

INFLUENCE OF THE TRAFFIC COMPOSITION AND TRAFFIC FLOW ON NOISE EMITTED BY TYPICAL BRAZILIAN ROADS

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ABSTRACT

This paper treats the problem of traffic noise in roads which have been transformed into big avenues in the city of Curitiba and its impacts on the community. Simultaneous measurements of noise levels, vehicle flow, and traffic composition were made around the main roads inside the urban perimeter of Curitiba. Mathematical models were then developed to estimate sound pressure levels. The measured levels were compared with the mathematical models as well as with the results using the German Standard RLS-90. The validity of the developed mathematical models was thus confirmed as well as the applicability of the calculation method adopted by the German Standard RLS-90. Finally, the traffic noise levels around these roads were assessed by the application of the noise urban limits of the municipal law 8583/1995.

SOMMAIRE

Cet article a rapport au problème du bruit causé par le trafic dans les rues qui ont été transformées en grandes avenues dans la ville de Curitiba, en ce qui concerne la mesure des niveaux de bruits et les conséquences causées à la communauté. Des mesures simultanées ont été conduites dans plusieurs avenues dedans le périmètre urbaine de Curitiba en ce qui regarde les niveaux de bruit, le flux de véhicules et la composition du trafic. Avec les résultats des modèles mathématiques on été construits pour estimer les niveaux de pression sonore. Ensuite, les niveaux de bruit mesurés on été comparés à ceux obtenus par les modèles mathématiques et le *standard* RLS-90 allemand. Par cette comparaison, il a été confirmé la validité des modèles mathématiques construits et l'application de la méthode utilisé par le *standard* RLS-90 allemand. A la fin, les niveaux de bruit du trafic autour de ces avenues et les limites des bruits urbains de la loi municipale 8583/1995 on été comparés et il a été confirmé que les personnes qui habitent ou travaillent à ces lieux sont exposés à des niveaux de bruit plus haut que ceux permis par la législation.

1. INTRODUCTION

Curitiba, with a population of 1.6 million, is one of the most ancient and populated cities in Brazil. Its economical growth has been very strong during the last 30 years due to the industrial development encouraged by the Brazilian government. Indeed, this fact have lead to deep structural changes in the city. Some of them are:

- Migration of people from country areas to urban areas in search of more lucrative jobs;
- Increase in circulating number of vehicles in the city;
- Increase in civil construction activities for the construction of new homes for the new inhabitants.

The increase in the population and in the number of circulating vehicles has led to an increase in the urban noise levels. The need therefore for studies regarding the urban noise pol-

lution and its consequences over the environment have motivated various researches on the problem in several countries (Burgess, 1977; Barbosa, 1992; Zheng 1996; Arana, 1998 ; Suksaard , 1999; Abdel-Raziq, 2000; Zeid 2000; Zannin et. al., 2001; Zannin et. al., 2001).

A recent survey carried out by Calixto (Calixto et. al., 2000) in the city of Curitiba, in which the answers collected from 860 questionnaires distributed among the population were analyzed, with the intention of verifying the impact of the urban noise over the people. The results of the survey are summarized in Figure 1. This study has shown that the noise generated by the traffic of vehicles is the most annoying noise source. Among all the respondents that felt annoyed by the noise generated in his/her street, 73% points the traffic as the main noise source.

The great population increase in the city of Curitiba has also

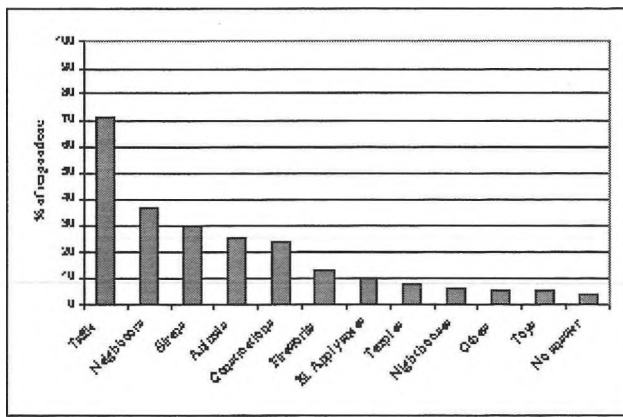


Figure 1. Results of Noise Annoyance Survey.

resulted in the intense occupancy of peripheral areas of the city, expanding the urban limits of the city. One of the consequences of this was the fact that the previously free areas along road margins have gotten to be highly occupied, severely increasing the demographic density by the road margins. So, these roads, which were intended only to serve the traffic that was arriving, departing or crossing the city, are now serving the purposes of normal traffic flow for those who want to go work or home. These roads have passed through a great functional change, as they now play the role of important avenues with intense traffic, but without losing its main role of serving as a road. In conclusion, these roads present characteristics of normal traffic due to its vehicle flow, the percentage of different vehicle classes, the average speed and the distance between traffic lights, which differ them from both a typical road and a normal avenue.

The objectives of this survey are many. The statistical and equivalent noise levels generated by the traffic circulating in the roads which has been transformed into big avenues will be presented first. The second one is to estimate the noise pressure levels emitted by the traffic through mathematical models, starting from the knowledge of the traffic flow and composition. Another objective is the comparison between the measured values and the ones predicted by the mathematical models so that the applicability of these models could be verified. The measured results will also be compared to the methodology adopted by the German standard RLS-90 (Richtlinien für Lärmschutz and Straßen, 1990) in order to verify its applicability to the Brazilian conditions.

Finally, the measured levels will be compared to the maximum allowed levels according to the legislation valid in the city, and then classify the acoustic quality of those areas.

2. METHODOLOGY

Brown and Lam have presented different strategies for evaluating the environmental noise in a city. They conclude that there are two main points to consider: measuring the noise levels in several points organized in an approximately regular grid and measuring the noise levels according to a previ-

ous classification of the urban noise according to the area usage, demographic density or the importance of the urban streets. The second strategy has been applied for the current investigation because its main goal is to evaluate the traffic noise generated by the roads BR-116 and BR-277. These two roads have previously been classified as the main roads which had been used as big avenues inside the urban limits of the city.

A total of 100 samples along the two roads were taken. For each sample the following parameters were simultaneously measured:

- The duration of each measurement, in seconds;
- The quantity of cars, motorcycles, trucks and buses that have passed by the observer during the time interval of each measurement;
- The equivalent and statistical levels in dB(A): L_{eq} , L_{10} and L_{90} , emitted by the traffic at a distance of 25 meters from the center of the nearest road band to the observer. Brüel & Kjaer 2238 sound level meter has been used for these measurements;
- The imission equivalent noise levels, in dB(A), at a distance of 40 meters from the center of the nearest road were with a Brüel & Kjaer 2260 sound level meter.

Every measurement was carried out in the fast response mode. In order to group the obtained results for the several measurement points in a single data matrix, some variables of the process has been fixed. Every measurement site had the following characteristics:

- Roads paved with smooth asphalt and in good conservation;
- Constant average traffic speed was 55 km/h, with an appropriate multiplying factor for the heavy vehicles;
- Longitudinal inclination less than 5%, i.e., the road was a flat stretch;
- Straight stretch;
- Flat nearby terrain, characterizing an open field, with no reflecting objects.

The total amount of input data was thus reduced to vehicle flow and traffic composition. As the traffic flow and composition cannot be controlled parameters, the only way to get a significant change in the input parameters was to perform measurements in different times and week days. The duration of time for each measurement has also been changed so that the sampled traffic conditions could approach the conditions of a regular traffic flow. The vehicle flow varied between 973 and 3680 vehicles per hour, and the percentage of heavy vehicles varied between 6.9% and 76.9%. Heavy vehicles, according the German standard RLS-90, are those that weighs more than 2,800 kg. The obtained mathematical expressions are therefore non-complex, and the data acquisition in the field is not difficult.

Finally, the acoustic qualification of the sampled regions was

established by applying the noise limits established by the law number 8583 adopted in Curitiba from January 10th of 1995.

3. RESULTS AND DISCUSSION

The mean values of the main process variables are presented in Table 1 and the correlation coefficients among these variables are shown in Table 2. The correlation coefficients shown in Table 2 indicate that they are dominant in the determination of the equivalent and statistical noise levels generated by the road traffic under the considered conditions. However, the percentage of heavy vehicles in the road traffic is also an important factor.

The vehicle flow is the sum of the light vehicle and heavy vehicle flow that passes at a road during a certain time interval. As a heavy vehicle generates more noise than a light vehicle, mainly under speeds considered in this survey, a pondering factor, n , has been considered for such vehicles, so that an equivalent value could have been achieved for the traffic flow, Q_{eq} . By considering Q as the real hourly vehicle flow, VP as the percentage of heavy vehicles and n as the pondering factor, we get:

VARIABLE	DISCRIMINATION	MEAN VALUE
X1	Vehicle flow, Q	2239.5 vehicle/h
X2	10 log Q	33.3
X3	Percentage of heavy vehicles, VP	31.2 %
X4	10 log VP	14.7
X5	L_{10}	76.3 dB(A)
X6	L_{90}	65.2 dB(A)
X7	L_{eq}	73.1 dB(A)
X8	Imission at 40 m	68.2 dB(A)

Table 1. Description and mean values of the variables.

	X1	X2	X3	X4	X5	X6	X7	X8
X1	1.000	0.955	0.216	0.302	0.629	0.532	0.676	0.551
X2	0.955	1.000	0.232	0.325	0.612	0.511	0.660	0.556
X3	0.216	0.232	1.000	0.928	0.548	0.456	0.589	0.488
X4	0.301	0.325	0.928	1.000	0.599	0.458	0.642	0.523
X5	0.629	0.612	0.548	0.599	1.000	0.586	0.936	0.829
X6	0.532	0.511	0.456	0.458	0.586	1.000	0.679	0.603
X7	0.675	0.660	0.589	0.642	0.936	0.679	1.000	0.883
X8	0.551	0.556	0.488	0.523	0.829	0.603	0.883	1.000

Table 2. Matrix of coefficient correlation among all the variables

$$Q_{eq} = Q (1 + n * VP / 100) \tag{1}$$

So, the term $10 \log(Q_{eq})$ will be transformed into $10 \log [Q(1 + n * VP / 100)]$.

The pondering factor value, n , is estimated so that the largest correlation coefficients result between the noise levels and the factor $10 \log [Q(1 + n * VP / 100)]$.

By varying the pondering factor among 4 and 10, the largest correlation coefficients between L_{eq} and the above term, and between L_{10} and the same term, are found when $n = 9.5$, and they are 0.8192 and 0.7692. On the other hand, as the influence of the heavy vehicle over the L_{90} is smaller, the pondering factor is also smaller, $n = 5$. For this case the correlation coefficient between L_{90} and the term $10 \log [Q(1 + n * VP / 100)]$ is 0.6275.

A mathematical model for the determination of the traffic equivalent noise level is schematically shown in Figure 2. The model considers the vehicle flow, Q , and the percentage of heavy vehicles, VP , and will be based on this strong correlation factor between these parameters, which its coefficient is 0.8192. For L_{10} the coefficient is 0.7692 and for L_{90} , 0.6275. Both of them are smaller than the coefficient for L_{eq} , but they are still very significant.

3.1. Development of the Mathematical Models:

In order that the mathematical models is able to predict, in a satisfactory manner, the equivalent and statistical noise levels, it is necessary that the models:

- Be simple enough so that they can be used by those responsible for urban planning;
- Only easily obtained data be necessary for the noise level calculus;
- Obtain accurate results according to the subjective perception of the noise.

Any mathematical model will only be an approximate estimation as there are many factors involved in the analysis. The mathematical models for the determination of the road traffic noise levels can be represented as follows:

Once the vehicle flow, Q , the percentage of heavy vehicles, VP , and the equivalent noise levels, L_{eq} have been measured, and the most adequate pondering factor has been deter-

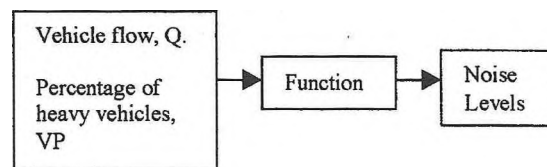


Figure 2. Graphical representation of the mathematical model.

mined, $n=9.5$, the values for L_{eq} and $10 \log [Q \cdot (1 + 9.5 \cdot VP / 100)]$ have been plotted on a graph, shown in Figure 3. Then, by means of the least-squared method, a curve has been adjusted to the measured points. Mathematically, this curve can be represented by:

$$y = a \cdot x + b \quad (2)$$

By applying the variables on the straight-line equation, we get:

$$L_{eq} = a \cdot 10 \log [Q(1 + 9.5 \cdot VP / 100)] + k \quad (3)$$

The values for the constants a and k , found after the statistical methods of linear regression had been applied, are:

$$a = 0.76; \quad k = 42.964$$

This way, the expression that mathematically represents the adjusted curve and can predict the equivalent levels for the road noise is:

$$L_{eq} = 7.7 \log [(Q(1 + 0.095 \cdot VP))] + 43 \quad (4)$$

where:

- L_{eq} is the equivalent noise level emitted by the road traffic, measured at 25 meters, in dB(A);
- Q is the vehicle flow (vehicles per hour);
- VP is the percentage of heavy vehicles, compared to the total number of vehicles.

By taking the same proceedings adopted for the equivalent levels, mathematical expressions have been obtained for the determination of the statistical levels L_{10} and L_{90} . They are as follows:

$$L_{10} = 6.2 \log [Q(1 + 0.095 \cdot VP)] \quad (5)$$

$$L_{90} = 10.2 \log [Q(1 + 0.050 \cdot VP)] + 27.1 \quad (6)$$

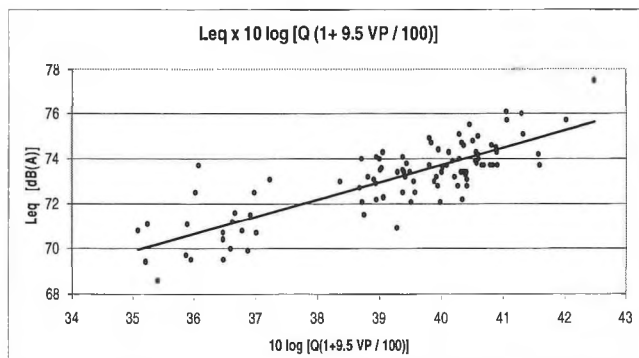


Figure 3. Adjusted curve for $L_{eq} \times 10 \log [Q(1 + 9.5 \cdot VP / 100)]$

However, as the measured levels are intended to be compared to the local legislation valid in the city, and it concerns only the equivalent levels, the statistical levels L_{10} and L_{90} will not receive further treatment in this research.

3.2 Leq Evaluation

Table 3 presents the averages, standard deviations, maximum positive variations and maximal negative variations of the differences between the calculated and measured values.

Figure (4) shows comparisons between the measured values and calculated ones according to the mathematical model (Eq. (4)) and by the German standard RLS-90, by 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. (4) is able to satisfactorily predict the equivalent noise levels generated by the vehicle flow in roads.

Furthermore, it allows us to say that the methodology adopted by the German standard RLS-90 can be applied to the Brazilian conditions, as it gives very close results to the ones

Statistical Parameter	Model-Measurements	RLS 90 - Measurements	Model-RLS 90
Average	-0.005	0.3	-0.3
Standard deviation	1.821	1.081	0.559
Maximal Positive Variation	2.261	1.5	1.8
Maximal Negative Variation	2.994	3.9	0.3

Table 3: Statistics of the differences between the calculated and measured values for L_{eq} [dB(A)]

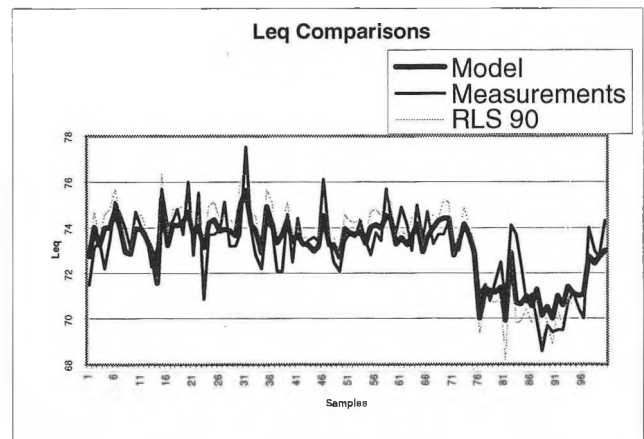


Figure 4. Calculated and measured values for 25-meter emission.

calculated by the Eq. (4), as well as the values obtained during the measurements.

3.3. Noise Levels Evaluation

The municipal law number 8583 from 01/10/1995 states about the limits for the urban noise in the city of Curitiba, according to a classification of areas called urban zoning.

Table 4 presents the allowed limits for the equivalent noise levels in some urban zones of the city for the period from 7 a.m. to 7 p.m., during which the measurements were carried out.

According to the mean values of the traffic flow and percentage of heavy vehicles, the mean equivalent level for the traffic noise, at a distance of 25 meters, is 73.7 dB(A).

4. CONCLUSIONS

The German standard RLS-90 seems to fit well with the calculation of the road traffic noise emitted by the vehicles, situated inside the urban limits of Curitiba. Consequently, the computer softwares developed according to the German standard RLS-90 can be used to calculate the traffic imission and emission on the Brazilian roads.

Mathematical models for predicting the equivalent and statistical levels generated by the road traffic can be developed by using the statistical methods of linear regression. The noise levels calculated by these models are nearly as precise as the ones calculated by the German standard RLS-90, and

ZONE	DESCRIPTION	ALLOWED L_{eq} [dB(A)]
ZR-1	Residential Zone (strictly)	55
ZR-2	Low density Residential Zone	55
ZR-3	Medium Density Residential Zone	55
ZR-4	Medium Density Residential Zone (mixed)	60
SE	Structural Sector	65
ZE	Service Special Zone	70
ZS	Service Zone	70
AV	Green Area	55
SR-2	Santa Felicidade Residential Sector	55

Table 4. Allowed equivalent noise levels according to the municipal law number 8583

satisfactorily correspond to the measured values.

The average value for the road traffic emission equivalent level measured by the roads situated inside the Curitiba urban limits is $L_{eq} = 73.7$ dB (A).

The roads that pass inside the urban limits of Curitiba cross, in the majority, ZR`s and ZS areas. According to the limits stated by the legislation, the allowed day noise emission inside the residential zones (ZR`s) is 55 dB(A). So, the average equivalent noise level generated by the traffic in these areas surpasses the maximum allowed noise level stated by the legislation in 18.2 dB(A) in the average, at a distance of 25 meters. For the Service Zone (ZS) the maximum allowed noise emission for the day is 70 dB(A). This level is surpassed by 3.1 dB(A) at a distance of 25 meters.

It is clear then that the environmental noise pollution problem caused by the traffic noise in the main roads situated inside the urban limits of Curitiba exists. The inhabitants living in these areas are bound to suffer from health impairments and low life quality. Under a technical point of view, it is necessary to take several measures in order to reduce the noise levels. Controlling the noise generation means adopting the necessary measures to reduce the sound power emitted by the vehicles when they pass on a road. In order to do so, measures should be considered as follows:

- Reduction of the speed limit, mainly near residential areas, schools and hospitals.
- Propose a new legislation for the reduction of the vehicle emission limits determined by the Brazilian standard NBR 8433/84, and offer incentives to the vehicle manufacturers to develop new systems in order to reduce the sound power emission.
- Limiting the vehicle flow and reducing the percentage of heavy vehicles. In order to achieve this, it is necessary that:
 - i) The conclusion of the new roads that are intended to circulate the city. These roads have already been in construction for 10 years;
 - ii) Quality and quantity improvements of existing public transportation, like: operating quality, safeness, rapidity, comfortable transportation and low cost. These factors constitute good reasons to make the population use them more often;
 - iii) Implementation of subways (metros);
 - iv) For short distances, incentive the of the use of bicycles or walking;

To control noise transmission intermediary obstacles such as noise barriers can be installed. These noise barriers, although they are normally made of concrete, can have improved external appearance by putting vegetation on its surface covering the whole barrier. The barriers can thus be integrated in the natural environment, without affecting the psychological aspect of the population.

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