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MODEL OF NOISE PREDICTION ADAPTED TO URBAN VARIABLES. IMPLEMENTATION IN THE CITY OF LEON

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ABSTRACT
The studies of acoustical impact of new infrastructures are solved applying a great variety of calculus models. There are two possibilities in this way: to test the accuracy of existing calculus models or create simplified tools shared by all the studies of acoustical impact.
Some european countries have developed standards in order to predict noise caused by road traffic. The aim of such standards is to evaluate the expected noise that planned roads will generate around it. Standards-prediction models- starts from a source model depending on traffic density, composition, speed, type of pavement, slope of the road assigning in short an acoustic power to the source. They afterwards introduce corrections due to the propagation such as spreading, reflections, barriers, ground and air absorption, etc. These corrections constitute the propagation model.
In this paper, Acoustics Laboratory of University of Leon explains the development of a method to predict the urban noise using statistical technology and the information of the Acoustic Map of León.

ACOUSTIC MAPS ELABORATION
Urban noise is, principally, traffic noise. Traffic noise is determined by a series of factors: a) The noise of the individual vehicles; b) The flow composition; c) The slope of the street; d) The type of profile. The noise maps are geo-referenced registries of the sonorous levels besides other pertinent acoustic information, obtained in a determined geographic area. A map can be obtained by measurement, by simulation, prediction or calculation, or in a mixed way. When the maps are measured, serve as tool to detect problems or zones to protect. When the maps are calculated, the noise maps allow getting studies of acoustic impact, which is useful for the urban planning.

A very important consideration when is planned the elaboration of a noise map is the selection of measurement points. Because works corresponding to each point have a considerable cost, it is important to reduce the amount of points to the minimum:

a) Using an uniform grid, for example a point each 200 m. The distance between successive points depends on the budget available and the area to represent.
b) Using a grid whose dot pitch is proportional to the population density.
c) Using a grid in which, the successive values differ a suitable differential (for example, 3 dB or 5 dB).
d) Classifying all the potentially measurable points according to its acoustic characteristics, vehicles flow, flow composition, slope, etc. measuring, after that, in a point of each class.

Due to the high cost that implies making a noise map, it is good practice to can bring it up to date. Our system allows obtaining a model with possibilities of correction for future changes in the conditions.

NOISE PREDICTIVE MODELS OBTENATION

We have based our calculation in statistical methods. The origin of the information is the “Acoustic Map of Leon 2002”. The principal information for our study was the following:

- Leq = Level equivalent of noise in dBA, measured in each point.
- Vhe/h = Number of heavy vehicles (trucks, buses, etc….) per hour in each point.
- Vli/h = Number of light vehicles (cars) per hour in each point.
- Mot/h = Number of motor-cyles per hour in each point.
- PN = Predominant noise in each point (voices, traffic, street works…).
- Zone = Residential, park, others.
- Height = Height of the buildings (meters).
- Width = Width of the street (meters).
- Type = Streets in “U”, “L”, opened streets, squares.
- Direction = Double, unique, pedestrian streets.
- PR = Parking rails: one, two, none.
- PM = Pavement material: asphalt, concrete, stone, others…
-

It is clear that with this information, it would be complicated to obtain a unique equation in order to explain all streets noise. For this reason, we decided to make a first study, eliminating part of this information and using only useful variables. In fact, a high number of variables do not guarantee a correct adjustment; on the contrary, model dispersion could be increased. With this goal in mind, we do not use the variables “predominant noise” and “zone. But, in the preliminary results, we observed that the coefficient of determination obtained with our equations was very small. This fact forced us to reframe the problem. We decided that it was more logical to elaborate a model for each type of street (“U”, “L”, squares, pedestrian streets). In this paper we have studied the results for the streets of type “U”, with buildings in both sides of the street.

Process steps

Once classified all the information for the type of street, we have investigated the model with the best adjust for our situation.

For each of the types of street the following study was done:

- Model of linear multiple regression.
- Model of linear simple regression.
- Model of curvilinear estimation, which it is composed of:
    1. Linear model
    2. Logarithmic model
    3. Inverse model
    4. Square model
    5. Cubic model
    6. Model of power
    7. Compound model
    8. “S” model
    9. Logistic model
    10. Model of growth
    11. Exponential model

LINEAL REGRESSION CONSIDERATIONS

The linear regression analysis is a statistical technique used to study the linear relationship between random variables. Although a scatter plot allows a very fast impression on the type or relationship between two variables, the relation between two variables not is perfect or null. We can describe the guideline observed in the scatter plot by means of a simple mathematical function, a line has a very simple equation $y = a + b \cdot x$.

There are different procedures to fit a simple function, to diminish the difference between a point measured and a point of the calculated function. The favourite election has been, traditionally, the straight line that makes minim the sum of the squares of the vertical ranges between each point and the straight line.

Correlation coefficient

Besides a formula, it could be useful to have some precise indication of the degree in which the straight line adjusts to the scatter plot. In fact, the best possible line does not have to be the correct. Therefore, we need additional information to determine the fidelity with which the line describes the relation between the variables.

The size of this coefficient has a very intuitive interpretation, represents the loyalty that we can obtain when we predict a variable basing us on the knowledge of other variables. The standard error of the estimation (S_e, residue) is the standard deviation of the existing distances between the scores in the dependent variable (Y_i) and the prognoses obtained with the regression straight line, although not exactly, because the sum of the square distances is divided by n-2. Generally, if the adjustment is better, the standard error is smaller.

Regression equation

The coefficient corresponding to the constant is the origin of the regression line (what we have called a):

$$a = y - b \cdot x \qquad \text{(Eq. 1)}$$

Coefficient b is obtained thus:

$$b = \frac{\sum X_i \cdot Y_i - \sum X_i \cdot \sum Y_i}{n \cdot \sum X_i^{\,2} - \left(\sum X_i\right)^2} \qquad \text{(Eq. 2)}$$

Coefficients of standardized regression

The coefficients Beta (standardized coefficients of partial regression) are the coefficients that define the regression equation when this one is obtained after standardizing the original variables. It is obtained from the following way: $\beta_1 = b \cdot (S_x/S_y)$.

In the simple regression analysis, the standardized coefficient of regression corresponding to the only independent variable present in the equation is exactly the Pearson correlation coefficient. In multiple regression the standardized coefficients of regression allow to value the relative importance of each independent variable within the equation.

MULTI-LINEAL REGRESSION ANALYSIS

In the multiple regression analysis, the regression equation not defines a straight line in the plane, but a hyper plane in a multidimensional space. With a dependent variable and two independent ones, we needed three axes to be able to represent the corresponding scatter diagram. And if instead of two independent variables we used three, it would be necessary a space of four dimensions to be able to construct the scatter diagram. And a space of five dimensions to be able to construct the diagram corresponding to four independent variables. Etc. Therefore, with more than an independent variable, the graphical representation is not useful.

It is easier use only the equation of the model of linear regression: $Y = b_0 + b_1 \cdot X_1 + \ldots + b_k \cdot X_k + e$

In agreement with this model, the dependent variable (Y) is interpreted as a linear combination of *k* independent variables (X_k), each one of which has a coefficient ($ß_k$) that indicates the relative weight of that variable in the equation. The equation includes in addition a constant ($ß_0$) and a random component (the residues: ε).

COMPLEMENTARY INFORMATION

Besides the regression equation and the quality of their adjustment, a descriptive statistical regression analysis does not have to resign to the obtaining of some elementary statistical aspects like the matrix of correlations, the average and the standard deviation of each variable and the number of cases with which it is working.

Residues analysis
The residues are very important in the regression analysis. In principle by the information on the exactitude of the prognoses: if the standard error is small, the prognoses are better and the regression straight line adjusts to the scatter plot. Secondly, the analysis of the characteristics of the cases with great residues (positive or negative) can help us to detect atypical cases and, consequently, to perfect the regression equation through a study detailed of such case.

MODEL OF MULTIPLE LINEAR REGRESSION FOR STREETS TYPE "U"
The variables introduces are:

- Heavy vehicles
- Light vehicles
- Motor-cycles
- Parking rails
- Streets width
- Buildings height

Table I.- Statistical descriptors streets type "U"

Statistical descriptors	Average	Standard deviation	Number
Leq	66.7476	3.666	208
Heavy veh./h	8.47	11.51	208
Light veh./h	172.8	125.1	208
Motor-cycles/h	4.45	3.537	208
Parking rails	1.52	0.890	208
Streets width (m)	16.37	6.239	208
Build. height (m)	14.37	5.076	208

In the table of correlations it is possible to observe that the variable that influences more in the level equivalent noise (L_{eq}) is the number of light vehicles per hour, with a coefficient 0.786.

Table II.- Correlation coefficients between variables

Pearson correlation	Leq	Vhe	Vli	Motor-cycles	Parking rails	Buildings height	Streets width
Leq	1.000	0.591	0.786	0.562	-0.432	-0.075	0.115
Vhe	0.591	1.000	0.744	0.379	-0.214	-0.011	0.247
Vli	0.786	0.744	1.000	0.607	-0.411	0.017	0.367
Motor-cycles	0.562	0.379	0.607	1.000	-0.313	-0.035	0.233
Parking rails	-0.432	-0.214	-0.411	-0.313	1.000	0.184	0.216
Buildings height	-0.075	-0.011	0.017	-0.035	0.184	1.000	0.314
Streets width	0.115	0.247	0.367	0.233	0.216	0.314	1.000

MODELS OF CURVILINEAR ESTIMATION
Between all the models, the best result was obtained with the cubic model which is specified next:

Table III.- Correlation coefficients cubic model

R	R square	R square corrected	Standard error
0,846	0,715	0,711	1,951

Table IV.- Cubic model coefficient

	Nonstandardized coefficients		Standardized coefficients		
	b	Standar error	Beta	t	Sig.
Vehicles number	0.06	0.006	2.238	9.343	0.000
Veh. number ** 2	0.0001040	0.000	-2.503	-4.640	0.000
Veh. number ** 3	6.64E-008	0.000	1.077	3.185	0.002
(Constant)	59.590	0.498		119.632	0.000

The adjustment is of R^2=0.711 and the equation obtained is, in agreement with the model
Y = b_0 + (b_1·t) + (b_2·t) + (b_3·t):

$$L_{eq} = 59{,}59 + 0{,}06\cdot(V_{pe} + V_{li} + Mot) - 1{,}04\cdot10^{-4}\cdot(V_{pe} + V_{li} + Mot)^2 + 6{,}64\cdot10^{-8}\cdot(V_{pe} + V_{li} + Mot)^3$$

(Eq. 3) Equation cubic model

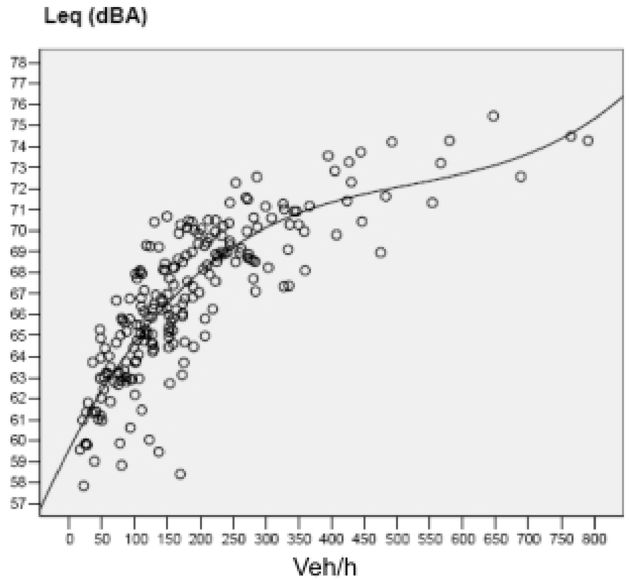

Figure 1.- Model adjustment

Te mean error (residue) is:

$$Err_{med} = \frac{\sum \left| y - y_{pro} \right|}{n^{o}} = \frac{321}{217} = 1{,}5$$

(Eq. 4) Mean error

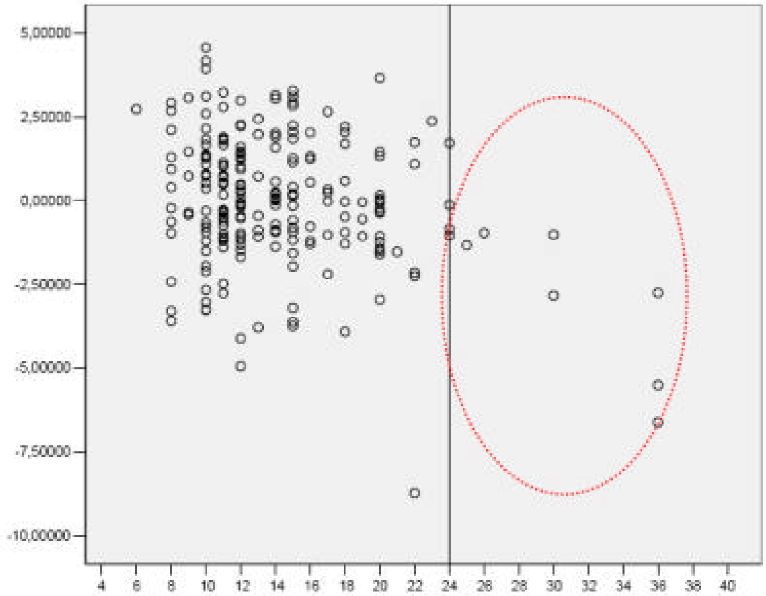

Figure 2.- Residues distribution for the variable width (m)

We can observe above in the graph of Residues-Width, that below 24 m of width there is not a tendency clear of the residues, with which we cannot do nothing. Nevertheless, for widths greater than 24 m, all the residues are negative, with which it could be interesting to introduce a factor of correction for these cases. Taking the average of these errors in streets of more from 24 m, we have seen that it was of -2.7 dBA. For this reason we have introduced negative factor K for these cases of -2.7dBA:

$$Err_{med} = \frac{311.7}{218} = 1,4$$

$$L_{eq} = 59,59 + 0,06 \cdot n - 1,04 \cdot 10^{-4} \cdot n^2 + 6,64 \cdot 10^{-8} \cdot n^3 + \Delta_{width}$$

(Eq. 5) Equation to calculate noise in streets type "U"

n: number of all type of vehicles

Δ_{width}: correction for streets of more than 24 m (-2.7 dBA)

CONCLUSIONS

Our model is an alternative to the propagation models, more economic and adapted to the peculiar characteristics of each city.

A model of this type allows us to look for areas and zones with the same acoustic behaviour, identifying the best points for the measurements.

Besides is possible study the evolution of the noise throughout the years, design new infrastructures with acoustics criteria and analyze the modification of the external factors.

References: [1] E. García et al.: Mapa Acústico de León - 2002. Secretariado de Publicaciones. Universidad de León, León, Spain (2005)

[2] K. Uesaka et al.: Prediction and evaluation methods for road traffic noise in built-up areas. Proc. of 29th International Congress and Exhibition on Noise Control Engineering. InterNoise 2000. Niza, Francia (2000)