Nonlinear regression model for predicting environmental traffic noise

Modelo de regressão não linear para prever o ruído do tráfego ambiental

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ABSTRACT

Transport is an essential activity for urban life and for the economy, however, bad planning of the city script causes some movement in some places, causing excessive noise levels generated by road traffic. We aim to present a mathematical model that represents the relationship between the equivalent level of sound and vehicle volume quantities using the nonlinear logistic regression model in order to facilitate decision-making in relation to urban planning. We collected the data of sound pressure and vehicle volume for ten days during five hours totaling a collection of 50 hours, with a total of 180 thousand data of sound pressure level. The place of data collection is a highway that passes through the city of Maringá, in Paraná, being an intense traffic highway. The results show the performance of the proposed model were differences between measured and predicted traffic noise levels ranged from -0.3 dB (A) to +0.3 dB (A) and the mean difference was -0.006 dB (A). The proposed road traffic noise forecasting model can be used as a decision support tool in urban planning, considering the same boundary conditions as the road study.

Keywords: Sound Equivalent Level. Traffic noise. Mathematical Optimization Model.

RESUMO

Muitos estudos sobre o impacto ambiental em áreas urbanas estão relacionados ao ruído do tráfego rodoviário. O transporte é uma atividade essencial à vida urbana e à economia, seja ele de pessoas ou bens de consumo, os tipos de veículos para transporte são classificados em veículos leves ou pesados. Entretanto, o mau planejamento da roteirização das cidades ocasiona certa movimentação em demasia em alguns pontos, causando níveis excessivos de ruído gerados pelo tráfego rodoviário. Este estudo tem como objetivo apresentar um modelo matemático que represente a relação entre as grandezas Nível Equivalente Sonoro e Volume Veicular, utilizando o modelo de regressão logística não linear, a fim de facilitar a tomada de decisão em relação ao planejamento urbano. Os dados de pressão sonora e volume veicular foram coletados por dez dias durante cinco horas totalizando uma coleta de 50 horas, com um total de 180 mil dados de nível de pressão sonora e 124.316 veículos. O local de coleta de dados foi uma rodovia que passa pela cidade de Maringá, no Paraná, sendo uma rodovia de tráfego intenso. Os resultados mostram que as diferenças entre os níveis de ruído de tráfego medido e previsto variam de -0,3 dB (A) a +0,3 dB (A) e a diferença média foi de -0,006 dB (A). O modelo de previsão de ruído de tráfego rodoviário proposto pode ser utilizado como ferramenta de apoio à decisão no planejamento urbano, levando em consideração as mesmas condições de contorno da rodovia estudada.

Palavras-chave: Nível Equivalente Sonoro. Ruído de Tráfego. Modelo de Otimização Matemática.

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1 INTRODUCTION

Ever since the emergence of cities, man has always sought ways to move around and move his goods. With its evolution and with the industrialization, this need is even greater, for the movement of goods and people at substantial distances, while a globalization has strongly increased these flows (Molina and Molina, 2012). This has resulted in problems with the construction of a supply system, as well as problems of congestion and urban mobility (Cattaruzza et al., 2017).

Transportation systems, whether urban or freight, cause damage to health, accidents and pollution, which may be due to the emission of air pollutants, high noise, and contamination of soils and water, in this sense the emission of these harmful agents must be minimized in order to preserve the population at high levels of these pollutants. (Taniguchi et al., 2014). Allied to this, the increasing use of motor vehicles has increased the occurrence of environmental problems, besides the problems of flow in urban roads (Who, 2009; Tadic et al., 2004; Hesse and Rodrigue, 2004; Melo, 2002; Smith, 2015; Goines and Hagler, 2007).

The development of countries is directly related to problems such as congestion, accidents and environmental pollution (Jica, 2007), and together with the lack of planning of cities, problems such as noise production occur (Marques, 2010), which according to Zannin et al. (2003) and Nunes (1999), is one of the most common and troublesome environmental problems that has affected the world population (Suthanaya, 2015). Koç et al. (2016) mentions that such problems can be solved through innovative mechanisms developed between public and private sector partnerships.

From the above, it can be seen that urban logistics is a very important tool, since it consists of a combination of transportation planning and urban environment, contributing to the achievement of economic and environmental objectives (Lidasan, 2001). Urban logistics is defined as the process of optimizing logistics and transport activities by private companies in urban areas, considering traffic, congestion and energy consumption (Taniguchi et al., 1999). Dutra (2014) shows that the movement of goods in urban areas affects urban planning and causes environmental and health problems. Based on the population's awareness in this regard, and the integration between the precepts of urban logistics and the concern with physical infrastructure logistics and road safety, resulted in City logistics (Gwillian, 2012). City Logistics aims to reduce traffic congestion, increase mobility, reduce pollution and noise levels considerably (Ricciardi et al., 2003; YANG et al., 2016).

"Traffic noise is an undesirable sound", the noise level, related to urban problems and noise pollution generated by traffic, is one of the major problems of the lack of urban planning, responsible for reducing the quality of life of the population, and to cause degradation of acoustic comfort in urban areas. (Ow and Ghosh, 2017; Maijala et al., 2012; Debnath and Singh, 2018; Morillas et al., 2002, Lee, 2007). In this sense, it can be affirmed that considering the problems caused by the movement of goods and people in urban areas, evaluating the problems and the actions to control the adverse effects are becoming a concern for the community, evidenced by the great number of laws and regulations that limiting noise (Mansouri et al., 2006). Ramírez and Domínguez (2013) report that studies on traffic noise have been growing considerably, especially in countries where the maximum levels of tolerance established by regulations are exceeded, notably Spain, India, China and Brazil.

According to the World Health Organization (Who, 2009), excess noise in urban areas causes problems in the health and well-being of the inhabitants, generating diseases such as stress and discomfort for noise up to 55 dB, and from 65 dB promotes degrative stress, increases the risk of heart attack; stroke; infections, among others.

In a study carried out by Aragão (2016), the Brazilian city of Maringá - Paraná, is governed by law number 218/98, which provides limits of tolerance of noise levels for each area of urban zoning. Also, the Brazilian Association of Technical Standards (ABNT) defines the limits of acceptable noise levels for each type of area, according to the period of the day, in decibels, as described in NBR 10151:2000, which describes that in mixed areas, predominantly residence, the acceptable noise level in daytime is 55 dB and in night time is 50 dB.

In addition, according to research by Calixto et al. (2001), the noise that most annoys the population is the traffic generated by vehicles. Therefore, according to Guarnaccia (2013), the need to measure traffic noise in urban areas is evident, and necessary for urban planning (Garg and Maji, 2014).

For Suthanaya (2015); Giraldo and Fernandez (2011) and Guarnaccia (2013), the development of models and methodologies that monitor the environmental noise is necessary to know the critical points, to map sensitive areas and to apply the measures of reduction of the sound levels. Kumar et al. (2014) used an artificial neural network model to predict traffic noise, Li et al. (2016) used the Monte Carlo simulation to develop a statistical model of probability to predict traffic noise, and all studies take into account the contour characteristics of each location using known mathematical techniques to predict noise from traffic.

The development and use of mathematical modeling to monitor the Sound Pressure Level (SPL) of vehicle traffic represents a gain for the study of the noise pollution problem and for urban planning of existing and under way roadways (Calixto et al., 2001). Silva and Mendes (2012) elaborated an index of environmental quality for cities, which considers indicators of air pollution and noise pollution, in its application, it was efficient in the combination of only one technique that could help urban planning in decisions strategies. Cai et al. (2015) carried out a study on road traffic noise mapping through the creation of a regional noise calculation algorithm for the Guangzhou region of China. Maijala et al. (2012) proposed a concept of SPL monitoring by means of an algorithm, which classifies the sound sources by means of a wire sensor.

According to Regazzi and Silva (2004), the study between a dependent variable and one or more independent variables can be performed using the nonlinear regression model, and also, according to Mazucheli et al. (2011) nonlinear regression models are formulated based on the theoretical knowledge inherent to the object of study, being the method used in this article.

Thus, we aim to develop a mathematical model, which represents the relationship between vehicular volume and the sound equivalent level, allowing control and support to the application of control measures of the pathway under study, also, to compare noise levels measured at the site with the limits acceptable by NBR 10151: 2000 and by the levels acceptable by the World Health Organization, classifying the acoustic quality of this area. For this, we collected the data on a highway in Maringá, Paraná, characterized by intense traffic of light and heavy vehicles. In addition, the highway passes through the middle of the city, in mixed areas, predominantly residential.

2 MATERIALS AND METHODS

In this section, we described the methodological procedures of the research, starting from the characterization of the studied area, and later the method of collection and processing data, as follows.

2.1 Characterization of The Studied Area

The area of evaluation of this work is situated in the city of Maringá, located in the northwest of Paraná - Brazil, being the third largest city of the State, positioned in the geographical coordinates: Latitude 23 ° 25 '31' 'S and Longitude 51 ° 56' 19 ' 'W, cut by the Tropic of Capricorn, having an altitude of 555 meters.

The acoustic monitoring points are located at Colombo Avenue (Federal Highway BR-376), which is characterized as an Urban Crossing, being described as an intense traffic and long distance road composed of heavy vehicles, light vehicles, motorcycles and bicycles. BR-376 is a Diagonal Highway connecting the cities of Garuva / SC and Dourados / MS, crossing the State of Paraná, with an extension of approximately 958,3 Km.

The highway under study has intersections with streets of local traffic and viaducts to access the collecting traffic ways. The track section is variable, depending on the presence of central beds, however, the width of the tracks is constant, being 3.1 m each lane. As the highway is inserted in the city, the maximum speed allowed is 60 km h -1. In addition, the sites of the collection point are characterized by having, apart from intense traffic, trade spots and is predominantly residential.

2.2 Method of collecting and processing Data

Firstly, we performed the acoustic monitoring in the study sites where the Sound Pressure Levels were captured, according to equation 1, and the volume of vehicles passing through the site. In order to do it, a portable sonometer, model DL4200, of ICEL, with 1.4 dB precision, in addition to a Sony camcorder, model DCR-SX21, was used for the purpose of recording the flow of vehicles during the monitoring period.

The SPL is all acoustic energy emitted by a particular source. In sound monitoring the SPL varies during a given time interval (T), where the average one represents the Equivalent Sound Pressure Level (Leq) reports Bistafa, (2011). The SPL is defined by ISO 1996/1 (1987), having as unit the decibels (dB), according to equation 1.

$$SPL = 10\log\left[\left(\frac{P}{P_0}\right)^2\right] \qquad (1)$$

Where P: Sound pressure in pascal; P_0 : Reference Sound Pressure.

Leq is also defined according to ISO 1996/1 (1987), having as unit the dB, according to equation 2.

$$Leq = 10\log\left[\frac{1}{T} \times \sum_{i=1}^{n} t_i \times 10^{\frac{Li}{10}}\right] \qquad (2)$$

Where T: Total time in hours; Li: Sound Intensity Level in dB; Ti: Partial time in hours.

The data samples, vehicle volume and SPL, were collected on different days of the week and in the afternoon period with a duration of five hours, thus, being in accordance with ISO 11819-1, Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical Pass-By method, which provides that the monitoring for the calculation of Leq can vary between 1 and 4 hours of measurement during the day in the rush hour.

Regarding the meteorological conditions, the monitoring was carried out on days with conditions considered normal, with clear skies, without rain or any meteorological interference that could compromise the reliability of the data.

After tabulating the vehicle volume and sound pressure data, a regression analysis was performed, which consisted of investigating and modeling the dependence relation between a random variable and the possible explanatory causes of its variability, represented by one or more predictor variables. In this study, the noise level was considered as the random variable Y and the number of vehicles that as the predictor variable X. Firstly, we performed the study of the relation between the variables X and Y, looking for a mathematical function of X that explains Y. However, since this relation is not perfect, for the observed values would not be perfectly situated on a function that related X and Y, the type of function adopted was suggested by empirical evidence, that is, based on the observations of the variables. One can evaluate the behavior of the relation approaching a line or any other curve. After the study of the relation between the variables, we tested the regression models that represent the behavior of these variables, in order to find the model that best represents the parameters. To choose the best model, we used the criterion of the lowest AIC (Akaike Criterion Information). To apply such models to the data, we used the gcFitModel command belonging to the R software grofit package.

3 RESULTS AND DISCUSSION

After the collection stage, we organized the data on the amount of light and heavy vehicles per hour traveling in the studied road, and the value of Sound Equivalent Level (Leq), calculated from the monitored

SPL, in Table 1. A collection of information on the noise level caused by light and heavy vehicular traffic on Colombo Avenue occurred during ten days, with five hours a day and on different days of the week, excluding holidays or days that could cause changes in normal traffic conditions.

Data	Period		Light Vehicle Volume (Light Vehicle / h)	Heavy Vehicle Volume (Heavy Vehicle / h)	Leq measured period (dBA)
	Beginning	End			
1	13:00:00	14:00:00	2609	249	74,1
2	14:00:00	15:00:00	2658	291	74,3
3	15:00:00	16:00:00	2981	299	74,5
4	16:00:00	17:00:00	2271	237	74,0
5	17:00:00	18:00:00	2140	220	73,9
6	13:00:00	14:00:00	2306	287	74,3
7	14:00:00	15:00:00	2445	253	74,3
8	15:00:00	16:00:00	2308	238	74,1
9	16:00:00	17:00:00	2240	229	74,1
10	17:00:00	18:00:00	2357	273	74,2
11	13:00:00	14:00:00	2948	269	74,5
12	14:00:00	15:00:00	2514	272	74,1
13	15:00:00	16:00:00	2148	252	74,0
14	16:00:00	17:00:00	2105	207	73,6
15	17:00:00	18:00:00	1878	200	73,3
16	13:00:00	14:00:00	3228	332	74,6
17	14:00:00	15:00:00	2431	230	74,1
18	15:00:00	16:00:00	1960	201	73,8
19	16:00:00	17:00:00	2532	245	74,2
20	17:00:00	18:00:00	1938	193	73,5
21	13:00:00	14:00:00	2072	254	74,1
22	14:00:00	15:00:00	2218	236	74,2
23	15:00:00	16:00:00	2630	267	74,3
24	16:00:00	17:00:00	2807	257	74,4
25	17:00:00	18:00:00	2367	250	74,3
26	13:00:00	14:00:00	2174	224	74,2
27	14:00:00	15:00:00	2784	224	74,3
28	15:00:00	16:00:00	3319	338	74,6
29	16:00:00	17:00:00	2506	229	74,1
30	17:00:00	18:00:00	1924	199	73,7
31	13:00:00	14:00:00	2110	229	74,2
32	14:00:00	15:00:00	2028	223	74,0
33	15:00:00	16:00:00	2462	273	74,4
34	16:00:00	17:00:00	1446	142	72,5
35	17:00:00	18:00:00	1381	155	72,6
36	13:00:00	14:00:00	2658	231	74,2
37	14:00:00	15:00:00	2158	255	74,1
38	15:00:00	16:00:00	2094	209	73,8
39	16:00:00	17:00:00	2141	193	73,8

40	17:00:00	18:00:00	1621	161	72,9
41	13:00:00	14:00:00	2198	246	74,2
42	14:00:00	15:00:00	2050	229	74,1
43	15:00:00	16:00:00	2038	206	73,8
44	16:00:00	17:00:00	2053	204	73,8
45	17:00:00	18:00:00	1499	166	72,9
46	13:00:00	14:00:00	2132	211	74,0
47	14:00:00	15:00:00	1845	200	73,4
48	15:00:00	16:00:00	2159	279	74,3
49	16:00:00	17:00:00	2001	221	73,7
50	17:00:00	18:00:00	1768	188	73,2

Table 1: **Relation between vehicle volume and Leq**
Souce: Survey data (2018)

Considering that, in this study, the noise level is represented by the random variable Y and the number of vehicles that traveled through Colombo Avenue as the predictor variable X, the data pairs (X, Y) were plotted in the scatter diagram shown in Figure 1.

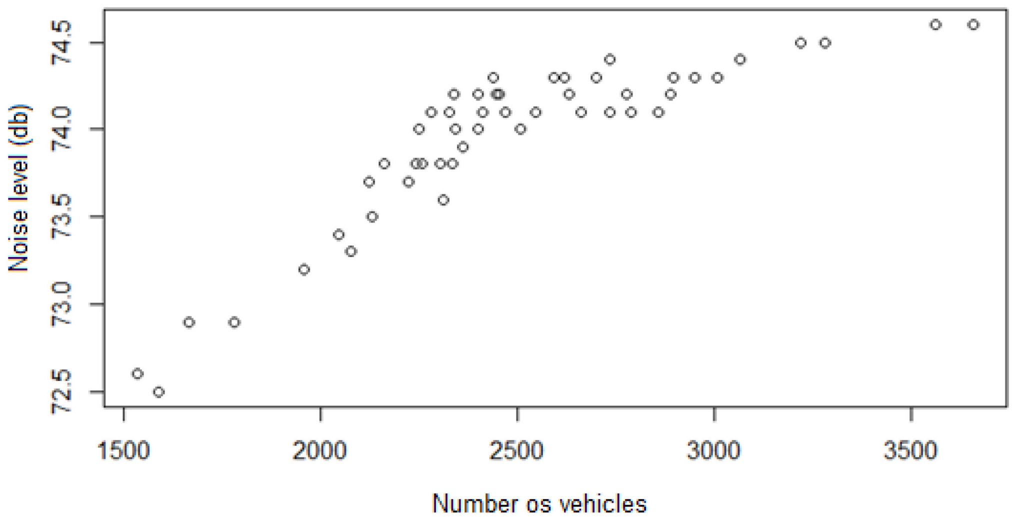

Figure 1: **Graphic relation between vehicle volume and sound level**
Source: The authors (2018)

From Figure 1, we verify that the relation between the variables X and Y does not resemble a line, suggesting that the mathematical function of X that explains Y must actually be nonlinear. In order to confirm this fact, a linear model was fitted to the data (AIC = 2.98), but the residuals showed non-random behavior, indicating the presence of patterns in the data not modeled by the adjusted linear curve.

The nonlinear function suitable to describe the relation between the variables X: "number of vehicles" and Y: "noise level" was the Logistics curve, which has three parameters A, μ and λ, being defined by equation 3.

$$f(X) = \frac{A}{1+e^{\left[\frac{4\mu}{A}(\lambda - X)+2\right]}} \qquad (3)$$

Where: μ is the maximum slope and A is the horizontal asymptote representing the maximum noise. In many nonlinear models, the parameters are characteristic points of the function and, not rarely, some parameters in the model do not have direct interpretation, such as the λ in the logistic curve, are necessary to guarantee flexibility to the model.

The estimates of the parameters A, μ and λ of the Logistics curve and their respective standard errors for the sample of vehicles collected in this study are represented in Table 2.

Parameter	Estimate	Standard error
μ	$\hat{\mu} = 0.025$	$\hat{\sigma}_{\hat{\mu}} = 0.003$
λ	$\hat{\lambda} = -2464.138$	$\hat{\sigma}_{\hat{\lambda}} = 474.207$
A	$\hat{A} = 74.705$	$\hat{\sigma}_{\hat{A}} = 0.109$

Table 2: **Estimates and standard error of the logistic curve parameters**
Souce: The authors (2018)

Also, the AIC was -45.18 while in the linear model it was 2.98. Besides that, the Confidence Intervals (CI) for the parameter estimates, with 95% reliability, were calculated to indicate the significance of the parameters. The results obtained were expressed in Table 3.

Estimator	IC (95%)	
	Inferior limit	Superior limit
$\hat{\mu}$	0.019	0.0314
$\hat{\lambda}$	-3393.583	-1534.693
$\hat{A}$	74.491	74.920

Table 3: **95% Confidence Intervals for Estimates**
Souce: The authors (2018)

Therefore, the nonlinear regression model adjusted to the data and describing the relationship between the variables X: "number of vehicles", light or heavy, and Y: "noise level" is the logistic model given by equation 4.

$$Y = \frac{74.7052}{1+e^{\left[\frac{4(0.0255)}{74.7052}(-2464.138 - X)+2\right]}} + \epsilon \qquad (4)$$

From equation 3, and from the data collected in Table 1, the graph that shows the relation between the variables X and Y described by the adjusted logistic model, in accordance with Figure 2, was drawn in red.

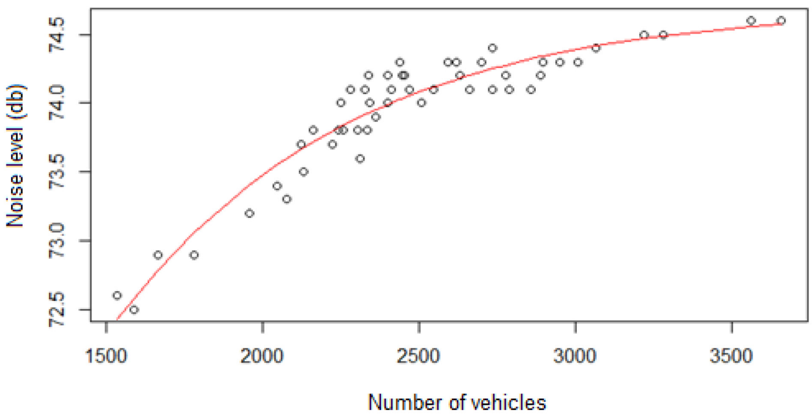

Figure 2: **Graphic of the adjusted logistic regression model (in red) describing the relation between the variables X and Y**
Source: The authors (2018)

It is noted in Figure 2 that the model seems to fit the data well. However, when adopting a regression model, some assumptions are assumed. By performing a residual analysis of the adjusted logistic model, we observed that the assumed assumptions regarding the random error were verified, as shown in the graphs of Figure 3.

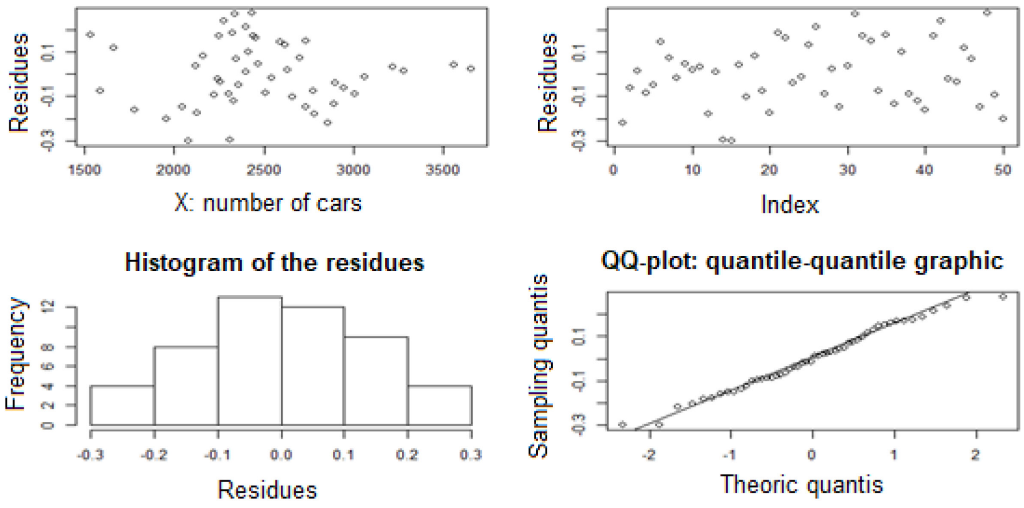

Figure 3: **Residual analysis**
Source: The authors (2018)

By the histogram and qq-plot presented in Figure 3, it is verified that the errors present normal distribution. Although not presented, correlograms and hypothesis tests that corroborated with the normality (Shapiro-Wilk) and the errors independency, that is absence of autocorrelation, were also verified.

Thus, from the tests of equation three, it was possible to conclude that the logistic model is valid to describe the variables under study.

From the nonlinear regression equation, the Leq was calculated, using equation 3, according to Table 4, in order to demonstrate the dispersion between the measured and calculated data.

Data	X (number of vehicles)	Leq measure period (dBA)	Leq calculated period (dBA)	Differences dB(A)
1	2858	74,1	74,3	-0,2
2	2949	74,3	74,4	-0,1
3	3280	74,5	74,5	0
4	2508	74	74,1	-0,1
5	2360	73,9	74	-0,1
6	2593	74,3	74,2	0,1
7	2698	74,3	74,2	0,1
8	2546	74,1	74,1	0
9	2469	74,1	74,1	0

10	2630	74,2	74,2	0
11	3217	74,5	74,5	0
12	2786	74,1	74,3	-0,2
13	2400	74	74	0
14	2312	73,6	73,9	-0,3
15	2078	73,3	73,6	-0,3
16	3560	74,6	74,6	0
17	2661	74,1	74,2	-0,1
18	2161	73,8	73,7	0,1
19	2777	74,2	74,3	-0,1
20	2131	73,5	73,7	-0,2
21	2326	74,1	73,9	0,2
22	2454	74,2	74	0,2
23	2897	74,3	74,3	0
24	3064	74,4	74,4	0
25	2617	74,3	74,2	0,1
26	2398	74,2	74	0,2
27	3008	74,3	74,4	-0,1
28	3657	74,6	74,6	0
29	2735	74,1	74,3	-0,2
30	2123	73,7	73,7	0
31	2339	74,2	73,9	0,3
32	2251	74	73,8	0,2
33	2735	74,4	74,3	0,1
34	1588	72,5	72,6	-0,1
35	1536	72,6	72,4	0,2
36	2889	74,2	74,3	-0,1
37	2413	74,1	74	0,1
38	2303	73,8	73,9	-0,1
39	2334	73,8	73,9	-0,1
40	1782	72,9	73,1	-0,2
41	2444	74,2	74	0,2
42	2279	74,1	73,9	0,2
43	2244	73,8	73,8	0
44	2257	73,8	73,8	0
45	1665	72,9	72,8	0,1
46	2343	74	73,9	0,1
47	2045	73,4	73,6	-0,2
48	2438	74,3	74	0,3
49	2222	73,7	73,8	-0,1
50	1956	73,2	73,4	-0,2

Table 4: **Measured Leq and calculated Leq**
Souce: The authors (2018)

It can be seen that the differences between measured and predicted traffic noise levels ranged from -0,3 dB (A) to +0,3 dB (A) and the mean difference was -0,006 dB (A).

Considering the regulatory norm that guides the evaluation of noise in inhabited areas, with the purpose of promoting comfort to the community, we established the limits of noise level, considering the type of environment in which the measurements were accomplished, represented by the value of the evaluation criterion level (NCA).

Considering the environment to which the measurements were made as a mixed area, predominantly residential, and, that the measurements were carried out during the daytime period, it is assumed that the limits pre-established is 55 dBA. Thus, from the measured and calculated Leq values, and the limit established by norm for a given region, it was possible to carry out the data scatter, comparing it with the Leq limit, according to Figure 4.

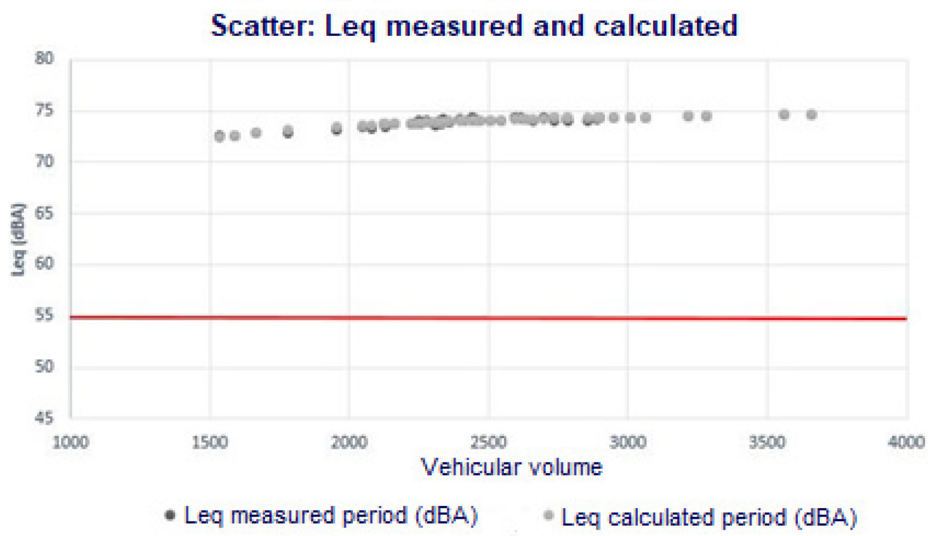

Figure 4: **Scatter between measured and calculated Leq**
Source: The authors (2018)

Therefore, from the graphic of scatter of SPL, measured and calculated, it was possible to analyze that the limit imposed by NBR 10151: 2000 is not being fulfilled, directly affecting the quality of life of the population in the area. Besides that, it was possible to conclude that the equation 3, Logistic Model, allows to perform the calculations of the noise level of the place under study, in a reliable and representative form. The suggested model allows to perform the noise level calculations in cities similar to the study, having the same contour conditions of the analyzed pathway.

It should be noted that the volume of traffic flow plays a significant role in the emission of traffic noise, which reflects the environmental impact on public health. The present study showed that the use of the environmental noise prediction model could be used in urban planning in order to reduce traffic noise levels and minimize public health problems around busy highways.

4 FINAL CONSIDERATIONS

Globalization and urbanization in centers cause great flows of movement of cargoes and people. Urban logistics has been applied in order to bring greater harmony in the transport sector and urban planning, contributing to the fulfillment of the economic objectives and environmental laws, enabling an improvement in the life quality of the population. The evidence available on the impacts of vehicular pollution on human health is overwhelming and sufficient for many years to demonstrate the importance of controlling emissions from mobile sources.

Thus, we studied the relation between vehicle volume and sound level at Colombo Avenue, which crosses the city of Maringá, in order to find a function capable of representing the relation between these variables at the location described. Hence, with the regression model found, we measure the noise level from a vehicle count in the area, facilitating the monitoring and supporting the decision-making and better control of the variables. Since, as said, they influence the quality of life of the surrounding population and are responsible for a portion of environmental pollution and degradation of public roads.

The results showed that the sound levels in the place exceeded the reference value, established by the Brazilian standard NBR 10151: 2000, thus requiring actions that reduce the vehicle volume and noise level. In addition, the results showed that the nonlinear regression model, Logistic Model, allows to perform the calculations of the noise level of the place under study, in a reliable and representative form, and can be used in other areas similar to the study, having the same contour conditions of the analyzed road.

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