were the noise pressure levels. As the traffic flow and composition cannot be controlled, the only way to appropriately consider the variability in the input parameters was to perform measurements in different times and weekdays. The duration of each measurement was also changed so that the sampled traffic conditions could approach the conditions of regular traffic flow along the studied highway. With this procedure, significant variations in the traffic parameters were obtained, with vehicle flow varying between 973 and 3,680 vehicles per hour, and the percentage of heavy vehicles varying between 6.9 and 76.9%. Heavy vehicles were considered those whose weight surpasses 2,800 kg [19].

3. Mathematical models

With the measurement results of the 100 sampled sites according to the methodology described in Sec. 2, the data were put into a matrix to obtain the correlation coefficients among the several variables. This procedure allowed the determination of which factors were the most significant ones for the determination of the noise levels. The mean values of the main variables are presented in Table 2 and the correlation coefficients among these variables are presented in Table 3.

Table 3 shows that the correlation coefficient between the noise descriptors L_{eq}, L_{10} and L_{90} and the vehicle flow VF is $r = 0.6758$, $r = 0.6295$, and $r = 0.5324$, respectively. This indicates that the vehicle flow VF is the predominant parameter determining the equivalent and statistical noise levels generated by the road traffic under the conditions considered. On the other hand, another variable showed in Table 3, the percentage of heavy vehicles HV is also an important factor that influences the noise descriptors. The correlation coefficients between the noise descriptors L_{eq}, L_{10} and L_{90} and the percentage of heavy vehicle HV are $r = 0.5895$, $r = 0.5476$ and $r = 0.4564$, respectively.

Table 2. Description and mean values of the variables.

Variable	Discrimination	Mean value
X1	Vehicle flow, VF	2239.5 vehicle/h
X2	10 log VF	33.3
X3	Percentage of heavy vehicles, HV	31.2%
X4	10 log HV	14.7
X5	L_{10}	76.3 dB(A)
X6	L_{90}	65.2 dB(A)
X7	L_{eq}	73.1 dB(A)

Table 3. Matrix of correlation coefficients for all variables.

	X1	X2	X3	X4	X5	X6	X7
X1	1.0000	0.9555	0.2165	0.3017	0.6295	0.5324	0.6758
X2	0.9555	1.0000	0.2324	0.3250	0.6119	0.5113	0.6607
X3	0.2165	0.2324	1.0000	0.9281	0.5476	0.4564	0.5895
X4	0.3017	0.3250	0.9281	1.0000	0.5988	0.4577	0.6420
X5	**0.6295**	0.6119	**0.5476**	0.5988	1.0000	0.5864	0.9361
X6	**0.5324**	0.5113	**0.4564**	0.4577	0.5864	1.0000	0.6790
X7	**0.6758**	0.6607	**0.5895**	0.6420	0.9361	0.6790	1.0000

VF is the sum of the light vehicle flow and that of the heavy one that passes at the road during a certain time interval. As a heavy vehicle generates a stronger noise than the light one, mainly under speeds considered in this survey, a weighting factor, n, was considered for such vehicles, so that an equivalent value could be obtained for the traffic flow, VF_{eq}.

Considering VF as the real hourly vehicle flow, HV as the percentage of heavy vehicles and n as the weighting factor, we have:

$$\text{VF}_{\text{eq}} = \text{VF}(1 + n\,\text{HV}/100). \tag{1}$$

In consequence, the term 10 log (VF_{eq}) from Table 2 will be transformed into 10 log (VF(1 + n HV/100)). The weighting factor value n will have a certain value that results in the largest correlation coefficients between the noise levels descriptors and the factor 10 log (VF(1 + n HV/ 100)). By varying the weighting factor between 4 and 10, the largest correlation coefficients between L_{eq} and VF_{eq} are found when $n = 9.5$ ($r = 0.8192$). For the noise descriptor L_{10}, the largest correlation coefficient between L_{eq} and VF_{eq} is found when $n = 9.5$ ($r = 0.7692$). On the other hand, as the influence of the percentage of heavy vehicles over the L_{90} is smaller, the weighting factor is also smaller, $n = 5$. In this case the correlation coefficient between L_{90} and the term 10 log (VF (1 + n HV/100)) is 0.6275.

Vehicles (and drivers) differ one from another. This means that the noise generated by a particular vehicle is a function of several parameters, such as: driving skills, total load, vehicle type and condition, tire calibrating, exhaust system type and conditions and the mechanical stress degree of the vehicle. According to this, the variable changes will be verified on the measured noise immission levels for different samples, even if the traffic flow and composition remain approximately the same. Therefore, any mathematical modeling will be an approximate estimate since many factors are involved in the analysis.

A mathematical model for the determination of the traffic emissions levels which considers the vehicle flow VF, and the percentage of heavy vehicles HV, will be based on the strong correlation coefficient between these parameters and the noise descriptors L_{eq}, L_{10} and L_{90}. In the sections below, the mathematical models for predicting noise emission levels based on one variable, the vehicle flow VF, and based on two variables, the vehicle flow VF and the percentage of heavy vehicles HV, will be presented.

3.1. Mathematical model for the equivalent level for one variable

Although it was already demonstrated that the traffic composition is also a relevant parameter for the noise level determination, as can be seen in Table 3, it is clear that a mathematical model that considers only the vehicle flow as the input variable will be easier to deal with. Using that approach it is only necessary to count the total number of vehicles in a certain time interval without discriminating between light and heavy vehicles. As the vehicle flow VF is the variable providing the highest correlation coefficients with the noise descriptors L_{eq}, L_{10}, and L_{90}, the model calculated with this single input variable can be presented in the scheme of Fig. 2.

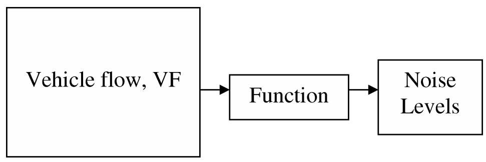

Fig. 2. Graphical representation of the mathematical model for one variable.

The function that relates the input variable to the output variable is

$$L_{\text{eq}} = a\ 10\log(\text{VF}) + k,$$

where L_{eq} is the continuous sound level, VF is the vehicle flow and a and k are constants. The coefficients a and $k$were obtained using a linear regression (square minimum method). The curve in Fig. 3 was obtained in this way.

Using the linear regression, the coefficients a (0.951) and k (41.42) were derived. The equation for the prediction of the continuous sound level L_{eq} is:

$$L_{\text{eq}} = 9.5 \log \text{(VF)} + 41.4 \text{ dB(A)}. \tag{2}$$

This equation, considering only VF, is effectively a simplified tool for the prediction of noise emission from road traffic.

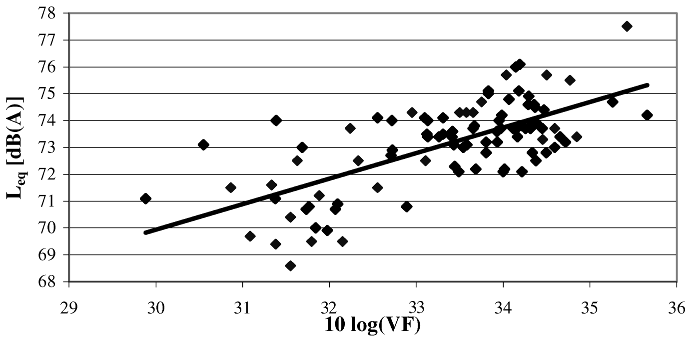

Fig. 3. Adjusted curve for L_{eq} vs 10 log (VF).

3.2. Mathematical models for L_{10} and L_{90} for one variable – Vehicle Flow VF

Mathematical expressions were obtained for the determination of the statistical levels L_{10} and L_{90} employing the same procedure used for the equivalent levels, as can been seen in Eqs. (3) and (4) and in Figs. 4 and 5:

$$L_{10} = 7.6 \log \text{(VF)} \ + 50.9 \text{ dB(A)}, \tag{3}$$

$$L_{90} = 11.9 \log \text{(VF)} \ + 25.5 \text{ dB(A)}. \tag{4}$$

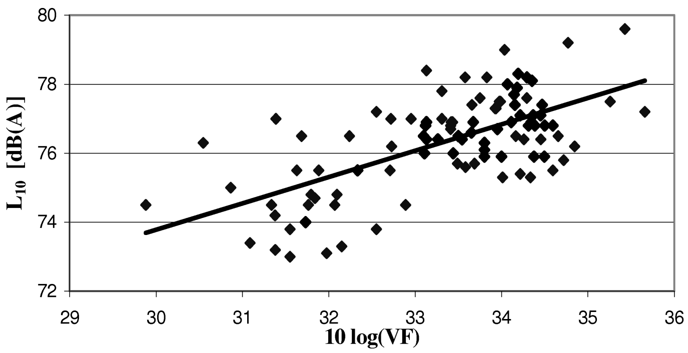

Fig. 4. Adjusted curve for L_{10} vs 10 Log (VF).

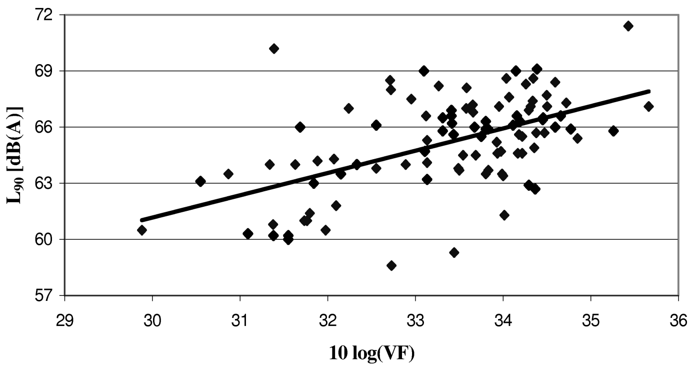

Fig. 5. Adjusted curve for L_{90} vs 10 Log (VF).

3.3. *Mathematical model for the equivalent level for two variables – Vehicle Flow VF and percentage of Heavy Vehicle VF*

Figure 6 shows the schematic representation of the model for the prediction of noise emission using two variables.

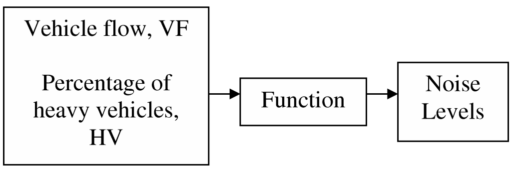

Fig. 6. Graphical representation of the mathematical model for two variables.

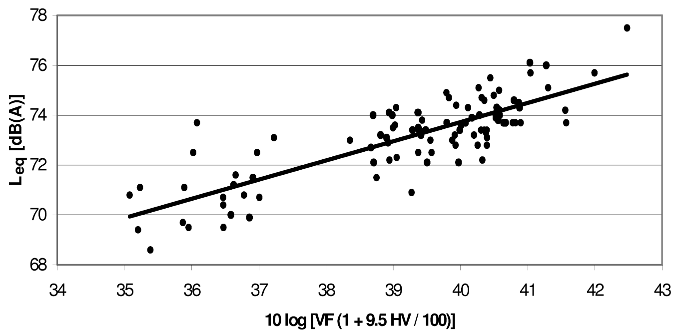

Fig. 7. Adjusted curve for L_{eq} vs 10 log [VF (1 + 9.5 HV / 100)].

Once the vehicle flow VF, the percentage of heavy vehicles HV, and the equivalent noise levels L_{eq} were measured, and the most adequate weighting factor was determined, $n = 9.5$, the values for L_{eq} and 10 log [VF (1 + 9.5 HV/100)] were plotted on a graph presented in Fig. 4. Then, using the minimum squares method, a curve was adjusted to the measured points. Mathematically, this curve can be represented by:

$$y = ax + k. \tag{5}$$

Applying the variables to the straight line equation, we have:

$$L_{\text{eq}} = a\ 10 \log\left[\text{VF}\ (1 + 9.5\ \text{HV}\ /100)\right] + k. \tag{6}$$

The values of the constants a and k, found by the application of the methods of statistical regression, were: $a = 0.769$ and $k = 42.964$. In consequence, the expression that mathematically represents the adjusted curve and can predict the equivalent levels for road noise is:

$$L_{\text{eq}} = 7.7 \log\left[\ \text{VF}\ (1 + 0.095\ \text{HV}\ )\right] + 43, \tag{7}$$

where L_{eq} is the equivalent noise level in dB(A); emitted by the road traffic measured at a distance of 25 m, VF is the vehicle flow (vehicles per hour); HV is the percentage of heavy vehicles compared to the total number of vehicles.

3.4. Mathematical models for L_{10} and L_{90} for two variables

Adopting the same procedure as that adopted for the equivalent levels, mathematical expressions were obtained for the determination of the statistical levels L_{10} and L_{90}, as can been seen in equations (8) and (9) and in Figs. 8 and 9:

$$L_{10} = 6.2 \log\left[\ \text{VF}\ (1 + 0.095\ \text{HV}\ )\right], \tag{8}$$

$$L_{90} = 10.2 \log\left[\ \text{VF}\ (1 + 0.050\ \text{HV}\ )\right] + 27.1, \tag{9}$$

where L_{10} is the sound level exceeded by 10% of the measurement period; L_{90} is the sound level exceeded by 90% of the measurement period; both measured at a distance of 25 m, in dB(A); VF is the vehicle flow (vehicles per hour); HV is the percentage of heavy vehicles, compared to the total number of vehicles.

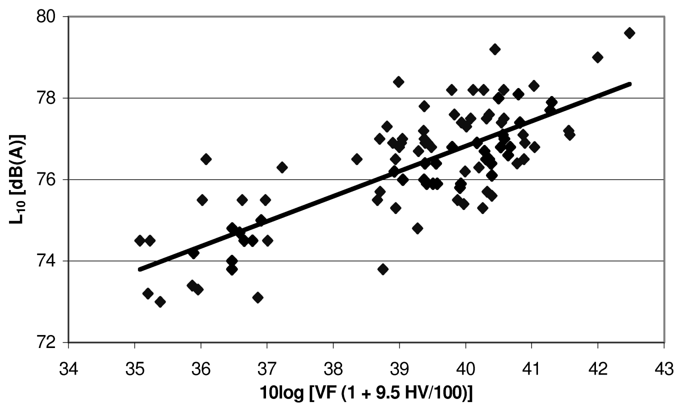

Fig. 8. Adjusted curve for L_{10} vs 10 log [VF (1 + 9.5 HV / 100)].

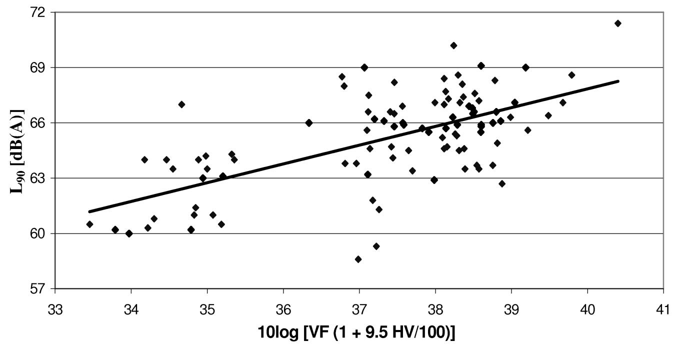

Fig. 9. Adjusted curve for L_{90} vs 10 log [VF (1 + 9.5 HV / 100)].

4. Results and discussion

Table 4 presents the averages and standard deviations of the differences between the calculated and measured values for the noise index L_{eq}. The small deviations for the noise descriptor L_{eq} between the measured and calculated values using the equations for one and for two variables and the German Standard RLS 90, demonstrate that the models here developed can accurately predict the levels of noise emission in an urban setting. That is, under the assumptions presented in the methodology.

Table 4. Statistics of the differences between calculated and measured values for noise index L_{eq} dB(A).

Statistical Parameter	Model with 1 variable × Measurements	Model with 2 variables × Measurements	RLS 90 × Measurements	Model with 1 variable × RLS 90	Model with 2 variables × RLS 90
Average	0.01	−0.005	0.3	−0.2	−0.3
Standard Deviation	1.7	1.8	1.1	1.2	0.6

Statistics presented in Table 4 indicate that the model with two variables is a more accurate predictor than the model with a single variable, as would be expected. The German Standard RLS 90 also fosters the use of the model based on both vehicle flow and the percentage of heavy vehicles.

Figure 10 shows a comparison between the measured and calculated values according to the mathematical model for two variables, Eq. (7). Figure 11 shows comparisons between the model for two variables in Eq. (7) and and the German Standard RLS 90 values for the emissions noise levels L_{eq} in dB(A) considering a speed of 55 km/h.

The calculated values do not get significantly distant from the measured values. This fact allows us to affirm that the Eq. (7) is able to predict satisfactorily the emission noise

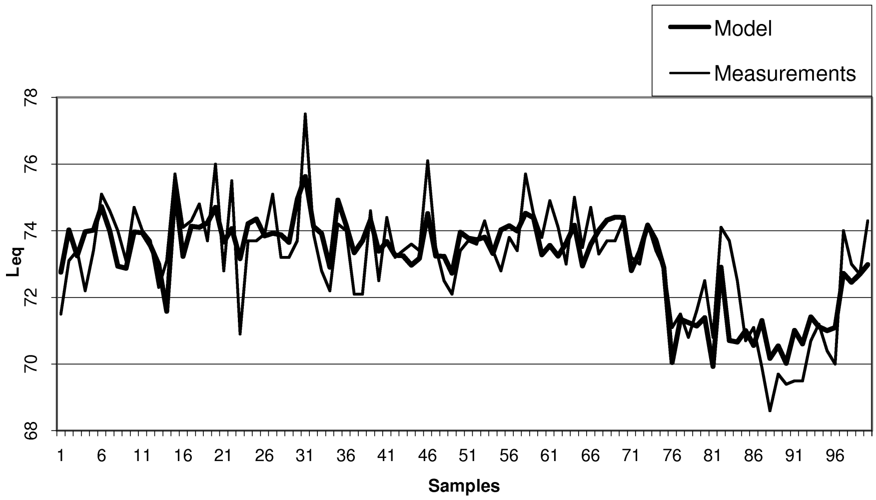

Fig. 10. Comparison between calculated and measured values for the emission noise levels L_{eq} in dB(A) measured at 25 m from the center of the road.

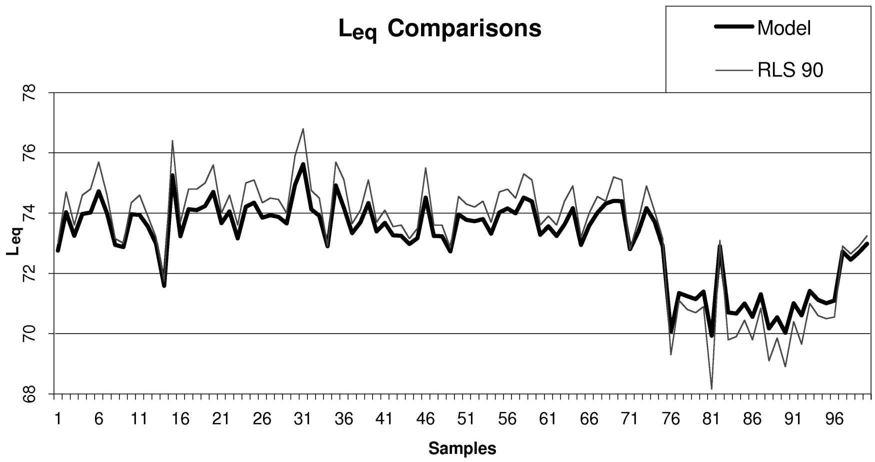

Fig. 11. Comparison between calculated and the German Standard RLS 90 values for the emissions noise levels L_{eq} in dB(A) measured 25 m from the center of the road.

levels generated by the vehicle flow in roads. The German Standard RLS 90 proposes the use of those two variables in the building of models for noise emission prediction at a distance of 25 m. However, this standard considers corrections in the calculations of noise emission levels taking into consideration ground absorption and meteorological factors besides the influence of the topography and the built environment surrounding the road. As described in the methodology, none of these factors was considered in the current study, but the results could be considered to be good if referred to a situation similar to that one in paragraph 3 of the Methodology.

5. Conclusions

The present survey has shown that noise emission levels, such as the percentile level L_{10} and L_{90}, and the equivalent noise level L_{eq} from a highway in an urban setting can be estimated by the application of a simple model for a reasonably accurate estimate of traffic composition.

Mathematical models for the prediction of equivalent noise levels of road traffic in highways can be developed satisfactorily using simple linear regression.

Models for the calculation of levels L_{eq} and L_{10} are more precise than those for the calculation of L_{90}. This outcome has been already expected because the vehicle flow is not continuous, and thus the influence of other noise sources is higher on L_{90} than on L_{10} and L_{eq}.

The models that consider two input variables, vehicle flow and percentage of heavy vehicles, provide a more accurate prediction than single variable models of traffic noise in urban highways.

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