Building noise maps in Uruguay: a practical methodology

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ABSTRACT

Uruguay is a small country in Latin America, with around 3400000 inhabitants. Its environmental legislation is still incomplete; for example, there is no national regulation on noise but only departmental Ordinances in each of its 19 Departments. Although it is well-known that they are very good management tools, noise maps are not mandatory in Uruguay. The Research Group on Environmental Noise at Universidad de la República has developed a research project that seeks the best practical methodology to build noise maps through manual measurements. The field work included the determination of the stabilization time of noise measurements, the comparison between long- and short-time measurements, the comparison between measurements taken at 1,20 m and 3,50 m, and the obtention of a national curve of highly annoyed people (%HA) with basis in the field measurements and simultaneous survey carried out on site. In this paper we present the results of these works and the proposed methodology for building noise maps throughout the country.

1. INTRODUCTION

The construction of acoustic maps by measurement is a common practice in many countries where the data to implement software modelling is not as abundant. Indeed, knowing the absorption coefficients of facades or having a good characterization of their typologies requires detailed knowledge that may not be available even in the main cities of the country, much less in the smaller ones. Furthermore, even when acoustic maps are

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created using software, it is inevitable to carry out measurements to adjust/calibrate the model results, to ensure their validity.

Ensuring the representativeness of the measurements implies, among other things, guaranteeing that the stabilization time has been reached, that the height of the measurements is in accordance with the objective pursued and that the equation that relates the density of classified traffic to the sound pressure levels is valid in the place. The selection of measurement points trying to identify/characterize homogeneous areas is also a very sensitive aspect in the development of noise maps.

This article presents the results of a research project aimed at defining a methodology applicable to the development of noise maps through manual measurements in Uruguay. The following sections present a summary of the main aspects considered and the results obtained in each case. Finally, a synthesis is presented with the recommendations arrived at for the main aspects of the methodology.

2. BACKGROUND

When addressing the issue of noise pollution in urban environments, a very useful tool is noise maps.

According to the European Union definition, a noise map *is "the presentation of data on an existing or predicted noise situation based on a noise indicator, indicating the exceedance of any relevant current limit value, the number of people affected in a specific area, or the number of dwellings exposed to certain values of a noise indicator in a specific area"* (Official Journal of the European Communities, 2021). The application of these maps to territorial management, among many other applications, is indisputable (González, 2011).

Acoustic maps have been widely used as diagnostic tools, whose objective is to survey and communicate in an easily understandable way the existing situation regarding sound pressure levels recorded in areas of interest. The level of detail of the documents that accompany the graphic pieces is a key aspect. They must include the basic information used to construct them, the way that information was obtained, the measurement or calculation methods used, or the estimate of the number of people or dwellings exposed to certain values of a chosen indicator.

In Latin America they are only mandatory in Colombia, in cities with more than 100,000 inhabitants (Universidad de Medellín, 2009).

Over the years, many authors and research groups have worked on the characterization of noise features within noise prediction models, analysing particular situations.

Faced with this challenge and in order to make the results of different countries and authors comparable, some of the European Union projects that have worked on the topic are: CNOSSOS (JRC, 2009; JRC, IHCP, 2010), IMAGINE (Imagine Consortium. 2008), HARMONOISE (Barelds et al., 2005; Salomons et al., 2011), GIpSynoise (Vallet and Vincent, 2004), among others. The Good Practice Guides "Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure" (European Commission Working Group, 2006) solved some of the problems that were arising, but their success was partial.

From the experience regarding strategic acoustic maps at an international level, it is possible to know how these studies are currently carried out, in order to ensure the representativeness and comparability of the methods in all their stages (Official Journal of the European Communities, 2021).

Among the main antecedents developed in Uruguay, it must be mentioned the development of two acoustic maps of Montevideo, completed respectively in 1998 (IMFIA, 1998) and 1999 (Intendencia Municipal de Montevideo – Facultad de Ingeniería, 1999). In both works, the need to develop a methodology for measuring and modelling environmental sound levels was demonstrated due to the frequent occurrence of certain acoustic events that were designated as “anomalous events” and which the literature of the time did not consider: horns, violent braking, motorcycles with free exhaust, sirens, alarms, barking, etc. The presence of this type of events was so strong that they ended up becoming a research topic (González, 2000). They also appeared clearly identified in studies of sound levels in some areas of the city of Salto carried out in 1997 (González and Gerardo, 1997), in the acoustic map of the city of Rivera (Bracho, 2004) and in surveys carried out by the same team in different points of the country. These experiences are compared and synthetized in González et al. (2005).

Measurements at different heights have been analyzed by Jaramillo et al. (2009). The problem of spatial optimization of sampling points was discussed by González and Jorysz (2001), who proposed a methodology for its selection, based on combining the application of multivariate analysis tools. The predictive equation for sound pressure levels developed and adjusted for the reality of Montevideo (González, 2000) was later updated by González et al. (2020) at Avenida 18 de Julio, one of the main commercial avenues in Montevideo.

2. FIELD WORK

The field work was carried out with two class 1 sound level meters, a Bruel & Kjær 2250 and a Casella CEL-63X, both with wind screen and tripod. Both recorded sound pressure levels in A-weighting scale and in third-octave bands. In addition, a pole was used for height measurements, to carry out simultaneous records at two different heights.

Measurements lasting 12 hours and 1 hour were carried out in the cities of Montevideo, Maldonado, Minas and Rocha. In Montevideo, 12-hour measurements were carried out at three points with different characteristics. The cities inside the country are departmental capitals that were chosen for their different population and socio-productive profile. The city of Maldonado (capital of the Department of Maldonado) is the second most populated city inside the country and the one with the highest population growth rate in the entire country; It is as if it were a single city with the Punta del Este resort. The town of Minas is the capital of the Department of Lavalleja; It is a small city in a hilly area dedicated mainly to forestry; It has some small industries. The town Rocha (capital of the Department of Rocha) is a small city in the eastern side of the country. It has little productive activity of its own -it depends on summer tourism on the coast of the Department- and it has a sustained decline in its population.

Simultaneously, an opinion survey was carried out following a previously developed form. Table 1 summarizes the main data of the work carried out.

	Inhabitants	12-hours measurements	1-h measurements	Average hourly traffic	Opinion survey cases
Montevideo	1318800	3	---	---	240
Maldonado	87000	1	28	350	80
Minas	38400	1	20	196	78
Rocha	25400	1	26	367	82

Table 1. Summary of the field work

2.1. Selection of sampling points

The selection of sampling points responded to different criteria in Montevideo and in the cities inside the country.

In Montevideo, points with different types of streets, building, density and traffic composition were searched. The point on Ellauri Street corresponds to a residential area of medium to high purchasing power, it is close to a primary and secondary school, the traffic flow is relatively low and the passage of trucks and buses is scarce. The point on Uruguay Avenue is located on a wide street, with old single-story buildings on both sides of the street and a high flow of buses and trucks. The point on Rivera Avenue is in a middle-class neighbourhood and has a high flow of traffic of all types, from light vehicles to buses.

In the cities inside the country, the points for the 12-hour measurements were chosen so as to work on one-way streets, close to the commercial downtown of the cities and with access to electric current to ensure the continuity of the measurement records. The other points were chosen based on the location of health care centres, schools, high schools and other singularities, in order to define fairly homogeneous areas between measurement points. The number of points chosen in each city allowed to obtain the relationships shown in Table 2.

City	Minas, Lavalleja	Maldonado, Maldonado	Rocha, Rocha
Inhabitants, according to 2011 National Census	38400	87000	25400
Approximate area	8.2 km²	25 km²	8 km²
1-h registration points	20	28	26
Average point density (points/km²)	2.4	1.1	3.3
Average point density (points/1000 inhabitants)	0.52	0.32	1.02

Table 2. Summary of measurements' features at cities inside the country

2.2 Height measurements

During the 12-hour measurements, simultaneous recordings were taken at two different heights: 1.20 m and 3.50 m. The records at both heights were statistically compared, applying the Mann & Whitney test (Sachs, 1980). This is a non-parametric statistical test (it should be remembered that urban noise samples are mostly non-parametric or, as said by Don and Rees in 1982, 'anything but Gaussian') that allows us to check whether or not two samples belong to the same population, with a certain degree of confidence that has been chosen to be 95 %.

The comparisons confirmed the result obtained by Jaramillo et al. (2009) in the city of Medellín, Colombia: although the equivalent continuous sound pressure levels show very close values, the realities that describe the series of sound levels obtained at the same point at different heights are different. A summary of the results obtained is presented in Table 3.

	Comparable	Not comparable
Montevideo – Ellauri St.	11	1
Montevideo – Uruguay Ave.	12	0
Montevideo – Rivera Ave.	0	12
Maldonado City	1	11
Minas Town	7	5
Rocha Town	5	7

Table 3. Percentage of comparable and not comparable simultaneous measures at two different heights, in the same point during 12-h measurements

Consequently, to evaluate the situation at street level, it will be necessary to take measurements at a height of 1.20 m and not at 4 m, as required for acoustic maps obtained by software tools.

2.3 Determination of measurement stabilization time

The stabilization time of environmental measurements of sound pressure levels is a concept introduced by González (2000). It refers to the time t*, which is the minimum time from which the $L_{A,eq,t*}$ and the $L_{A,eq,T}$ of the time studied (in this case, 1 hour) differ by less than a predetermined tolerance ε, which can be set depending on the objective pursued.

To select a representative measurement time of the sound pressure level of 1 hour, 6 measurements of 12 hours of measurement were carried out at different points: three of them were carried out in Montevideo, at points chosen for their different typology and traffic density, and the others in the three abovementioned cities inside the country. The results are summarized in Figure 1.

The smaller the population of the city, the longer the stabilization times obtained. But this does not mean that stabilization times in Montevideo are much shorter: this strongly depends on the flow and typology of traffic. In general, it is not advisable to take a measurement time of less than 45 minutes if a tolerance not greater than 1 dB and achieve stabilization of 95 % of the measurements is needed. To maintain the same tolerance but stabilizing 90 % of the samples, the measurement time can be reduced to 40 minutes.

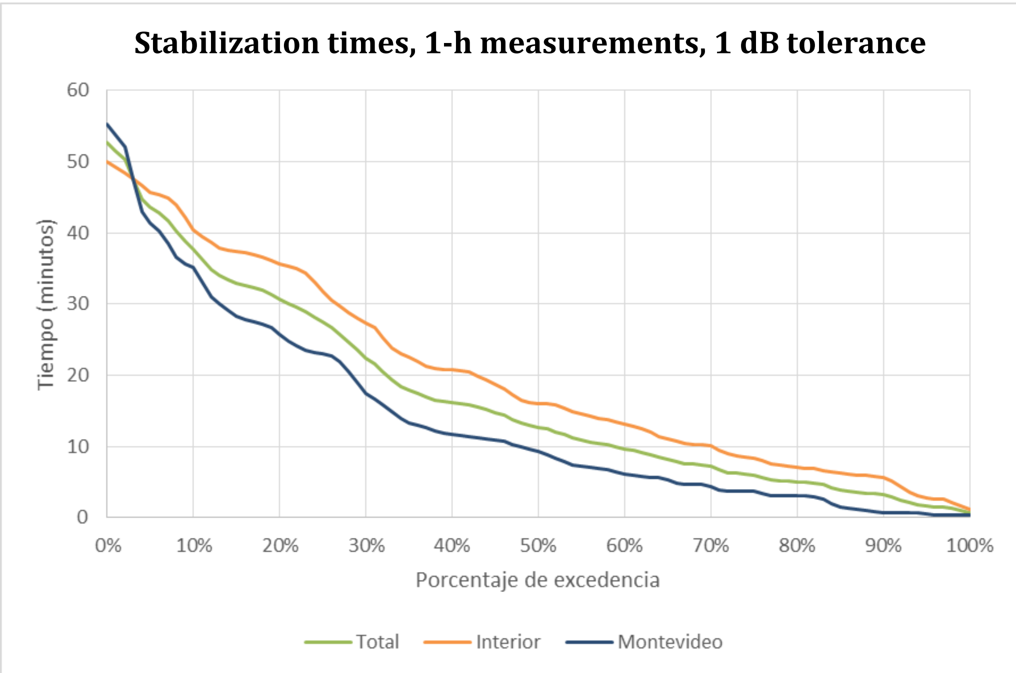

Figure 1. Average stabilization times for Montevideo and inside cities for 1-h measurements, with 1 dB tolerance

The relationship between the stabilization time according to hourly traffic flow (considering all data) is shown in Figure 2.

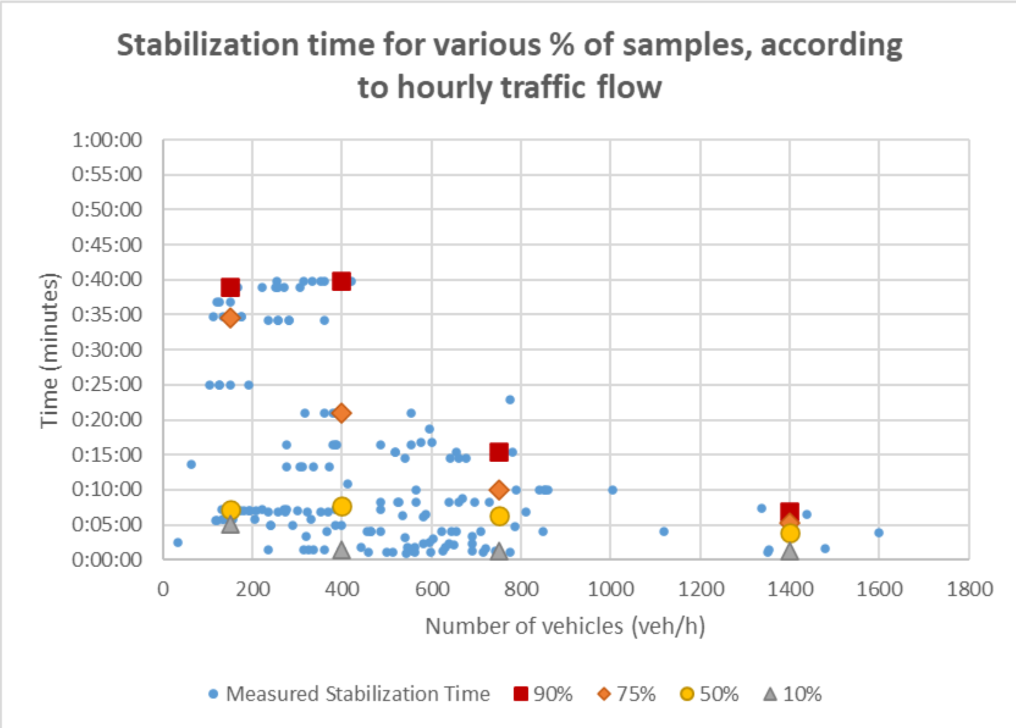

Figure 2. Stabilization time for different % of samples according to hourly traffic flow

2.4 Annoyance levels experienced by the people

A survey form of ten (10) questions was applied, plus another five (5) to obtain data about the respondent (age, sex, occupation, educational level, weekly work hours).

Firstly, it should be noted that noise did not appear as a relevant problem in most responses: at all points, less than 10 % of respondents considered it as an urgent problem to be solved. In Montevideo, traffic appears as the main source of annoyance in about 50 % of cases, but in none of the three inland cities considered does it exceed 20 %. Among the components of traffic noise, at the six sampling points it turned out that the most annoying are motorcycles and free exhausts.

Although the number of surveys is not large, it was sufficient to draw a curve of $L_{Aeq,12h}$ and highly annoyed population (% HA), as shown in Figure 3. Although the comparison parameter is not the one used conventionally (L_{DN}), it can be understood as a first approximation for a case in which records of sufficient duration are not available to obtain the L_{DN} value.

Likewise, through the correlation of the measured sound pressure levels and the level of instantaneous annoyance expressed by the respondents ("*How do you rate the noise you feel at this moment, here and now?*"), noise maps could be drawn. level of annoyance on a scale of 1 to 5, where 5 is extremely annoying and 1 is not at all annoying. The annoyance level map corresponding to the town of Minas is presented in Figure 4.

When respondents were asked what their suggestions were to improve the acoustic quality of the city, the answers focused mainly on the control and monitoring of free exhausts on motorcycles.

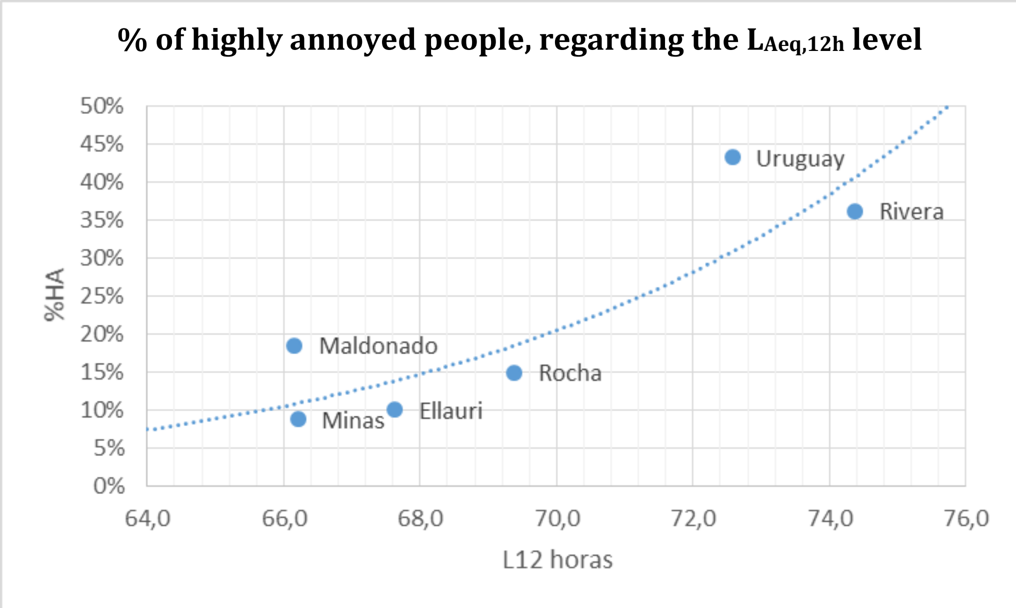

Figure 3. Percentage of highly annoyed population based on the measured $L_{Aeq,12h}$

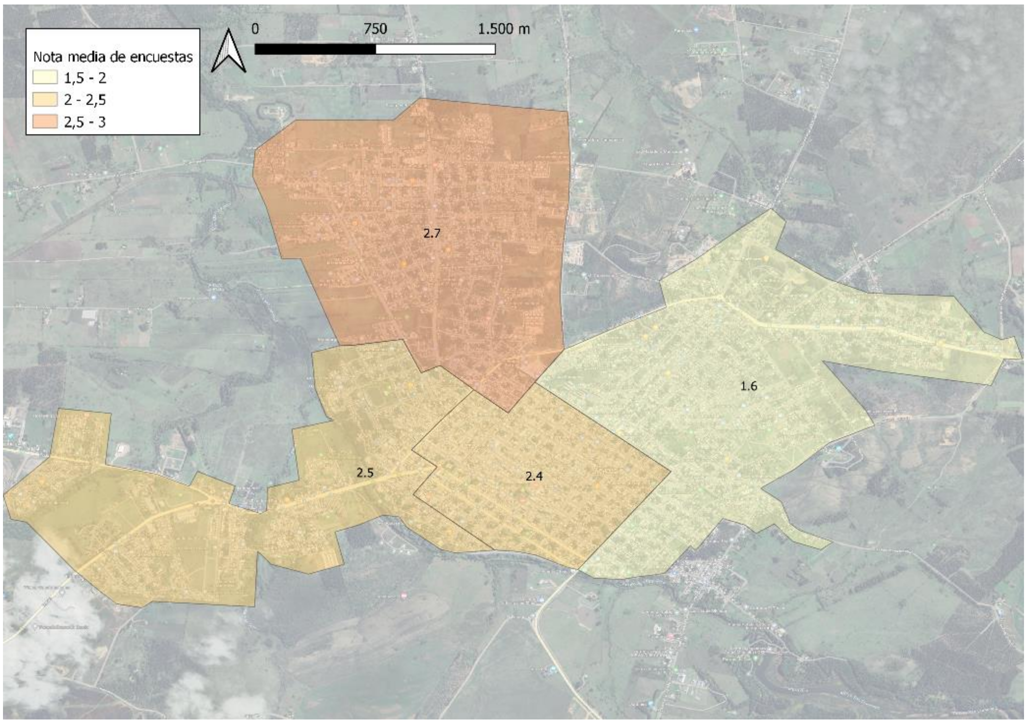

Figure 4. Percentage of highly annoyed people related to the measured $L_{Aeq,12h}$ value in Minas town

3. PROPOSED METHODOLOGY

The proposed methodology to build acoustic maps by measurement in Uruguay includes the following aspects:

- **Selection of measurement points:** Desirably, the different realities of the city should be covered, without omitting singular points, such as points close to health care centres and educational facilities. According to the results obtained and the guidelines resulting from the field work given in Table 2, it is suggested to use the highest value between 4 points per km^2 or one point per 1000 inhabitants.

- **Measurement height:** unless a different objective is pursued, to characterize sound levels and annoyance at pedestrian level, measurements will be made at a height of 1.20 m.
- **Duration of measurements:** in Uruguayan cities, unless better site-specific information is available, measurements of sound levels on public roads must last a minimum of 45 minutes to be representative of the sound pressure levels of a (1) hour long.
- **Evaluation of the highly annoyed people**: to evaluate the percentage of highly annoying people, in a first approximation, it is suggested to use the curve in Figure 2 and the daytime sound pressure levels of the place. To evaluate the percentage of the highly bothersome resident population, it is suggested to consider the population density data from the Official Population and Housing Census and reduce the sound pressure levels measured on the sidewalk by 5 dB (Cuadro, 2023).

4. MAIN LIMITATIONS OF THIS STUDY

Without a doubt, having more field information would have allowed us to achieve better approximations for the stabilization times of the measurements and for the number of points depending on the size of the city.

However, it is considered that this methodological approach will allow the construction of noise maps by direct measurement that will be comparable, reasonably well described and at an affordable cost.

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REFERENCES

1. Barelds, R.; Nota, R.; Van Maercke D. (2005). *Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine-tuning*.
2. Bracho Rodríguez, Alberto (2004). *Mapa acústico y análisis de datos preexistentes de la ciudad de Rivera.*
3. Cuadro, Vivian (2023). Personal communication.
4. Don, C.G. & Rees, I.G. (1985) Road traffic sound level distributions, *Journal of Sound and Vibration*, 100(1), (1985), pp. 41-53.
5. European Commission Working Group (2006). *Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure*. Assessment of Exposure to Noise (WG-AEN). Position Papes. Version 2. 13th Jan. 2006.
6. González, Elizabeth; Gerardo, Rocco (1997). *Niveles de contaminación sonora en la ciudad de Salto.*
7. González, A.E. (2000). *Contaminación Sonora en Ambiente Urbano: Optimización del tiempo de muestreo en Montevideo y desarrollo de un modelo predictivo en un entorno atípico.* Tesis para obtener el grado de Doctora en Ingeniería (Ingeniería Ambiental). Facultad de Ingeniería, Universidad de la República. Montevideo, Uruguay.
8. González, AE; Jorysz, A (2001). Herramientas para potenciar un mapa acústico. *4ª Jornada Regional sobre Ruido Urbano*, 14th July 2001, Montevideo, Uruguay.

9. González, AE; Gavirondo Cardozo, M; Pérez Rocamora E; Bracho AA (2007). Urban noise: measurement time and modeling of noise levels in three different cities. *Noise Control Engineering Journal*, 55 (3), (May-June 2007), pp. 367-372.
10. González, A. E. (2011). Mapas acústicos: Mucho más que una cartografía coloreada. *Congreso Latinoamericano de la Audio Engineering Society AES 2011*, Congreso de la Sociedad de Ingeniería de Audio. Montevideo, Uruguay, agosto 2011. https://www.fing.edu.uy/imfia/grupos/contaminacion-acustica/archivos/90115_Gonzalez_mapas%20acusticos.pdf
11. González, Alice Elizabeth; Gianoli Kovar, Pablo; López Parard, Malena; Luzardo Rivero, Micaela; Pais, Juan Ignacio; Ramírez, Lady Carolina (2020). *Estudio de niveles sonoros en Avda. 18 de Julio. Informe Final.* [Sound pressure levels in 18 de Julio Ave. Final Report] November, 2020. DIA-IMFIA, Facultad de Ingeniería, UdelaR.
12. IMAGINE CONSORTIUM, *Imagine Project*, (2008).
13. IMFIA (1998). *Contaminación Sonora en Ambiente Urbano. Informe Final. Proyecto de Iniciación a la Investigación CONICYT 2040*. Montevideo, Uruguay: Facultad de Ingeniería Udelar.
14. Intendencia Municipal de Montevideo – Facultad de Ingeniería (1999). *Mapa Acústico de Montevideo, Informe Final del Convenio,* Montevideo, Uruguay.
15. Jaramillo, A., González, A., Betancur, C., Correa, M. (2009) Estudio comparativo entre las mediciones de ruido ambiental urbano a 1,5 m y 4 m de altura sobre el nivel del piso en la ciudad de Medellín, Antioquia – Colombia. *Revista Dyna*, 157 pp. 71-79.
16. JRC European Commission, *Workshop on Selection of common noise assessment methods in EU*, (2009).
17. JRC, IHCP, *Common Noise Assessment Methods in EU (CNOSSOS-EU*), Draft JRC Reference Report (2010) 1-131.
18. Official Journal of the European Communities. *Directive 2002/49/CE of the European Parliament and the Council, 25th June 2002. Consolidated version 2021*, 1088 pp.
19. Sachs, Lothar (1980). *Estadística aplicada.* España: Labor.
20. Salomons, Erik; van Maercke, Dirk; Defrance, Jérôme (2011). *The Harmonoise Sound Propagation Model.*
21. Universidad de Medellín. *Protocolo para la medición de emisión de ruido, ruido ambiental y realización de mapas de ruido*, Medellín, Colombia, 2009.
22. Vallet, J.; Vincent, B. (2004). *GIpSyNOISE: a GIS tool adapted to the European Directive on Assessment and Management of Environmental Noise: operational aspects.*