Development of a Road traffic noise model prediction considering news variables

Abstract

Noise pollution in urban centers is directly linked to the traffic flow on the roads, avenues and streets as well as the types of vehicles, average speed, the type of flooring and several other independent variables. This fact has worried increasingly urban planners seeking to design cities least affected by traffic and them pathologies, among which stands out the noise. In this context, predict or estimate the traffic noise is an important procedure to the urban planning process. Therefore, the models calibration to predict noise, more current and consistent with the constant changes of type of vehicles and cities, brings significant collaborations to perform the function of being able to simulate, to different configurations, which would be the present noise levels. Thus, this study presents the relations found between parameters of traffic and noise, through the calibration of a predicting traffic noise model in the urban area of the city of Belo Horizonte - MG, Brazil. The results show significant relation between noise levels with the composition and volume of traffic and, in particular, the average velocity of flow.

1 Introduction

Noise is an invisible disease, but that has direct effects to the human been. These effects may be impaired or not and still segregated in physical, physiological and psychological (Banerjee et al., 2008). In the cities, the largest portion of noise is generally due to vehicular traffic (Querrien, 1995).

Concerns about traffic noise in cities have increased every day. In a survey conducted by Burgess (1996) it was found, through statistics performed on the publications of the previous 25 years, presented at conferences of the International Congress on Noise (INTERNOISE), the articles in this area were already around 10% of posted total on the various topics and with acoustics growth trends.

Several surveys conducted around the world, with the aim of measuring the noise coming from vehicular traffic show that, in general, the values found in urban roads are always higher than what is indicated or recommended by laws and specific technical standards (ALBA et al., 2003; ALI 2004, ALI & Tamura, 2003; ÁLVARES & SOUZA, 1992; BORTOLI, 2002, Li et al., 2002a; MORILLAS, 2002; TYAGI et al., 2006, Banerjee et al., 2008).

Therefore, the planning of new roads or urban areas should consider the likelihood of having significant noise levels and, therefore, need to esteem them, and then take steps to minimize them still in the planning phase.

One way to estimate the noise levels of traffic is through the use of predictive models. These equations models are usually calibrated by statistical methods, and have, in general, accurate and applicable results. It was presented by Steele (2001), just over a decade, an extensive review of the predicting traffic models, them origins, methodologies and applications. According to the author, the first model for predicting traffic noise generated by vehicular traffic must have been calibrated around 1952, and the dependent variable was the predicted percentile level L50. In the same study, the author has done a detailed description of the models most used in the wolrd, for example, the one developed by the Federal Highway Adminstration (FHWA), the CRTN (Department of Transport, 1988) developed and widely used in the UK, RLS 90 (Richtlinien für den Larmschutz an Straßen), developed in Germany, the commercial software MITHRA, of French origin, among others.

Generally, these models are empirically calibrated as a function of the environment around them. Thus, whereas the trend of vehicle technology is constantly evolving, it is necessary to constantly check the accuracy of these models, as well as the calibration of others to the characteristic of specific countries or regions, since the composition of the fleet vehicle and driver behavior varies from location to location.

In this way, is proposed on this article the calibration of a statistical model for predicting urban traffic noise in the city of Belo Horizonte, state of Minas Gerais, Brazil. The research area has about 3.5 million inhabitants and a vehicle fleet of more than 1.5 million vehicles.

2 Methodology

2.1 Data Collection

2.1.1 Noise

The Thecnical Standard considered for defining the measurement methodology was the ISO11819-1 "Acoustics - Method for measuring the influence of road surfaces on traffic noise."

The points to measurement were chosen intentionally with different features. Some of them with low flow and others with large capacity and traffic demand, with different characteristics and classification vehicular to diversify the samples. Additional points were chosen to compose strategically atypical situations. That is, a highway in a urban center with high speed and a avenue with low average speed and traffic flow less significant. A total of 11 measurement points werer monitored.

It is important to characterize that the goal of making measurements in points with different characteristics was to check different behaviors and compositions from the traffic flow in order to make the analysis of the relationship between noise and traffic, as well as to calibrate a model more comprehensive in respect to applicability.

The measuring periods were separated in two different situations, in order to make diverse sample concerned about traffic flow and vehicle noise levels, during the morning, in the interval between 05:00am and 10:00am and in the afternoon between 4:00pm and 9:00pm.

The results of noise measurements, as well as for all the others parameters, explained later, were grouped into 15-minute periods. In the study conducted by Rodrigues (2006) it was found that for very short periods the precision of the calibrated model is significantly smaller and, in some trials, are invalid (very low precision). For each of these intervals were obtained, with exclusive focus on the model calibration, the Equivalent Sound Level (Leq). Once that traffic noise is a random variable, this one has to be treated statistically. For this, the NBR 10151 (ABNT, 2000) establishes as a parameter for the description of environmental noise the adopted parameter Equivalent Sound Level.

2.1.2 Environment Data Measurement

For each point was carried out a detailed road inventory, to compose the database and evaluate the possible influence of such information on noise present, such as:

• Number of traffic lanes;

• Width of the avenues and highways (between buildings);

• Distance from the soundmeter to the center of the track;

• Distance to nearest traffic control sinal light;

• Presence of parking;

•• Paviment Type;

• Ramp (%);

• Presence of vegetation;

• Land Use.

• Hierarchy Road.

2.1.3 Data Flow Vehicular

Traffic was measured and segregated into motorcycles, cars, trucks and buses, with totals every 15 minutes for each direction of the road, as usual in traffic studies (Rodrigues, 2008), as already mentioned.

The vehicles average speed also was measured, refereneced by several renowned models (FHWA, CRTN, etc.). Thr measurement was done with a portable handheld radar. The measured was separately by type of vehicle, with the same classification of volumetric counts and still distinguished by flow direction on the avenue/higway. The collected samples were sufficiently to garantee 95% statistical precision.

2.2 Calibration of the model prediction

The prediction urban traffic noise model calibrated (for prediction of Leq) was, as already mentioned, a statistic one, using the multiple linear regression theory, whose mathematical formulation is shown in equation 1:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad 1$$

where:

- Y is the dependent variable to be estimated;
- β_0 is the constant of the model;
- β_n are the coefficients;
- x_n are the independent variables;
- ε are random variations.

It has to be noted that this statistical methodology has been adopted and presented by several Brazilian and foreign authors in the prediction traffic noise models development such as traffic noise Silva & Goldner (1998), Reis & Faria (2000), Steele (2001), PAMANIKABUD & VIVITJINDA, (2002), Calixto et al. (2003), Valadares & Suyama (2003), Alves Filho et al., (2004), Rodrigues (2006), Rodrigues et al. (2007), Banerjee et al. (2008), CAN et al. (2008).

To calibrate the model, was tested the independent variables, as already presented, in several possible configurations. It can be inferred that the noise is a function of several parameters, which are a significant number of installments. A generic model, that expresses the composition of the various portions of the road traffic noise, can be seen in the equation 2:

$$R = f(Q_m, D) \qquad 2$$

where:

- R is the total noise;
- Q_m is the noise generated by various types of vehicles and can be expressed by:

$$Q_m = \sum_{i=1}^{n} P_i.V_i \qquad 3$$

where:

- Pi is the sound power of vehicles of type i;
- V_i is the traffic flow classification i.

The variable D in the equation 2 represents all the other independent variables that can be explanatory of urban traffic noise. Thus, the process of model calibration in this study verified the correlation with all parameters potentially explanatory, already mentioned, as can be seen in the following equation:

$$\mathrm{L_{eq}} = f(Q_l, Q_c, Q_b, Q_m, GS, v, f, n_f, l_v, D_m, v_g, r, tp, U_s, H_v, L_{cc}, D_{Sem}, E) \qquad 4$$

where:

- Q_l, Q_c, Q_b, Q_m are, respectively, the flow of light vehicles, trucks, buses and motorcycles (vehicles / hour);

• GS is the saturation degree of the avenue or highway (%);

• v is the average flow speed (km/h);

• f is the time that was verified queues formation at the measurement point (min/min);

• n_f is the number of traffic lanes;

• l_v is the track width, considering the neighboring buildings (m);

• D_m is the distance between the source and the soundmeter (m);

• v_g is the presence of vegetation;

• r is slope of the avenue or highway (m/m);

• t_p is kind of pavement (asphalt, concrete, etc.);

• U_s is the classification of land use nearby;

• H_v is road hierarchy;

• L_{cc} is the width of the center fisic segregation on the avenue or highway;

• D_{sem} is distance to the nearest traffic light;

• E is the presence of parking.

It is Important to alert that several variables are correlated, as procedures performed in other studies (Rodrigues, 2006). For example, the noise is proportional to the flow speed and inversely proportional to the distance between the source and the receiver. Thus, it was tested some relationships, as exemplified on the equation 5:

$$\mathrm{y} = \log\left(\frac{V}{d}\right) \qquad 5$$

where:

• **y** is the variable to be made the correlation with the noise level;

• V is the average flow speed;

• d is the distance between the source and the receiver.

To calibrate the model and to procedure the statistical analyzes necessary, it was used the software SPSS 17.0. The software is a statistical package with various tools for help on models calibration, correlation analysis, validation, reliability testing, etc. With the aid of software problems such as, for example, high ratio between independent variables are easily solved.

To check the significance of the statistical model were used as the validation parameters the correlation coefficient R2 (as done by Banerjee et al., 2008), the standard error of estimate, testing "F", the "Student's test", the comparison between the residues of each estimate, and frequency analysis of the estimation errors ranging between 0 and 3 dB, as performed by Rodrigues (2006) and Rodrigues (2007).

All these data are easily obtained from the output data of the software, as illustrated in Figure 1.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,908[a]	,825	,819	1,36188	,825	137,899	10	292	,000

a. Predictors: (Constant), HierarquiaViaria, DistMedCentroVia, LnBusAD, LNVelocidAD, LnPercentPesado, LnBUSOP, LnVelocidOP, LnMotoTotal, LnAutoAD, LnAutoOP

b. Dependent Variable: Leq

Figure 1 - illustration of data outputs from the utilized software

3 Presentation of Collected Data

3.1 Traffic Noise

Preliminarily, the Figure 2 shows the general average variation of Leq for all points during the measurement. It can be seen that the noise is lower in the beginning of the day and then increase, remaining practically constant throughout the day (between 72 and 74 dB). After 20:00 it is also possible to identify a decreasing trend, coincident with a traffic flow reduction on the roads.

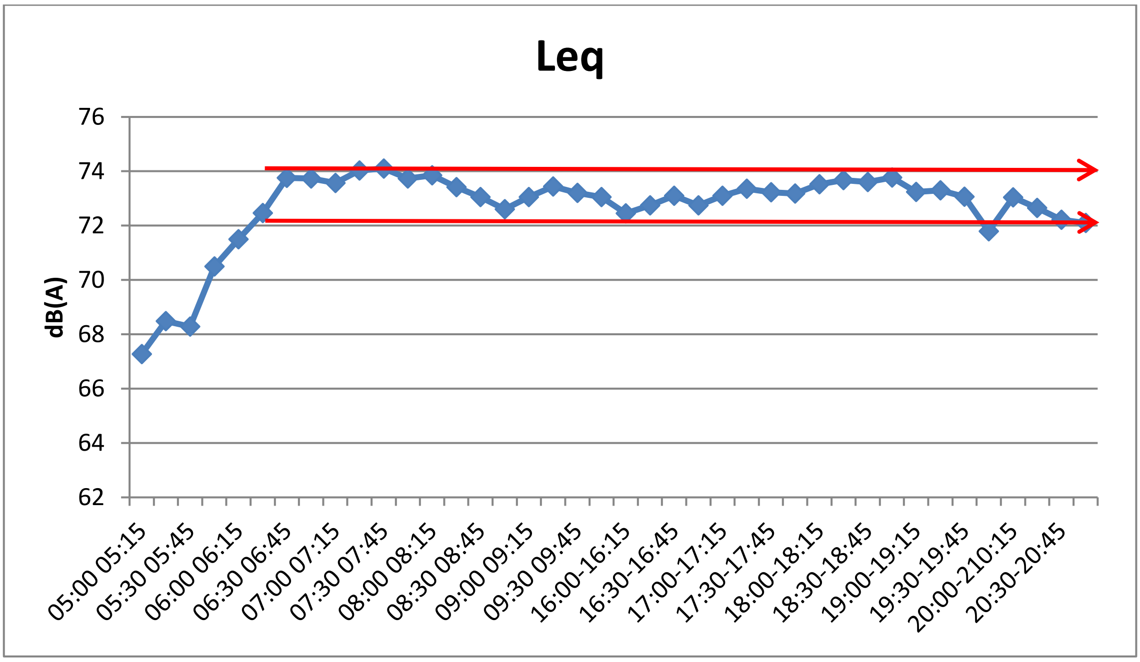

Figure 2 - Variation of Leq during the measurements

3.2 Vehicular Flow

The Figure 3 shows the traffic flow variation in both directions, neighborhood >> center and center >> neighborhood. As expected, there is an inversion with respect to the peak shifts.

That is, the morning peak (largest volume) is toward the center area of the city and in the afternoon in the opposite direction.

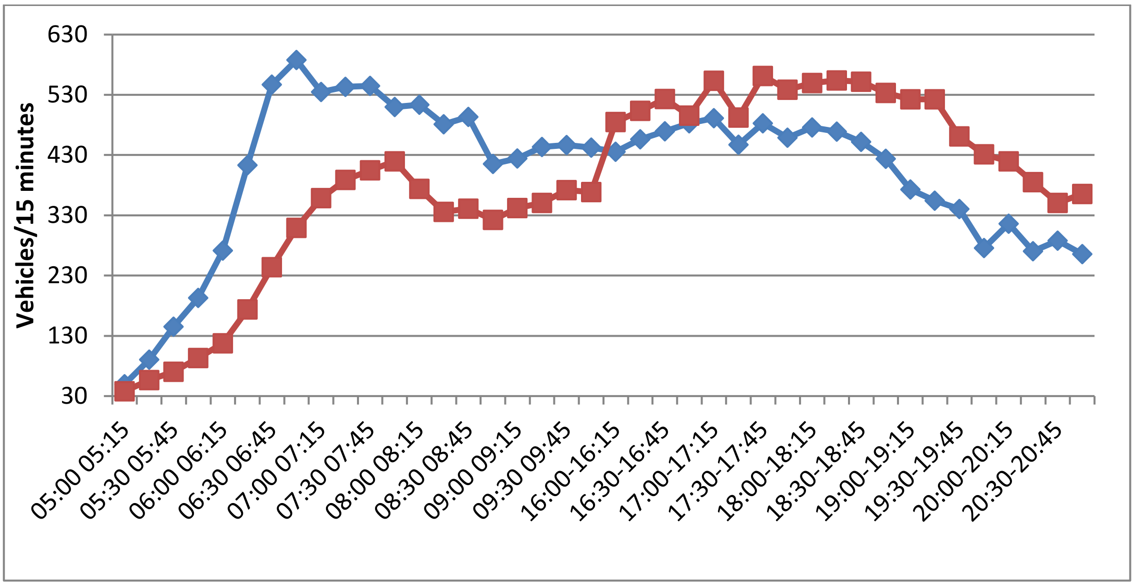

Figure 3 - Variation of vehicles flow

3.3 Average Flow Speed

The Figure 4 shows the average speed variation in each direction (VM Bairro >> Centro means the traffic average speed going to the central area and VM Centro >> Bairro the opposite). It is noted that this parameter is greater at the beginning of the morning and throughout the day decreases, returning to increase again in the beginning of the night. This behavior is the exactly the opposite of the vehicle flow, which it was expected considering the classical relationships between traffic volume and average speed flow.

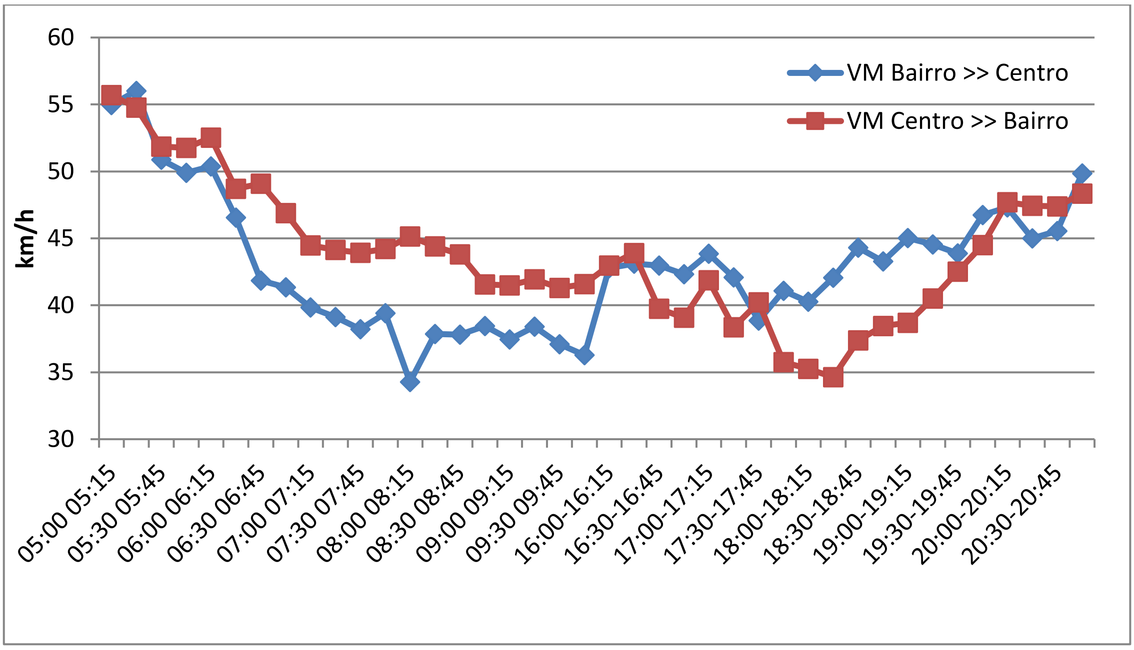

Figure 4 – Average flow speed variation

4 Model Calibration

To calibrate the model were tested a lot of independent variables combinations, as already mentioned, making 52 in total. With the software was evaluated various combinations of these variables in order to obtain the most accurate statistically model.

Among the various attempts were being discarded settings variables that were less accurate on the model. Similarly procedure was done with the independent variables that were less explanatory, or who had high correlation. At the end of the tests, it was obtained the most accurate model, as shown on the equation 6:

$$\begin{aligned} \mathrm{Leq} = {} & 23{,}234 + 1{,}307.\mathrm{Ln}(\mathrm{A}_{\mathrm{ad}}) + 0{,}432.Ln(O_{ad}) + 1{,}368.Ln(Vm_{ad}) + 1{,}057.Ln(A_{op}) + \\ & 0{,}863.Ln(O_{op}) + 1{,}543.Ln(Vm_{op}) + 0{,}432.Ln(M_{ad} + M_{op}) + 0{,}951.Ln(\%P) + \\ & 13{,}915.(H) - 0{,}391.(D) \end{aligned} \tag{6}$$

where:

- Leq is the equivalent sound level (15 minutes);
- Ln (A_{ad}) is the neperian logarithm of cars in the adjacent (same side) flow direction of the receiver (15 minutes);
- Ln (O_{ad}) is the neperian logarithm of bus in the adjacent (same side) flow direction of the receiver (15 minutes);
- Ln (Vm_{ad}) is the neperian logarithm of the adjacent (same side) average flow speed (15 minutes);
- Ln (A_{op}) is the neperian logarithm of cars in the opposite (other side) flow direction of the receiver (15 minutes);
- Ln (O_{op}) is the neperian logarithm of bus in the opposite (other side) flow direction of the receiver (15 minutes);
- Ln (Vm_{op}) is the neperian logarithm of the opposite (other side) average flow speed (15 minutes);
- Ln ($M_{ad} + M_{op}$) is the logarithm of the motorcycle flow on both direction (15 minutes);
- Ln (*%P*) is the neperian logarithm of the heavy vehicles percentage (15 minutes);
- H is road hierarchy (bettwen 0 and 3);

• D is the distance in meters between source and receiver (center of the track).

In Table 1 can be seen that the coefficient of determination obtained is statistical significant (greater than 0.80) and the also the resultos of F test, which showed a high value (greater than 100). The standard error of estimate presented a low value (less than 1,5 dB).

Table 1 - Results summary for the calibrated model

R	R2	R2 ayusted	Std. Error of estimate	Test F	Df1	Df2	Sig.
0,908	0,825	0,819	1,36188	137,899	10	292	0

The Figure 5 shows the frequency of occurrence for the noise estimates, made by the model, in terms of decibels variation from the real value (measured). That is, it can be seen that the highest frequency of occurrence for the noise estimates made by the model error is close to zero decibel (two bars leading to the center). It can also see that a few points were estimated errors of the order of 3dB.

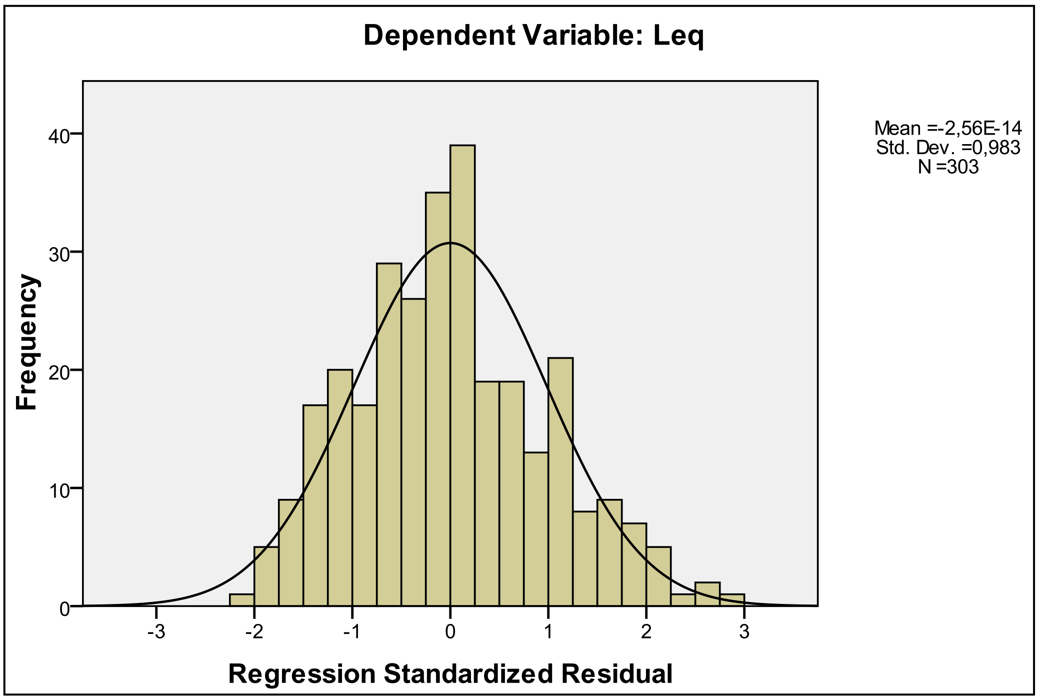

Figure 5 - Curve precision calibrated model (frequency of occurrence)

5 Model Aplicattion

As presented before, the calibrateded model achieved a statistical coefficient of determination (R2) equal to 0.825, which corresponds to an accuracy quite satisfactory for a kind of variable as random noise. Furthermore, the model showed good results when performed tests of statistical significance.

When it is applied to perform the prediction of noise to the points where measurements were made, that composed the present work, the results are also satisfactory, with an average error of 1.06 dB, calculated by the following equation:

$$E = \frac{\sum_{i=1}^{n} \sqrt{\left(\mathrm{Leq}_{\mathrm{measured}} - \mathrm{Leq}_{\mathrm{estimated}}\right)^2}}{n} \qquad 7$$

where:

- E is the mean error;
- $\mathrm{Leq}_{\mathrm{real}}$ is the equivalent sound level measured;
- $\mathrm{Leq}_{\mathrm{estimated}}$ is the equivalent sound level estimated by the model;
- n is the total estimates considered.

The Table 2 presents the main results of the errors obtained with the application of the calibrated model.

Table 2 - Summaries of the errors obtained with the model application

Error dB		
Minimun	Average	Maximun
0,0032	1,0676	3,6342

On the Figure 6 it can be seen how was the grip of the curve estimation when confronted with the actual data. It can clearly be seen the trend of increased noise levels along the x-axis 'x', both for the actual values (in red) and for the predicted (blue). The thinner line (black) is the trend estimated by the software, which one is closer to the logarithmic behavior.

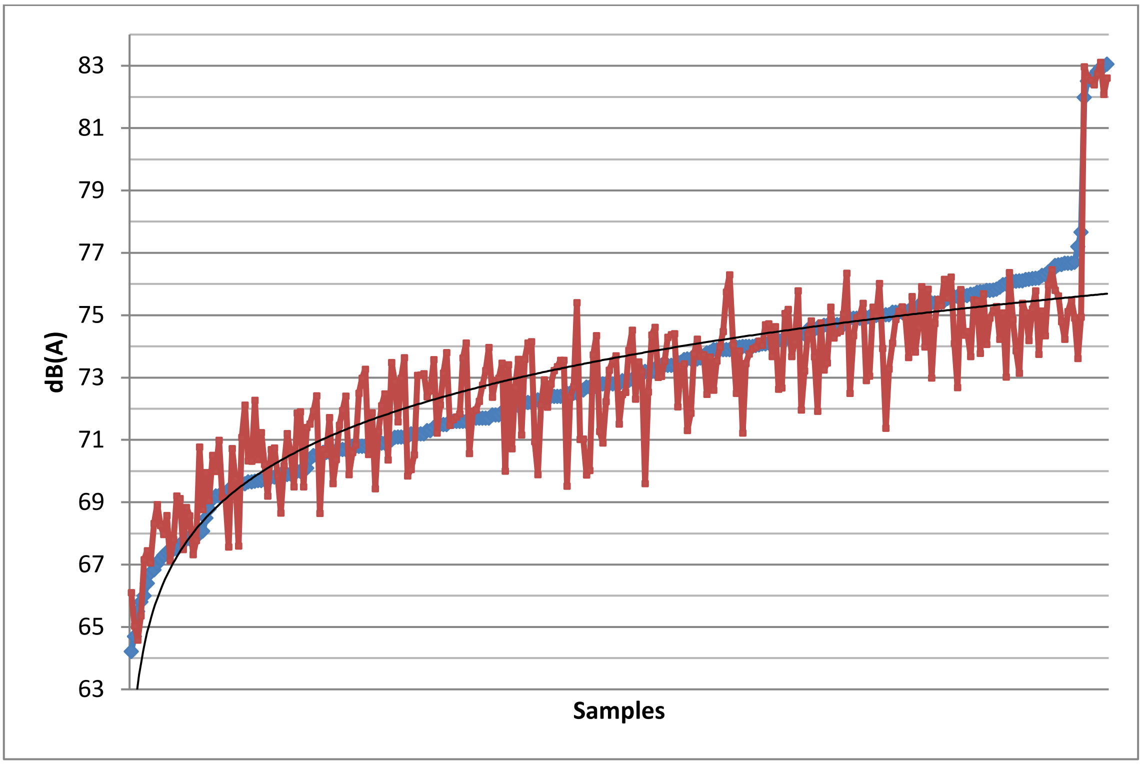

Figure 6 - Actual and predicted data noise, using the calibrated model

Conclusions

It was calibrated a predicting traffic noise model for urban roads with some innovative features, such as segregation of the flow in each direction on the road, consider the hierarchical classification pathway and consideration of the flow of buses, trucks and motorcycles separately.

Validations performed statistical showed that the model has sufficient accuracy to prove its applicability. Furthermore, as a recent calibration, the same can consider the peculiarities of the new vehicle fleet composition, as newer vehicles have lower noise than those of 10, 15 or 20 years ago.

In this way, this model can contribuiteto noise studies on citys around the world and, specially, in Brazil.

References

ALBA, J. R., GARCIA, D., & HERNANDEZ, F. (2003). Noise Effects of Reducing Traffic Flow Trought a Spanish City. *Applied Acoustics , Volume 64* (Número 3), pág. 343-363.

ALI, S. A., & TAMURA, A. (2003). Road Traffic Noise Mitigation Strategies in Greater Cairo, Egypt. *Applied Acoustics , Volume 64* (Número 8), pág. 815-823.

ALVES FILHO, J. M., LENZI, A., & ZANNIN, P. H. (2004). Effects os Traffic Composition on Road Noise: a case study. *Transportation Research Part D , Volume 9* (Número 1), pág. 75-80.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. (2000). *NBR-10151: Avaliação do Ruído em Áreas Habitadas Visando o Conforto da Comunidade* . ABNT.

BANERJEE, D., CHAKRABORTY, S. K., BHATTACHARYYA, S., & GANGOPADHYAY, A. (2008). Modeling of Road Traffic Noise in the Industrial Town of Asansol, India. *Transportation Research Part D , Volume 13* (Número 8), pág. 539-541.

BORTOLI, P. S. (2002). *Análise da Poluição Sonora Urbana em Zoneamentos Distintos da Cidade de Curitiba* . Curitiba, Paraná: Dissertação de Mestrado, Programa de Pós-Graduação em Tecnologia, CEFET-PR.

BURGESS, M. (1996). Trends in Traffic Noise Research over 25 Years. In: F. A. Hill, & R. Lawrence (Ed.), *In: Anais do Congresso Internacional de Engenharia de Controle de Ruído - Internoise 96. Vol. 1.* Liverpool: Institute of Acoustics.

CALIXTO, A., DINIZ, F., & ZANNIN, P. H. (2003). Modelamento Matemático da Emissão Sonora em Rodovias Federais que Adentram Áreas Urbanas. *Revista de Acústica , Vol. 34*.

CAN, A., LECLERCQ, L., & LELONG, J. (2008). Dynamic Estimation of Urban Traffic Noise: influence of traffic and noise source representations. *Applied Acoustics , Volume 69* (Número 10), pág. 858-867.

LI, B., TAO, S., & DAWSON, R. W. (2002a). Evaluation and Analysis of Traffic Noise from Main Urban Roads in Beijing. Applied Acoustics , Volume 63 (Número 10), pág. 1137-1142.

MORILLAS, J. M. (2002). An Environmental Noise Study in the City of Cáceres, Spain. Applied Acoustics , Volume 63 (Número 10), pág. 1061-1070.

PAMANIKABUD, P., & VIVITJINDA, P. (Novembro de 2002). Noise Prediction for Highways in Thailand. Transportation Research Part D , Vol. 7 (Nº 6), pp. pp. 441-449.

QUERRIEN, A. (1995). A Civilização das Cidades e Patologias Urbanas. *Ciência e Tecnologia Hoje* . (N. Witkowski, Ed., & R. L. Ferreira, Trad.) São Paulo: Ed. Ensaio.

REIS, J. N., & FARIA, C. A. (2000). *Poluição Sonora Decorrente do Fluxo de Veículos: um Estudo de Caso* . Uberlândia: Relatório Técnico, FECIV-UFU.

RODRIGUES, F. (2006). *Análise de Ruído em Terminais de Transporte Coletivo Urbano: Desenvolvimento de Modelos de Previsão* , Dissertação de Mestrado, 136 p. Uberlândia: Faculdade de Engenharia Civil, Universidade Federal de Uberlândia.

RODRIGUES, F., VECCI, M. A., & MOURA, L. C. (2007). Noise in Highways: Development of a Statistical Prediction Model. *In: 14º Internacional Congress of Sound & Vibration, ICSV-14* . Cairns, Austrália.

RODRIGUES, F., NASSI, C. D., RESENDE, C. C., & RODRIGUES JÚNIOR, A. L. (2008). Development of a Prediction Traffic Noise Model to Roads in Duplication Process. In: 15º International Congress of Sound & Vibration, ICSV-15. Daejon, Korea.

SILVA, G. C., & GOLDNER, L. G. (1998). Tráfego e Meio Ambiente: Avaliação dos Níveis de Monóxido de Carbono e Ruído nas Áreas Urbanas de Florianópolis. *In: III Encontro Ibero-Americano de Unidades Ambientais do Setor de Transportes*.

STEELE, C. (2001). A Critical Review of Some Traffic Noise Prediction Models. *Applied Acoustics , Volume 62* (Número 3), pág. 271-287.

VALADARES, V. M., & SUYAMA, E. (2003). Traffic Noise on Arterial Street in Belo Horizonte City: a Comprehensive Database. *In: 32º International Congress and Exposition on Noise Control Engineering, Inter-noise 2003*.