Elsevier Editorial System(tm) for Applied Acoustics
Manuscript Draft

Manuscript Number:

Title: Study on the relation between urban planning and noise pollution

Article Type: Research Paper

Section/Category: Europe and Rest of the World

Keywords: Traffic noise; urban form; urban planning; environmental decision support.

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The obtained model was validated, and its prediction capacity was analyzed with 30 new randomly selected independent sampling points, showing a global uncertainty lower than 2 dBA, similar to that obtained in noise mapping techniques.
The proposed methodology could be extrapolated to other cities, and the obtained models could be an important tool for city planning agents.

Study on the relation between urban planning and noise pollution

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Abstract

Different streets of a city of Spain were randomly selected and analyzed, extracting 135 different urban variables. The urban variables were compared with measured noise levels, and the possible significance in the relationships among them was analyzed. From the variables with a significant correlation, a multiple regression model for urban traffic noise was developed, which allows explaining 63% of the variability of urban noise. In this regression model, only eight of the initial urban variables were included.
The obtained model was validated, and its prediction capacity was analyzed with 30 new randomly selected independent sampling points, showing a global uncertainty lower than 2 dBA, similar to that obtained in noise mapping techniques.
The proposed methodology could be extrapolated to other cities, and the obtained models could be an important tool for city planning agents.

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Highlights:

- A model for urban noise prediction with only urban variables is presented.
- The explicated variability of urban noise was higher than 60%.
- The predictive capacity was analyzed with average differences lower than 2 dBA.
- The proposed methodology can be also applied to other cities.

1. Introduction

In the last centuries, the economic success associated with cities has led to an important growth in the population living in them (Glaeser, 2012). In addition, how modern cities represent a savings of energetic aspects and a reduction in the pollutants emitted by citizens is considered (Owen, 2009). Nevertheless, the urbanistic design of several modern cities, which is generally conditioned by road traffic, has produced an increase in noise pollution. Thus, a recent publication by the World Health Organization points out that noise pollution ranked second among a series of environmental stressors for the public health impact in European countries (WHO, 2011). Adequate city planning could reduce the effect of this important environmental problem and, besides, could result in profits in terms of the reduction of other atmospheric pollutants, considering the known correlation between some of them (Jaeger et al., 2008; Weber et al., 2014).

The functionality of streets as a communication path among different parts of a city and between a city and other urban areas (an alternative concept to accessibility) has been shown to be associated with noise pollution (Rey et al., 2013). Functionality is clearly conditioned by the urban planning of our cities. So, the geometry of the street, and the pavement type, street width, average street height, etc., are factors with influence on the use of a street. The influence of urban forms on vehicle transport or a street environment has been previously studied (Tang & Wang, 2007; Givargis & Karimi, 2010). A model of urban noise has also been developed without propagation expressions but using the data of traffic flow and traffic conditions and some urbanistic variables (Torija et al., 2010).

To our knowledge, until now, no model for estimating urban noise based only on urban variables (and, thus, excluding variables related to traffic) has been proposed. This paper presents the first results achieved in this line. Obtaining a model like the one previously described could be an important tool for city planning agents, and, besides, it could help to improve the noise predictions of current noise maps. It is not an objective of our work to present a unique and comparable model but to begin the study of this possibility by analyzing a medium-sized town of Spain.

2. Methods

154 streets of the city of Cáceres (a medium-sized city located in the southwest of Spain with about 95000 inhabitants) were randomly chosen. Previously, this city was also used in the initial development of a categorization method, which was applied afterwards to other cities with very different sizes and locations (Barrigón et al. 2002; Rey Gozalo et al., 2013). In each street, sound measurements were carried out in diurnal period (from 7 a.m. to 7 p.m.) following the ISO 1996-2:2007 guidelines. Sound measurements were conducted in four different time periods throughout the diurnal period in distinct days to include the variability in the cycle of activity in the city. Moreover, each street was characterized by 135 urban variables, which could be classified in the following groups: 1) location of the street and demography, 2) urban land use, 3) street geometry, 4) circulation and connectivity and 5) public and private transport.

After characterization of the streets and noise measurements, the relationships among the urban variables (independent variables) and measured equivalent sound levels [Leq (dBA)] were analyzed. For this analysis, Spearman's correlation coefficient (R) was used. This non-parametric test was chosen as some of the studied variables did not present a normal distribution, and, in other cases, the small number of samples in some variables meant that the normality of the data was doubtful. This test was also used to study the possible relationship among independent variables (collinearity).

The urban variables with a significant correlation with sound levels (p-value < 0.05) and without collinearity among them [$R^2 < 0.9$ (Kleinbaum et al., 1988)] were chosen for the multiple linear regression model. The categorical variables and the quantitative variables with low frequency of occurrence (generally associated to the type of land use) were transformed into dummy variables (No = 0 and Yes = 1). Then, the potential impact of each urban variable on the estimation of the Leq (dBA) was analyzed. For this purpose, a stepwise multiple linear regression analysis was carried out. The model selected was stepAIC (Venables & Ripley, 2002). Although stepAIC labels the criterion in the output as "AIC", the Bayesian information criterion (BIC) was employed as a selection criterion. The AIC penalizes the number of parameters less strongly than the BIC does. The direction selection "backward/forward" and "forward/backwards" was used.

Once the multiple linear regression model was obtained, it was validated for normality (Shapiro-Wilk test), homoscedasticity (Breusch-Pagan test) and linearity (RESET test). Additionally, the absence of multicollinearity was verified by using the variance inflation factor (VIF).

Finally, the prediction capacity of the regression model was analyzed with 30 new independent sampling points located in different streets of the city, randomly selected.

3. Results and Discussion

Firstly, as previously mentioned, the possible significance in the relationships between urban variables and noise levels [Leq (dBA)] was studied. In Table 1, only those variables whose relationship with noise levels was significant and which did not present collinearity problems are presented. As can be seen, only 52 urban variables of the 135 variables initially selected showed a significant correlation (p-value < 0.05) with respect to Leq (dBA) and did not present collinearity problems.

Some of these variables had been used in previous studies to obtain a noise urban model or to be correlated with noise levels (Torija et al., 2010; Salomons & Pont, 2012). Nevertheless, in these previous studies, these variables were treated as associated to the noise source (traffic). In the present study, the approach is different and original as only the relationship of noise levels with urban characteristics is considered, without considering any variable associated with traffic.

Table 1 – List of urban variables whose Spearman correlation coefficients were significant with respect to Leq (dBA). (***) p-value < 0.001; (**) p-value < 0.01; (*) p-value < 0.05.

Variables	**Meaning**	**Value Range**	**R**
V_1	Number of inhabitants	[0-1288]	0.296***
V_2	Presence of gyms	[0,1]	0.182*
V_3	Presence of pubs	[0,1]	0.395***
V_4	Presence of bullring	[0,1]	0.194*
V_5	Presence of relaxation areas	[0,1]	0.223**
V_6	Presence of walking areas	[0,1]	0.198*
V_7	Presence of commercial areas	[0,1]	0.437***
V_8	Presence of public administration buildings	[0,1]	0.267***
V_9	Presence of private administration buildings	[0,1]	0.350***
V_{10}	Presence of schools	[0,1]	0.322***
V_{11}	Presence of high schools	[0,1]	0.196*
V_{12}	Presence of academies	[0,1]	0.196*
V_{13}	Presence of schools of music	[0,1]	0.168*
V_{14}	Presence of university buildings	[0,1]	0.262**
V_{15}	Presence of hospitals	[0,1]	0.168*
V_{16}	Presence of health centers	[0,1]	0.193*
V_{17}	Presence of student housings	[0,1]	0.264***
V_{18}	Length (m)	[22-1414]	0.502***
V_{19}	Width (m)	[3.4-48.2]	0.566***
V_{20}	Mean height of buildings (m)	[0-30.5]	0.204*
V_{21}	Number of lanes in the city exit direction	[0-2]	0.462***
V_{22}	Number of lanes in the city entrance direction	[0-2]	0.515***
V_{23}	Number of service lanes in the city exit direction	[0,1]	0.265***
V_{24}	Number of service lanes in the city entrance direction	[0,1]	0.280***
V_{25}	Equivalent length of parallel-parking places (m)	[0-377]	0.197*
V_{26}	Type "U" street geometry	[0,1]	-0.230**
V_{27}	Type "mix" street geometry	[0,1]	0.193*
V_{28}	Connection with national roads	[0,1]	0.386***
V_{29}	Number of traffic lights	[0-17]	0.595***
V_{30}	Number of pedestrian crossings	[0-16]	0.320***
V_{31}	Number of exit crossings in the city exit direction	[0-18]	0.364***
V_{32}	Number of entrance crossings in the city exit direction	[0-17]	0.368***
V_{33}	Number of exit crossings in the city entrance direction	[0-18]	0.344***
V_{34}	Number of entrance crossings in the city entrance dir.	[0-18]	0.380***
V_{35}	Number of direction changes when leaving the city	[0-7]	0.500***
V_{36}	Number of direction changes when going into the city	[0-6]	0.511***
V_{37}	Number of distribution nodes	[0-1]	0.165*
V_{38}	Number of urban bus stops	[0-5]	0.485***
V_{39}	Number of urban bus lines	[0-11]	0.531***
V_{40}	Number of taxi stops	[0-1]	0.213**
V_{41}	Parking surface (m^2)	[0-19902]	0.232**
V_{42}	Number of gas stations	[0-2]	0.206*
V_{43}	Number of long-distance bus lines	[0-2]	0.173*
V_{44}	Number of urban wastes collecting points	[0-10]	0.251**
V_{45}	Pavement surface "good" condition	[0,1]	0.317***
V_{46}	Pavement surface "fair" condition	[0,1]	-0.197*
V_{47}	Pavement surface "bad" condition	[0,1]	-0.258**
V_{48}	Asphalt pavement	[0,1]	0.301***
V_{49}	Paved pavement	[0,1]	-0.198*
V_{50}	Concrete pavement	[0,1]	-0.231**
V_{51}	Number of street directions	[1,2]	0.229**
V_{52}	Total number of parking lot places	[0-2080]	0.268***

The multiple regression analysis of all the urban variables presented in Table 1 leads to the following results:

- Multiple R^2: 0.72
- F-statistic: 5.42 (p-value < 0.001)
- BIC: 1113.55

The multiple R^2 value obtained was high, although the BIC value was also high. According to the *t test*, a major part of the variables included in the model did not contribute significantly to the explanation of the variability of sound levels. Therefore, secondly, as noted in the previous chapter, we opted for a stepwise multiple linear regression analysis. The model selected was stepAIC and the coefficients of the resulting model are shown in Table 2:

Table 2 – Coefficients of the resulting model. Dependent variable: Leq (dBA)

Model	**Estimate**	**Std. Error**	**t value**	**Sig**
(Intercept)	47.12	1.23	38.35	< 0.001
V_{19}	0.26	0.05	4.90	< 0.001
V_{29}	0.47	0.15	3.18	< 0.01
V_{17}	8.50	1.85	4.59	< 0.001
V_7	3.40	0.78	4.35	< 0.001
V_{24}	8.22	2.22	3.71	< 0.001
V_{10}	3.13	1.09	2.88	< 0.01
V_{45}	2.78	1.16	2.41	< 0.05
V_{34}	0.28	0.12	2.30	< 0.05

The multiple regression analysis of the variables presented in Table 2 leads to the following results:

- Multiple R^2: 0.63
- F-statistic: 30.32 (p-value < 0.001)
- BIC: 950.85

As can be seen, the resulting model, with only eight street characteristics, leads to an explanation of 63% of the variability of sound levels. Analyzing the street characteristics included in the model, three of them correspond to urban land use [V_7: Presence of commercial areas; V_{10}: Presence of schools and V_{17}: Presence of student housings]. This is an important fact to be considered in urban planning and indeed is indicated in some international regulations (EC, 2002). Another variable of the model is the width of the street (V_{19}), which is a variable used in some administrations for road stratification and which was also used in some studies of urban noise stratification (Suárez & Barros, 2014). The variable "number of traffic lights" (V_{29}), also present in the obtained regression model, is related with street functionality as previously described (Rey Gozalo et al., 2013). Considering the two variables associated with the lanes of the streets [V_{24}: Number of service lanes in the city entrance direction and V_{34}: Number of entrance crossings in the city entrance direction], the presence of service lanes is related to those streets with a high volume of road traffic or with a presence of heavy vehicles due to urban land use (i.e. commercial or industrial areas). The fact that the two variables included in the model correspond to the entrance direction and not to the exit direction could be indicative of some failure related to traffic in the urban planning of the city. Finally, the inclusion of the variable "pavement surface 'good condition'" (V_{45}) instead of the other "pavement" variables seems to indicate a minor use and a minor speed of streets with bad pavement conditions and, consequently, lower sound levels with respect to the good pavement condition streets.

Thirdly, the multiple linear regression model was validated for normality (Shapiro-Wilk test) and homoscedasticity (Breusch-Pagan test) and with a linearity test (RESET test):

- Shapiro-Wilk test: P-value = 0.05
- Breush-Pagan: P-value = 0.13
- RESET test: P-value = 0.99

These results presented a p-value > 0.05, which allows concluding the mentioned validity of the model. Additionally, the variables of the final regression model presented a VIF value > 1.6 indicating no collinearity among them.

Finally, once the regression model was validated, its prediction capacity was analyzed by means of new noise measurements. Thus, 30 new streets were measured. These new sampling points were also randomly selected. In Figure 1, a comparison among measured noise level values and the values estimated from the model whose coefficients were shown in Table 2 are presented.

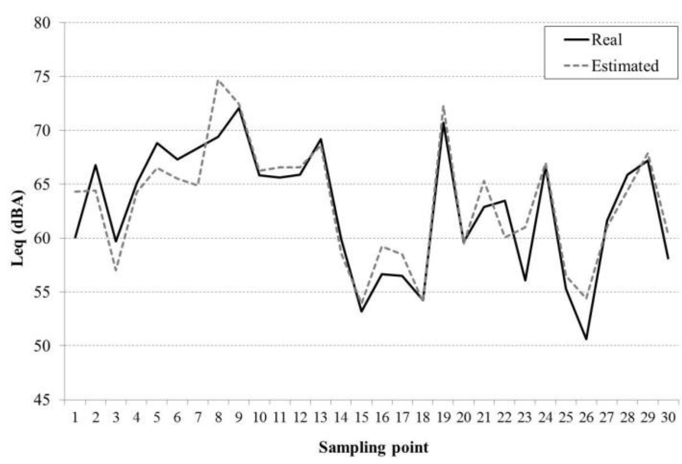

Figure 1. Comparison between measured noise levels and noise levels estimated with the multiple regression model (Eq. 1).

As can be seen in Figure 1, the estimated values are in good agreement with the measured noise levels for the different streets. The average of the absolute values of the difference among measured and estimated noise levels was 1.8 dBA, uncertainty similar to that obtained for noise mapping with prediction software (Suárez & Barros, 2014). These differences among measured and estimated noise levels were analyzed by using the

Wilcoxon signed-rank test, obtaining a p-value = 0.38, which indicated that the mean value of the difference did not present a significant difference with the zero value.

4. Conclusions

A model for urban traffic noise based only on urban variables was developed.

From the 135 variables initially selected, only 52 urban variables, those without problems of collinearity, showed a significant correlation with noise level. Finally, with only eight variables, a multiple regression model was achieved. This model explains 63% of the urban noise variability.

The eight variables included in the final regression model are: (a) three associated with urban land use (educational, residential and commercial use), (b) one associated with the urban structure (the street width), (c) one associated with the pavement and (d) three associated with the urban planning of the city (traffic lights and street lane numbers and uses).

Some of the variables were divided considering the direction of traffic (two directions were considered: entrance and exit of the city). In the final regression model, only variables of one direction (entrance) are relevant. This fact is interesting as it could be indicative of some problems in the urban planning of the city. Further studies seem to be necessary.

The proposed methodology could be applied to any other city and could allow obtaining different specific regression models of other cities. These regression models could provide information about the strengths and the weaknesses of the urban planning of the studied cities.

Acknowledgements

The authors wish to thank the Government of Extremadura, the Regional Ministry of Economy, Trade and Innovation (GR10175), the European Social Fund, the European Regional Development Fund (ERDF) and the Ministry of Economy and Competitiveness (TRA2012-37117) for funding the project. This work was also partially supported by the National Commission for Scientific and Technological Research (CONICYT) through the National Fund for Scientific and Technological Development (FONDECYT) for research initiation Nº 11140043.

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