23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

APPLICATION OF MATHEMATICAL MODELS IN THE ANALYSIS OF TRAFFIC NOISE IN THE CITY OF BELÉM, PARÁ, BRAZIL

Caiane Ribeiro Oliveira
Wilson Luna Machado Alencar
Gabriel Soares Quixaba
Gerardo Alves Nogueira Braga Neto
Wagner de Sousa Santos
Newton Sure Soeiro
Universidade Federal do Pará, Grupo de Vibrações e Acústica. Rua Augusto Corrêa, 01 – Guamá. Belém – Pará - Brasil
caiane-ribeiro@hotmail.com
wilson.alencar@ifpa.edu.br
gjsmqgabrielsoares@gmail.com
gerardo-nogueira@hotmail.com
wsantos@ufpa.br
nsoeiro@ufpa.br

Abstract. *The fast expansion of the Brazilian cities, associated with the lack of urban planning, affects the life quality of the population from large urban centers. Thus, the noise has been pointed as being a major source of human stress and to offer health risks. Therefore, this paper use mathematical models for the characterization of traffic noise in one of the busiest avenue of Belém, which has a diversified geometry and intense traffic in all its extension. In this context, ninety measurements of noise pressure level were undertaken in six different points along the avenue, including counting and classifying of motorcycles, light and heavy vehicles during the acquisitions. Some mathematical models have been used for the prediction of statistical levels analyzed in the standard* L_{10}, L_{50}, L_{90}, *and the equivalent level,* L_{eq}. *The results of the mathematical models show a close approximation with measurements, showing that the mathematical models are an important tool for noise analysis.*

Keywords: *Traffic noise, intense traffic, mathematical models, experimental values, noise pressure level.*

1. INTRODUCTION

Based on the data from World Health Organization (WHO), noise pollution is the second biggest one in the world, losing only to water pollution (Who, 2010). Modernization of society and the growth, most of the time, disorderly, of urban centers allowed noise pollution to increase, decreasing life quality.

To solve noise related problems, it is necessary the identification and the characterization of the noise source, allowing the modeling of the case under study, in order to establish the relevant parameters.

In that scenario stands out the negative impact caused by the traffic noise, whose reclamations have intensified during the last few years, due to demographic density increase and number of vehicles growth of (Niemeyer and Slama, 1998). Traffic noise is mainly composed by three basic parcels: engine noise, tires and flooring interaction, and aerodynamic noise (Carvalho and Rocha, 2008).

There are several parameters that present correlation with traffic noise levels, namely: traffic composition, vehicle speed, street *greide*, and the distance between source and receptor, as was described by Garcia and Faus (1991), Golebiewski, *et al*. (2003), and Sattler (1999), *apud* Paz (2004).

For this work, the main objective is the study of traffic noise in the city of Belém-PA, which is composed by corridors of intense traffic, negatively affecting life quality of the population. In order to achieve that goal, the "Governador José Malcher" avenue was chosen to be investigated, due to its importance to the city and road traffic characteristics.

By definition, the statistic levels L_{90} (background noise level), L_{50} (average noise level), and L_{10} (peak noise level) represent the sound pressure levels that were exceeded during 90%, 50%, or 10% of the measurement time, respectively. On the other hand, the equivalent sound pressure level, L_{eq}, is defined as being the stationary sound level that occurs during the register interval and would generate the same sound energy produced by the other sound events registered.

From the various mathematical models developed during the last decades for road traffic noise prediction, the work of Bolt *et al.* stands out, as well as the ones developed by Griffiths and Langdon (1968), Silva and Goldner (2004), Calixto (2002), and CSTB (1991). Those models were chosen because they are already well renowned, and due to their historic importance or actual relevance.

2. MATHEMATICAL MODEL

Since 1950, many mathematical models were developed to predict road traffic noise levels. Those models make use of the correlated parameters to the generation of this kind of noise, and estimate the sound pressure levels, expressing them in the form of statistic levels (also called exceedance levels), or equivalent levels of energy.

Since singularities of each pathway influence the observed noise levels, prediction models, frequently developed through interpolation of experimental data, are very particular, which leads to constant development of new models, according to each individual case.

2.1 First Model Developed to Road Traffic Noise

According to Steele (2001), the first mathematical model developed to the prediction of the sound pressure level generated by road traffic noise was developed by Bolt *et al*. (1952), as shown in the Handbook of Acoustic Noise Control (1952). This model expresses the sound pressure level through L_{50}, according to Eq. (1), regarding to traffic velocities between 50 and 70 km/h, and distances between 6 and 9 m from the center of the pathway and the receptor:

$$L_{50} = 68 + 8{,}5 \cdot log(V) - 20 \cdot log(D) \text{ [dB(A)]} \quad (1)$$

Where *V* is the traffic volume (in hours) and *D* is the distance to the center of the pathway in feet.

2.2 Griffiths and Langdon Model

The model developed by Griffiths and Langdon (1968), *apud* Pais *et. al.* (2012), obtains the equivalent sound level, according to Eq. (2), by adding the statistic levels given in Eq. (3), Eq. (4) and Eq. (5):

$$L_{eq} = L_{50} + 0{,}018 \cdot (L_{10} - L_{90})^2 \text{ [dB(A)]} \quad (2)$$

$$L_{50} = 61 + 8{,}4 \cdot log(V) + 0{,}15 \cdot P - 11{,}5 \cdot log(D) \text{ [dB(A)]} \quad (3)$$

$$L_{10} = 44{,}8 + 10{,}8 \cdot log(V) + 0{,}12 \cdot P - 9{,}6 \cdot log(D) \text{ [dB(A)]} \quad (4)$$

$$L_{90} = 39{,}1 + 10{,}5 \cdot log(V) + 0{,}06 \cdot P - 9{,}3 \cdot log(D) \text{ [dB(A)]} \quad (5)$$

Where *P* is the percentage of heavy vehicles.

2.3 Model Developed to the city of Florianópolis-SC, Brazil

This model was developed by Silva and Goldner (2004) for the prediction of road traffic noise in the city of Florianópolis (Brazil), through linear regression, using the method of minimum squares from collected data, to distances of 0,5 m from the edge of the pathway and, a minimum of 1,5 m from reflective surfaces. The equivalent energy level (L_{eq}) is obtained from Eq. (6), and this model considers the influence of the vehicle type, since heavy vehicles have stronger correlations with noise levels:

$$L_{eq} = 62{,}044 + 1{,}779 \cdot log(VL) + 8{,}282 \cdot log(VP) \text{ [dB(A)]} \quad (6)$$

Where *VL* is the volume of light vehicles and *VP* is the volume of heavy vehicles, in 10 min.

2.4 Model for Road Traffic Noise Prediction in the city of Curitiba-PR, Brazil

Analogously to Silva and Goldner (2004), Calixto (2002) developed to the specific case of Curitiba (Brazil), prediction models of statistic levels (L_{10} and L_{90}), and the equivalent level (L_{eq}), to distances of 25 m from the center of the pathway to the receptor, because those levels have been the most utilized ones throughout the study of road traffic noise, as well as in the standards related to this topic:

$$L_{10} = 7{,}6 \cdot log(I) + 50{,}9 \text{ [dB(A)]} \quad (7)$$

$$L_{90} = 11{,}9 \cdot log(I) + 25{,}5 \text{ [dB(A)]} \quad (8)$$

$$L_{eq} = 9{,}5 \cdot log(I) + 41{,}4 \text{ [dB(A)]} \quad (9)$$

$$L_{10} = 6{,}2 \cdot log\left[I \cdot \left(1 + 0{,}095 \cdot \frac{VP}{100}\right)\right] + 52{,}2 \text{ [dB(A)]} \quad (10)$$

$$L_{90} = 10{,}2 \cdot log[I \cdot (1 + 0{,}050 \cdot VP)] + 27{,}1 \text{ [dB(A)]} \quad (11)$$

$$L_{eq} = 7{,}7 \cdot log[I \cdot (1 + 0{,}095 \cdot VP)] + 43 \text{ [dB(A)]} \quad (12)$$

Where *I* is the vehicle flow per hour and *VP* is the percentage of heavy vehicles.

2.5 Model Developed to França

As cited in Pais *et al.* (2001), this model was developed by *Centre Scientifique et Technique du Batiment* (CSTB, 1991) and predicts the equivalent level, according to Eq. (13), from L_{50} according to Eq. (14), to vehicle flows under 1000 vehicles per hour, and to Eq. (15), when dealing with greater flows:

$$L_{eq} = 0{,}65 \cdot L_{50} + 28{,}8 \text{ [dB(A)]} \quad (13)$$

$$L_{50} = 11{,}9 \cdot log(V) + 31{,}4 \text{ [dB(A)]} \quad (14)$$

$$L_{50} = 15{,}5 \cdot log(V) - 10 \cdot log(L) + 36 \text{ [dB(A)]} \quad (15)$$

Where *L* is the distance from the center of the pathway to the receptor, in meters.

2.6 Model Developed for Sydney, Australia

This model was developed for Sydney (Australia) by Burguess (1977). This model considers the sound pressure level as a function of the equivalent level L_{eq}, as in Eq. (16), for distances of 9 m between the receptor (microphone) and the center of the railway, and free vehicles flow:

$$L_{eq} = 55{,}5 + 10{,}2 \cdot \log(Q) + 0{,}3 \cdot P - 19{,}3.\log(D) \text{ [dB(A)]} \quad (16)$$

Where *Q* is the number of vehicles per hour, *D* is the distance from the receptor to the center of the pathway, in feet, and *P* is the percentage of heavy vehicles.

3. EXPERIMENTAL METHODOLOGY

The pathway to be studied in this paper is a busy avenue in Belém-PA, Brazil, that links the principal pathway of access to the city with its center. Since the avenue presents a varied geometry throughout its extension, it was divided in six points for the mathematical analysis. The avenue and its measurement points disposition can be seen in the Figure (1).

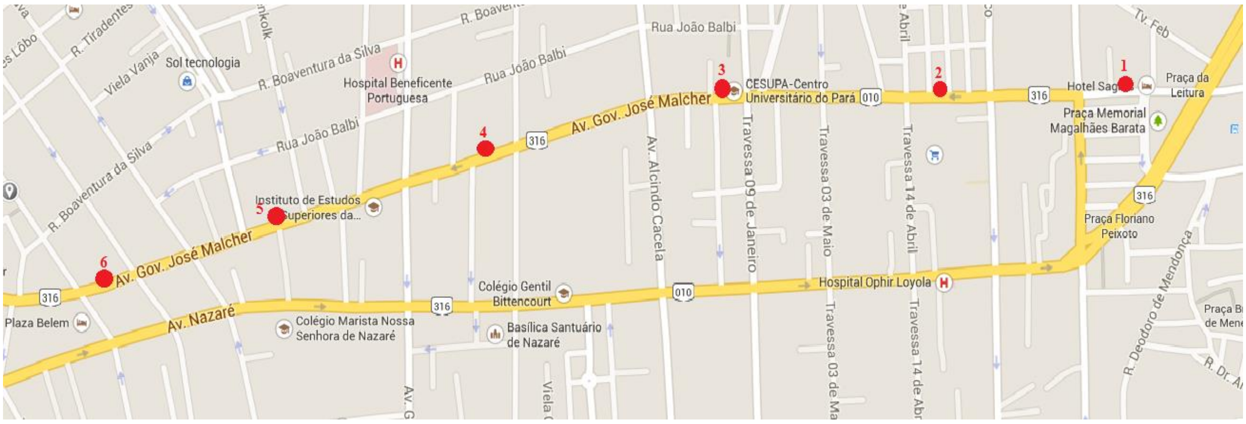

Figure 1 – José Malcher Avenue and measurement positions.

At each point, it was done 90 measurements, each lasting 2 min and performed between 7 am and 19 pm. The measurements occurred simultaneously and were held in several days until it could match the database required for each point. The Sound Level Meter (SLM) used was a 1,0 dB Blue Solo and the experimental procedures were performed according to NBR 10 151, with the SLM being located 1.5 m from the track edge. As the geometry of the path varies along its length, the distance from the meter to its center (distance applied in models) is different for each period, and for that reason, the general representation of the measurement scheme is given in Figure (2).

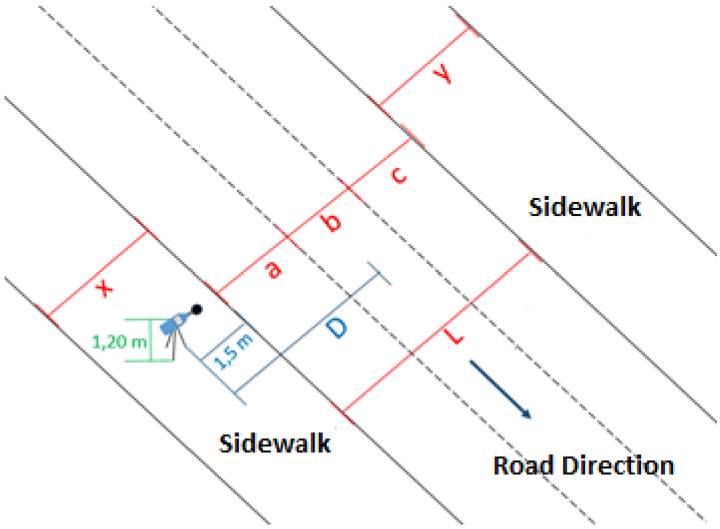

Figure 2 –Experimental set-up.

In figure (2), *x* represents the width of the right sidewalk (considering the flow direction), *y* is the width of the left sidewalk, *a*, *b*, and *c* are the widths of lanes 1, 2, and 3, respectively, *D* is the distance from the receptor to the center of the passage, and *L* is the total width of the passage. Those dimensions are specified in the Table 1 for each measurement point.

Table 1. Values, in meters, of the geometric characteristics of the measurement points.

Measurement point	*x*	*y*	*a*	*b*	*c*	*D*	*L*
1	4,10	12,00	5,40	3,50	3,50	7,70	12,40
2	6,40	6,60	5,00	3,00	3,00	7,00	11,00
3	6,40	6,60	4,20	2,50	2,50	6,10	9,20
4	5,40	5,20	2,80	2,55	2,55	5,45	7,90
5	5,80	4,50	3,10	2,70	2,70	5,75	8,50
6	5,40	5,20	3,90	3,60	0,00	4,75	7,50

All data is presented in the Table 2 as average values of measured sound pressure levels ($L_{10}, L_{50}, L_{90}\ e\ L_{eq}$), of the vehicle flow, along with its composition.

Table 2. Measurement results.

Measurement points	Vehicle Flow/h	% of heavy vehicles	L_{eq} [dB(A)]	L_{10} [dB(A)]	L_{50} [dB(A)]	L_{90} [dB(A)]
1	1970,7	13,4	73	76	70	67
2	1954	15,2	75	79	72	66
3	2140,3	12,5	74	78	71	64
4	2100,3	13	76	80	73	67
5	2259,3	11,9	75	79	71	65
6	1501,3	9,4	73	77	69	61

The 90 samples set taken from each point were defined using a previous experimental planing, based on the reliability degree and logistics issues. The replicas were carried randomly and the statistical techniques used were based on the Gaussian distribution of the experimental data since it was observed a high concentration of the results around the mean value.

4. RESULTS AND DISCUSSION

Applying the mathematical models described in section 2, with the data from the measurement, the achieved results are those presented in the Tables 3 and 4, for each analyzed point.

Table 3. Numerical results for points 1, 2, and 3.

POINT 1		
Model		Results [dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 68$
Griffiths e Langdon (1968)		$L_{50} = 74$; $L_{10} = 68$; $L_{90} = 61$; $L_{eq} = 75$
Silva e Goldner (2004)		$L_{eq} = 80$
Calixto (2002)	One variable	$L_{10} = 76$; $L_{90} = 65$; $L_{eq} = 73$
	Two variables	$L_{10} = 73$; $L_{90} = 63$; $L_{eq} = 71$
CSTB (1991)		$L_{50} = 78$; $L_{eq} = 80$
Burguess (1977)		$L_{eq} = 66$
POINT 2		
Model		Results [dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 69$
Griffiths e Langdon (1968)		$L_{50} = 75$; $L_{10} = 69$; $L_{90} = 62$; $L_{eq} = 76$
Silva e Goldner (2004)		$L_{eq} = 80$
Calixto (2002)	One variable	$L_{10} = 76$; $L_{90} = 65$; $L_{eq} = 73$
	Two variables	$L_{10} = 73$; $L_{90} = 63$; $L_{eq} = 71$
CSTB (1991)		$L_{50} = 78$; $L_{eq} = 80$
Burguess (1977)		$L_{eq} = 67$
POINT 3		
Model		Results [dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 70$
Griffiths e Langdon (1968)		$L_{50} = 76$; $L_{10} = 70$; $L_{90} = 63$; $L_{eq} = 77$
Silva e Goldner (2004)		$L_{eq} = 80$
Calixto (2002)	One variable	$L_{10} = 76$; $L_{90} = 65$; $L_{eq} = 73$
	Two variables	$L_{10} = 73$; $L_{90} = 63$; $L_{eq} = 71$
CSTB (1991)		$L_{50} = 80$; $L_{eq} = 81$
Burguess (1977)		$L_{eq} = 68$

Table 4. Numerical results for points 4, 5, and 6.

POINT 4		
Model		Results [dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 71$
Griffiths e Langdon (1968)		$L_{50} = 76$; $L_{10} = 70$; $L_{90} = 63$; $L_{eq} = 77$
Silva e Goldner (2004)		$L_{eq} = 80$
Calixto (2002)	One variable	$L_{10} = 76$; $L_{90} = 65$; $L_{eq} = 73$
	Two variables	$L_{10} = 73$; $L_{90} = 63$; $L_{eq} = 71$
CSTB (1991)		$L_{50} = 80$; $L_{eq} = 81$
Burguess (1977)		$L_{eq} = 69$

POINT 5		
Model		Results[dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 71$
Griffiths e Langdon (1968)		$L_{50} = 76;\ L_{10} = 70;\ L_{90} = 63;$ $L_{eq} = 77$
Silva e Goldner (2004)		$L_{eq} = 80$
Calixto (2002)	One variable	$L_{10} = 76;\ L_{90} = 65;\ L_{eq} = 73$
	Two variables	$L_{10} = 73;\ L_{90} = 63;\ L_{eq} = 71$
CSTB (1991)		$L_{50} = 80;\ L_{eq} = 81$
Burguess (1977)		$L_{eq} = 69$
POINT 6		
Model		Results [dB(A)]
Handbook of Acoustic Noise Control (1952)		$L_{50} = 71$
Griffiths e Langdon (1968)		$L_{50} = 75;\ L_{10} = 69;\ L_{90} = 62;$ $L_{eq} = 76$
Silva e Goldner (2004)		$L_{eq} = 77$
	One variable	$L_{10} = 75;\ L_{90} = 63;\ L_{eq} = 72$
	Two variables	$L_{10} = 72;\ L_{90} = 61;\ L_{eq} = 69$
CSTB (1991)		$L_{50} = 78;\ L_{eq} = 80$
Burguess (1977)		$L_{eq} = 67$

5. CONCLUSIONS

According to Bistafa (2011), variations in sound pressure levels below 3 dB are not noticeable to the human ear. Thus, according to this criterion, it may concluded that the discussed models have valid application to the studied avenue.

The mathematical model for predicting L_{50}, proposed on by Bolt *et al.*, has valid application to the referred road, since it provides good approximation of actual results, particularly for points 3 and 5.

The model developed by Griffiths and Langdon (1968) to predict L_{10} and L_{50} does not apply to this road, as in every point differences are greater than 3 dB, and the variations are very significant to be neglected. The model developed for L_{90} does not provide good approximation to real values and hence does not apply to this avenue.

The model developed by Silva and Goldner (2004) to predict the L_{eq}, showed differences between the calculated values and actual than 3 dB at all measurement points, which disqualifies the model for this route in particular. This is because the model has been developed for smaller distance between source and receiver and the nearest receiver of the reflective surfaces, then if an inverse correction is performed for the considered Calixto model, this model could be applied to the path, describing -a with best approach.

The models developed by Calixto (2002) show higher divergences 3 dB, which in this case are very significant, even for models developed with two variables and corrections made as the distance source-receiver. This is because such designs were developed for "highways, major avenues" and this type of road, the average speed of vehicles is much higher than the average speed Avenue analyzed. So how speed is one of the parameters that influence the traffic noise levels, another correction should be made in this model, to make feasible to apply to this particular occasion.

The models developed by CSTB (1991) to predict the L_{50} and L_{eq} are not applicable to this avenue because it presents very significant divergence of values. These models have been developed for French routes and its peculiarities, which interferes with the results, since the study pathway has different characteristics.

The last analyzed model was developed by Burgess (1977) for a road 20 km from the commercial center of Sydney, in cases where the receiver was at least 10 meters of reflective surfaces and the flow flowed as free as possible, far from traffic signals, in other words, when the vehicle had reached a constant speed. These characteristics differ from those on the path analyzed in this article, creating therefore a difference of up to 10 dB sound pressure level measured to calculated in the form of L_{eq}, as this is already a significant difference, this model is not recommended for application to this specific case of the city of Bethlehem.

Finally, it has been observed that the models that exhibit the most consistent results with the measurements were obtained in the model of Bolt et al. (1952) to predict the L_{50} and the model of Griffiths and Langdon (1968) to predict L_{eq} and L_{90}, the other models did not show a good approximation.

6. REFERENCES

Abbaspour, M., Golmohammadi, R., Nassiri, P. and Mahjub, H., 2006. "An Investigation on Time-Interval Optimization of Traffic Noise Measurement". *Journal of low frequency noise vibration and active control*, Vol. 25(4), p. 267-273.

Bistafa S. R., 2011. *Acústica Aplicada ao Controle de Ruído*. Bluncher, São Paulo, 2nd edition.

Bolt, R. H., Beranek, L. and Newman, R. "Handbook of acoustic noise control". WADC technical report: Wright Air Development Center, 1952.

Burgess, M. A., 1977. "Noise Prediction for Urban Traffic Conditions – Related to Measurements in the Sydney Metropolitan Area". *Applied Acoustic*, Australia, Vol. 10, p. 001-007.

Calixto A., Pulcides, C. and Zannin, P. H. T., 2008. "Evaluation of transportation noise in urbanized areas – A case study". *Archives of Acoustics*, Vol. 33(2), p. 151-164.

Calixto, A., 2002. "O Ruído gerado pelo Tráfego de Veículos em 'Rodovias-Grandes Avenidas', Situadas Dentro do Perímetro Urbano de Curitiba, Analisados Sobre Parâmetros Acústicos Objetivos e seu Impacto Ambiental". 125 p. Dissertação (Mestrado em Engenharia Mecânica), Universidade Federal do Paraná, Curitiba.

Carvalho, A. P. O. And Rocha, C., 2008. *Manual Técnico para Elaboração de Planos Municipais de Redução de Ruído*. Agência Portuguesa do Ambiente.

CSTB (Centre Scientifique et Technique du Batiment), 1991. "Etude théorique et expérimentale de la propagation acoustique". *Revue d'Acoustique*, n.70.

DENATRAN (Departamento Nacional de Trânsito). "Frota de veículos". 18 May. 2015 <http:/www.denatran.gov.br/frota.htm>.

Galloway, W. J., Clark, W. E. and Kerrick, J. S., 1969. "Urban highway noise: measurement, simulation and mixed reactions". *NCHRP* report, Vol. 78.

García A. and Faus L. J., 1991. "Statistical Analysis of Noise Levels in Urban Areas". *Applied Acoustics*, Vol. 3(91), p. 227-247.

Golebiewski, R., Makarewick, R., Nowak, M. and Preis, A., 2003. "Traffic Noise Reduction due the porous Road Surface". *Applied Acoustics*, Vol. 64, p. 481-494.

Golmohammadi, R., Abbaspour, M., Nassiri, P. and Mahjub, H., 2007. "Road traffic noise model". *J Res Health Sci*, Vol. 7(1), p. 13-17.

Griffiths, I. D. and Langdon, F. J., 1968. "Subjective Response to road traffic noise". *Journal of Sound and Vibration*, Vol.8, p. 16-32.

Johnson, D. R. and Saunders, E. G., 1968. "The evaluation of noise from freely flowing road traffic". *Journal of Sound and Vibration*, Vol. 7, n. 2, p. 287 – 309.

Masouri, N.A., Pour Mahabadian, M. and Ghasemkhani, M., 2006. "Road Traffic Noise in Downtown Area of Tehran". *Iranian Journal Of Environmental Health Science And Engineering*, Vol. 3(4), p. 261-266.

Niemeyer, M. L. and Slama, J. G., 1998. *Arquitetura: Pesquisa e Projeto*. Proeditores, São Paulo.

Pais, A. P. T. D., Aragão, F. V., Sousa, L., Marinho, L. H. N. and Soares, P. F., 2012. "Utilização de Modelos Matemáticos na Análise do Ruído de Tráfego em uma Travessia Urbana". In *Proceedings of the 3st Simpósio de Pós Graduação em Engenharia Urbana –SIMPGEU2012*. Maringá, Brazil.

PAZ, E. C., 2004. *Estudo de um modelo de avaliação e predição acústica para o ruído de tráfego*. Dissertação (Mestrado em Construção Civil), Setor de Tecnologia, Universidade Federal do Paraná, Curitiba.

Quartieiri, J., Mastorakis, N. E., Iannone, G., Guarnaccia, C., D'Ambrosio, S., Troisi, A. and Lenza, T. L. L., 2009. "A Review of Traffic Noise Predictive Models". In *Proceedings of the 5th WSEAS International Conference on Applied and Theoritical Mechanics*, Puerto De La Cruz – Tenerife – Canary Islands - Spain, p. 72-80.

Sattler, M.A., 1999. "Urban Noise Survey for the city Porto Alegre, Brazil". In *Proceedings of the 137th Meeting of the Acoustical Society of America – Fórum Acusticum*, Berlim, Germany.

Silva, G. C. and Goldner, L. G., 2004. "Modelos de Predição dos níveis de Ruído e Monóxido de Carbono Gerados pelo Tráfego: o Caso de Florianópolis – SC". In *Proceedings of the 18th Congresso de Pesquisa e Ensino em Transportes – ANPET2004.* Florianópolis, Brazil.

Steele, C. A., 2001. "Critical Review of Some Traffic Noise Prediction Models". *Applied Acoustic*, Vol. 62, p. 271-287.

Stefano, R., Danato, D. and Morri, B., 2001. "A Statistical Model for Predicting Road Traffic Noise on Poisson Type Traffic Flow". *Noise Control EngineeringJjournal*. Vol. 49(3), p. 137-143.

WHO (World Health Organization), 2010. *International Society of Hypertension Guidelines for the Management of Hypertension*. Guidelines Subcommittee.

7. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.