MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Dynamic Noise Map based on permanent monitoring network and street categorization

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ABSTRACT

A Dynamic Noise Map of the city of Badajoz has been developed from measurements of a permanent monitoring network, with more than 17 measuring stations. In addition to the measurements of the monitoring network, 150 short-term measures and various field campaigns have been carried out to study the different noise sources. The Dynamic Noise Map of Badajoz considers as noise sources: road and rail traffic, leisure noise and commercial and pedestrian sources. To ease the modelling of road traffic noise, an exhaustive road categorization has been carried out. However, leisure, commercial and pedestrian zones have been characterized based on noise measurements gathered over more than one year and extensive knowledge of the area that facilitates the characterization and modelling of complex noise sources.

The Dynamic Noise Map is complementary to a Strategic Noise Map that has been validated by experimental measurements, being able to determine its accuracy.

Keywords: Dynamic Noise Map, Log-term measurements, Accuracy, Validation.
I-INCE Classification of Subject Number: 76

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1. INTRODUCTION

1.1. State of the art

Dynamic noise maps are not explicitly contemplated in the current laws [1]. A dynamic noise map is essentially a tool that allows the estimation of the noise level existing in an area based on real measurements taken at specific points by means of which the estimation of the existing level in the rest of the points is updated in the calculation grid. Thanks to this continuous monitoring of the situation of the city, a dynamic map allows:

- Detecting annoying acoustic situations that are diluted in the annual average developed in strategic noise maps.
- Detecting conflictive points in certain key schedules.
- Obtaining a distribution of traffic and its development within the roads of the municipality.

Dynamic noise maps are useful tools for local administrations that allow the development of a comprehensive noise management plan and the improvement of the environment in which the inhabitants develop their daily lives [2].

Due to the growing demand of society, in the sense of achieving more comfortable spaces, especially in advanced societies, studies regarding this problem have multiplied in recent years and especially in relation to dynamic noise maps, as well as the effect of each source on the total noise level [3].

1.2. Project approach

In compliance with current legislation [4], during 2018 *Eurocontrol S.A*, in collaboration with *Proceso Digital de Audio S.L.*, developed the Strategic Noise Map of the agglomeration of Badajoz, as technical assistance for the Department of Environmental Protection of the City. The elaboration of the Dynamic Noise Map, based on TrasguNET tool, was also part of the project [5].

The total population of the census sections considered within the limit of the agglomeration adds up to 137,144 inhabitants, according to data from 2017.

In addition to the strategic noise mapping of the agglomeration, a Dynamic Noise Map of the city has been carried out, generated with the information provided by the fixed monitoring network present in the municipality. With this information, a map server has been implemented to obtain noise maps for each hour of the day, as well as to observe hourly and daily evolutions of the noise levels of the municipality [6].

2. METHODOLOGY

2.1. Monitoring Network

For the development of the project some permanent monitoring is needed in the study area. This is the reason why the initial investment for the implementation of an environmental management system based on a dynamic map is greater than that made for the incorporation of a strategic noise map, although there are currently studies based on low cost systems [7]. It also requires continuous maintenance, both of the instrumentation and of the model that describes the acoustic situation of the municipality.

In the case of the city of Badajoz, the Environmental Noise Supervision System (SSMmR) [8] is developed since 2010 by 17 monitoring devices distributed throughout the city and installed at strategic points in order to measure different noise sources.

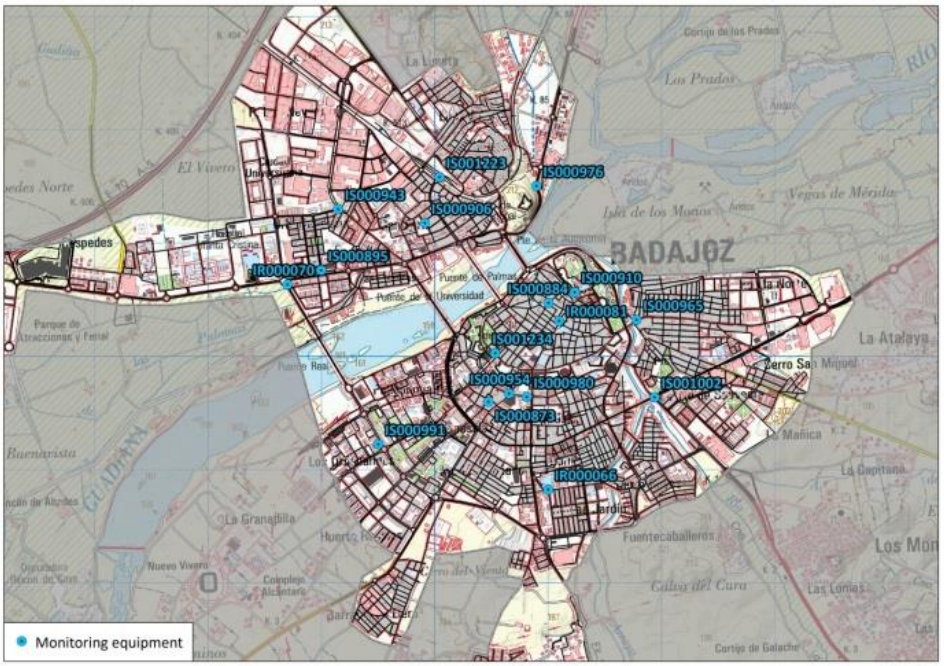

Illustration 1. Location map of the monitoring equipment

This fixed monitoring network has served both for the calibration of the model of the Strategic Noise Map [9, 10], and for the development of the Dynamic Noise Map of the city of Badajoz.

2.2. Short-term measures

For the implementation of the Strategic Noise Map of the agglomeration of Badajoz, a campaign of acoustic measurements and field work has also been carried out in 50 points homogeneously distributed throughout the city, obtaining 150 valid measurements. These measurements pursue the following objectives:

- Information about noise level through representative noise tests in the different time periods (Day, Evening and Night).
- Information regarding traffic data in order to complete and adjust the road traffic model (average daily traffic, distribution of light and heavy vehicles, speed and characteristics of the road).

These data have been used to adjust and calibrate the acoustic simulation model used both for the preparation of the Strategic Noise Map and for the Dynamic Noise Map [9, 10].

2.3. Road categorization

In order to assign average daily traffic and other traffic data to each of the roads included within the limits of the agglomeration, a road categorization of the municipality has been made. A good road categorization significantly reduces possible errors in the fulfilment of a noise map [11, 12]. In this project a total of 8 categories have been established: Pedestrian streets, Urbanization residential streets, Residential streets, Service streets, Main streets, Avenues, City Access and State roads.

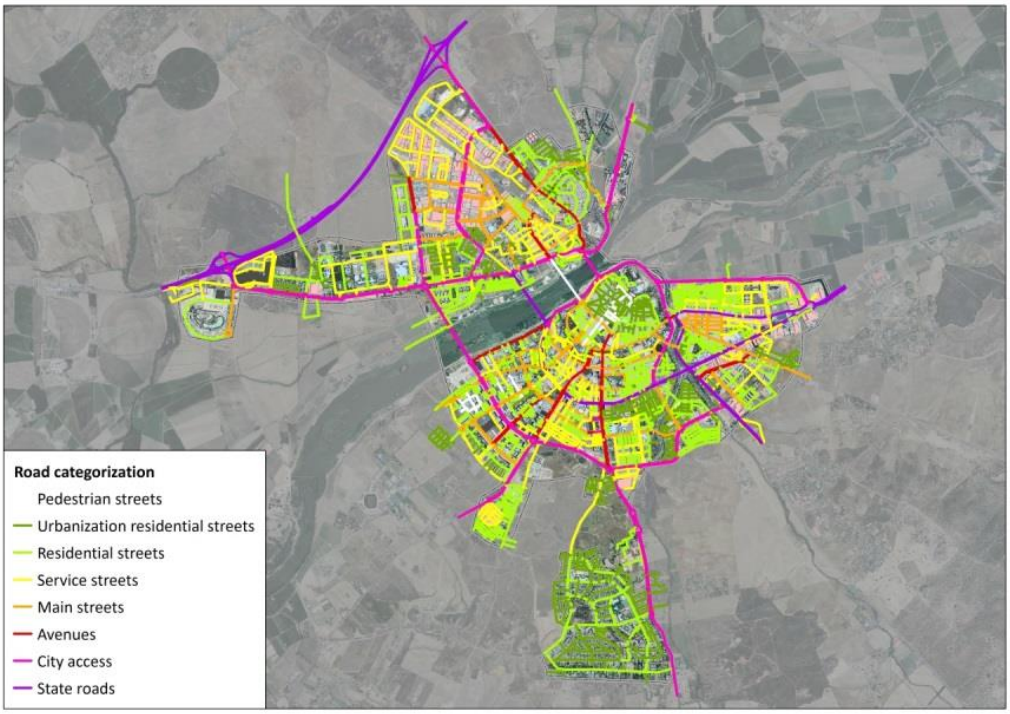

Illustration 2. Road categorization

2.4. Dynamic Noise Map

The software used for this project is TrasguNET, with which the distribution of sound levels in geographical areas is calculated by updating the acoustic power of existing sources based on measurements made in situ by the monitoring network. For this, it uses the reverse engineering method, characterizing the sources by means of sound pressure levels measured at specific points in order to assign sound power levels to the sources. The procedure for calculating the sound power is summarized below:

- The inverse calculation is made from the level registered at a point and knowing the noise sources that affects it.
- A sound power is assigned to each existing noise source based on the initial power assigned to it (initially determined by the characteristics defined for each noise source) and the distance to the measuring point by applying the geometric divergence in an inverse mode.
- Based on the updated power of each existing source in the map, the sound levels of the rest of the points of a mesh superimposed on the map are established and from those that are extrapolated to the rest of the levels for their graphic representation in the final map.

In this process, the following stages can be highlighted:

2.4.1. First stage

It covers the study of the area and the location of sources and their behaviour. It includes the detection of noise sources (commercial, pedestrian, leisure, road traffic and rail traffic), location of them, studying of their behaviour and location of conflicting areas.

2.4.2. Second stage

In this stage, measurements will be taken that will allow establishing the level of independence of the locations. The objective is to distribute the monitoring network in the best possible way, so that with the available sensors the levels of the largest number of independent sources in the city can be registered.

For this study, the Pearson correlation index was used, which made it possible to detect relationships between two points of measurements.

The following table shows the correlations of the 17 monitoring stations belonging to the SSMmR of the city of Badajoz, and their behaviour throughout the year.

Table 1. Study of correlations

	M1 - A	M10	M12	M13	M14 -	M15 -	M16	M17	M18 -	M19 -	M2 - H	M20	M21	M22	M23	M24	M25	M26	M3 - H	M4 - H	M6 R	M7 - H	M8 C	M9 - C
M1 - Ayuntamiento de Badajoz	1	0,57	0,61	0,57	0,64	0,65	0,57	0,57	0,66	0,65	0,63	0,61	0,78	0,5	0,56	0,6	0,7	0,62	0,57	0,59	0,57	0,61	0,61	0,57
M14 - Colon con Ramon y Cajal	0,64	0,97	0,98	0,97	1	0,92	0,97	0,97	0,95	0,89	0,98	0,97	0,88	0,9	0,95	0,95	0,98	0,93	0,97	0,97	0,97	0,98	0,98	0,96
M15 - Plza. Constitucion	0,65	0,89	0,88	0,89	0,92	1	0,89	0,89	0,84	0,89	0,87	0,87	0,92	0,79	0,86	0,88	0,93	0,92	0,89	0,89	0,89	0,88	0,88	0,87
M18 - Sinforiano Madronero	0,66	0,95	0,97	0,95	0,95	0,84	0,95	0,95	1	0,9	0,97	0,98	0,83	0,88	0,93	0,93	0,96	0,89	0,95	0,95	0,95	0,97	0,97	0,94
M19 - Plaza de los Alfereces	0,65	0,84	0,86	0,84	0,89	0,89	0,84	0,84	0,9	1	0,86	0,88	0,86	0,7	0,81	0,86	0,9	0,92	0,85	0,86	0,84	0,86	0,86	0,82
M2 - Hospital Materno	0,63	0,98	0,98	0,98	0,98	0,87	0,98	0,98	0,97	0,86	1	0,99	0,85	0,95	0,97	0,96	0,97	0,9	0,98	0,98	0,98	0,98	0,98	0,98
M20 Avda de Elvas	0,61	0,99	0,99	0,99	0,97	0,87	0,99	0,99	0,98	0,88	0,99	1	0,84	0,94	0,97	0,97	0,97	0,92	0,99	0,99	0,99	0,99	0,99	0,98
M21 Plaza de la Soledad	0,78	0,83	0,84	0,83	0,88	0,92	0,83	0,83	0,83	0,86	0,85	0,84	1	0,73	0,81	0,87	0,92	0,89	0,84	0,85	0,83	0,84	0,84	0,82
M22 Ctra De Caceres	0,5	0,97	0,95	0,97	0,9	0,79	0,97	0,97	0,88	0,7	0,95	0,94	0,73	1	0,97	0,9	0,89	0,79	0,96	0,96	0,97	0,95	0,95	0,98
M23 Estacion de Ferrocarril	0,56	0,98	0,97	0,98	0,95	0,86	0,98	0,98	0,93	0,81	0,97	0,97	0,81	0,97	1	0,94	0,93	0,86	0,98	0,98	0,98	0,97	0,97	0,99
M24 Somoza Rivera	0,6	0,96	0,96	0,96	0,95	0,88	0,96	0,96	0,93	0,86	0,96	0,97	0,87	0,9	0,94	1	0,96	0,94	0,96	0,97	0,96	0,96	0,96	0,95
M25 Avda Huelva	0,7	0,96	0,97	0,96	0,98	0,93	0,96	0,96	0,96	0,9	0,97	0,97	0,92	0,89	0,93	0,96	1	0,95	0,97	0,97	0,96	0,97	0,97	0,96
M26 Plaza Alta	0,62	0,91	0,91	0,91	0,93	0,92	0,91	0,91	0,89	0,92	0,9	0,92	0,89	0,79	0,86	0,94	0,95	1	0,92	0,93	0,91	0,91	0,91	0,89
M3 - Puente Real con Avd. de Elvas	0,57	1	0,99	1	0,97	0,89	1	1	0,95	0,85	0,98	0,99	0,84	0,96	0,98	0,96	0,97	0,92	1	1	1	0,99	0,99	0,99
M4 - Luis Chamizo	0,59	0,99	0,99	0,99	0,97	0,89	0,99	0,99	0,95	0,86	0,98	0,99	0,85	0,96	0,98	0,97	0,97	0,93	1	1	0,99	0,99	0,99	0,99
M7 - Puente San Roque	0,61	0,99	1	0,99	0,98	0,88	0,99	0,99	0,97	0,86	0,98	0,99	0,84	0,95	0,97	0,96	0,97	0,91	0,99	0,99	0,99	1	1	0,99
M9 - Ctra. Sevilla con N-V	0,57	1	0,99	1	0,96	0,87	1	1	0,94	0,82	0,98	0,98	0,82	0,98	0,99	0,95	0,96	0,89	0,99	0,99	1	0,99	0,99	1

2.4.3. Third stage

The main component of the dynamic noise map is the behaviour model of the city, which is composed of:

- The cartography:
  - Views: the model has been divided into 500 views of size 500 x 250 m.
  - Sensors: 17 sensors feed the map, defined according to their type, location and height at which they are installed.
  - Buildings, defined according to their height and absorption coefficient.
  - Traffic sources, defined according to traffic speed, traffic density, number of lanes, % of heavy vehicles, terrain slope and sensor that updates it.
  - Leisure sources.
- The description information of the noise sources and their relationships with the monitoring equipment that feeds the map.
- The most detailed information possible on the circulation in the different streets of the city.
- A good sampling of levels recorded at specific points to establish relationships through the use of correlation and study the possibility of separating sources with data from a single computer.
- Source-sensor relationship. Once the sensors are located so that they are sensing the sources independently, we proceed to analyse which sources are strongly correlated with each of the sensors, making the assignment of each of them, either to a meter or a spiral of traffic counting.

Calculation of noise sources separation

The availability of long-term data allows the study through the behaviour of the average values. There are noise monitors that control several sources and have been taken into account as they meet the following premises:

- Due to the difference in temporal behaviour: its different level patterns allow its contributions to be easily separated
- Due to the absence of one of them at some point: their different hours allow the recognition of each contribution separately, so that when they appear together, the contributions continue to have the same behaviour.

For example, a noise monitor measures the traffic noise source and the leisure noise source. If we observe the behaviour of the monitor a great influence of the leisure that takes place in the zone is observed. The following graph shows the great difference between the annual average of Tuesday and Saturday.

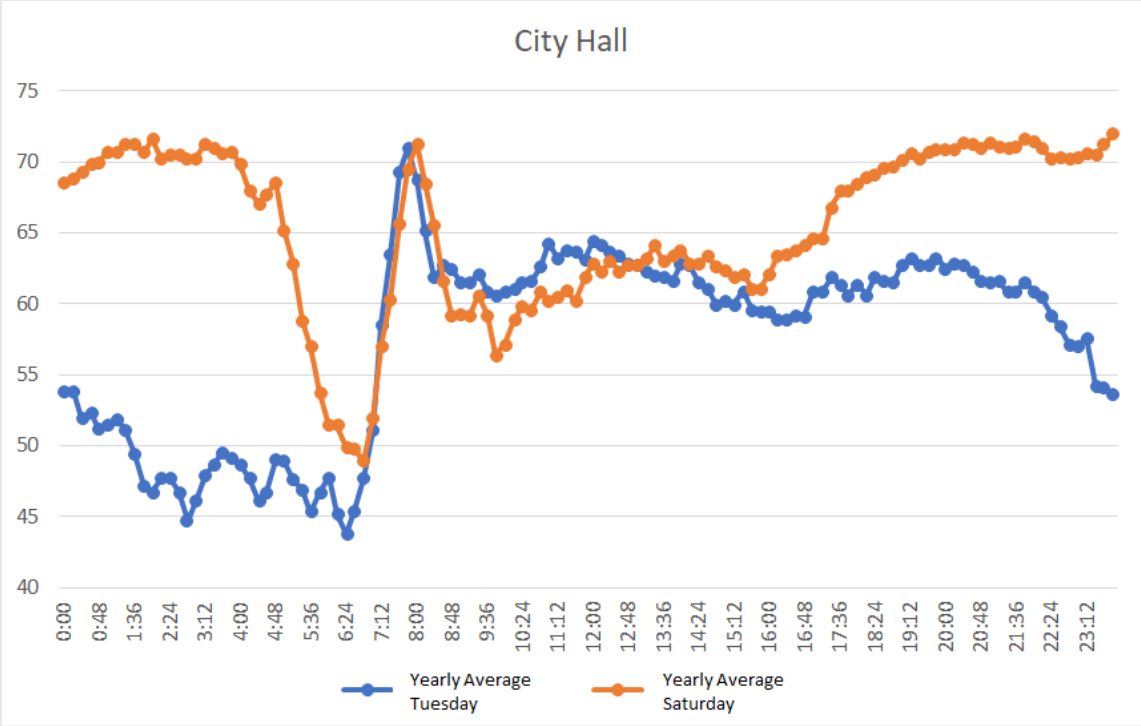

Illustration 3. Monitoring of leisure and traffic noise with the same equipment

Thanks to the study of the behaviour of the sources, the independence between the source of traffic and the leisure noise can be recognized, so that one measurement device can be divided into two virtual sensors, one for each of the sources that is capable to discern (traffic and leisure noise).

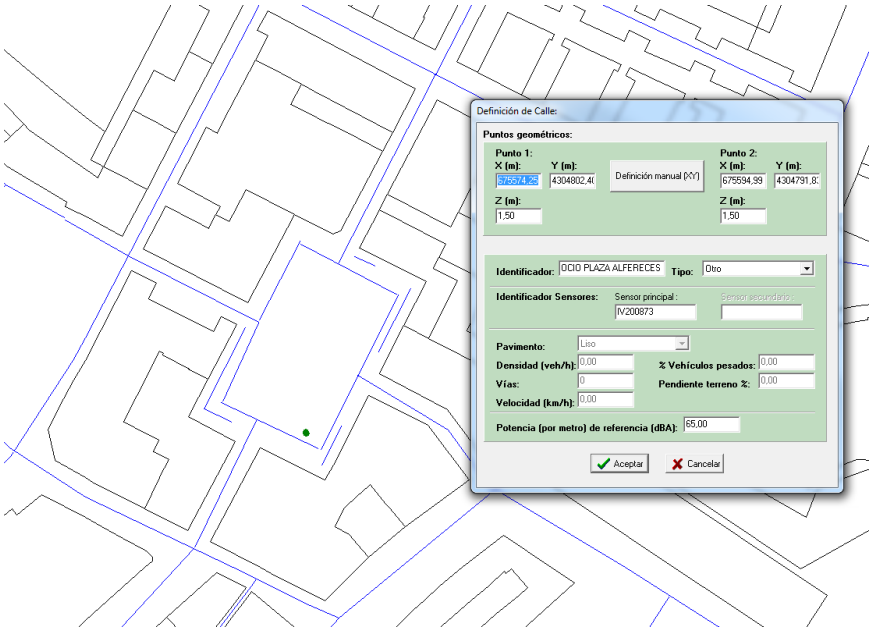

Illustration 4. Data feed of leisure noise and traffic noise with the same monitor

Leisure noise

Leisure noise sources are many and diverse: the noise produced indirectly by the drinking areas and the traffic that runs there, stadiums that have large concentrations of public, outdoor shows, etc. Mainly, among these noise sources, the most annoying and the ones with most complaints are the areas of high concentration of bars, in which, in addition to the activity of the places, the transit and crowding of people on the street is a source producing a high degree of discomfort. There are 7 monitors measuring in continuous that control the leisure areas of the city.

The method of noise sources separation and the existence of long-term data, allow the creation of independent sources, associated to the noise coming from the leisure area, not only of the noisy activities, such as the premises, but of the activities associated with it: displacement and agglomeration of people and cleaning tasks. The representation of the leisure premises in the dynamic noise map has been made taking into account the simulation of recording equipment installed inside the premises, whose information has been provided by the Badajoz City Council. There are 90 locations included in the Acoustically Saturated Zone. The following types have been taken into account:

Table 2. Different categories of leisure venues

Category	Sound reproduction	Schedule	SPL inside dBA)
Coffee bar	NO	07:00 – 01:30	90
Restaurant	NO	07:00 – 01:30	75
Fast food / Take away	NO	12:00 – 04:30	75
Pub, Disco - Bar	YES	– 02:30	90
Nightclub, Theatre	YES	– 04:30	90

In the Dynamic Map of Badajoz there are no data being updated with the values recorded from real sensors inside those leisure venues currently. However, these virtual sensors have been left activated, so that at any time, as soon as sensors are incorporated in the premises, or the value of the noise level generated inside the premises is provided, the location will be immediately updated in the area of influence.

2.4.4. Forth stage

It includes the calculation and adjustment of the model as well as its verification. To perform these calculations correctly, the following variables are taken into account:

- Calculation height.
- Number of rays per point.
- Length of the rays.
- Density / accuracy of the calculation points.
- Number of calculation points.

As the model has been developed, 500 grids have been used. This distribution allows the verification and adjustment if necessary of the source power of each of these elements of the grid. In addition, the map visualization tool that has been created for the representation, groups the individual result in a grid with all the values ordered by their coordinates. This method allows:

- The creation of a grid of points of the entire city by stacking the individual results generated in each grid.
- Quick substitution of each of the verified zones, in case they suffer modifications.
- It allows having a network of calculation points large enough to allow having points of the grid near the locations of the field measurements obtained from the measurement campaign.

3. RESULTS PRESENTATION

3.1. Strategic Noise Map

As the results of the Strategic Noise Map, isophone maps, exposed population, acoustic zoning maps based on the different areas, conflict maps, affectation maps and evaluation maps were developed.

The noise source generating greater acoustic affection is road traffic. In addition to the population calculation according to the European Directive (interim method) [1], a more detailed analysis of the affected population has been carried out, in line with other projects [13], according to the German VBEB method, which performs the calculations for the different heights of each building by distributing receivers of sound pressure level along the entire façade.

As can be concluded from the results of the Strategic Noise Map, the percentages of population exposed to higher levels than the Acoustic Quality Objectives established by state legislation for an existing residential acoustic area are very low, both analysed according to indicator B8 (at a height of 4 m), and analysed according to the German VBEB method.

3.2. Results validation

To determine the goodness of the calculation model of the Strategic Noise Map of the agglomeration of Badajoz, we have proceeded to validate the results of the sound levels, both in the calculation grid and in the model receivers by comparing them with the noise levels provided both by the monitoring network and by the measurement campaign carried out [9, 10]. In order to validate the traffic model through experimental measures, those tests that met the following conditions have been taken into account:

- The main noise source is due to road traffic.
- There have been no sound events influencing the results.
- The passage of vehicles in the sampled period is representative of the road category.
- The passage of vehicles in the sampled period is representative of the period of the day in which it was measured.
- The percentage of light and heavy vehicles in the sampled period is reasonably similar to that of the road category in which the tests were carried out.

In the case of long-term measures (approximately 1 year duration), only the levels measured by those monitors mainly related to road traffic noise, excluding monitors located in areas with nocturnal leisure noise and anomalous results, have been considered [14].

Taking into account these considerations, 84 pairs of data have been compared between measured and simulated values.

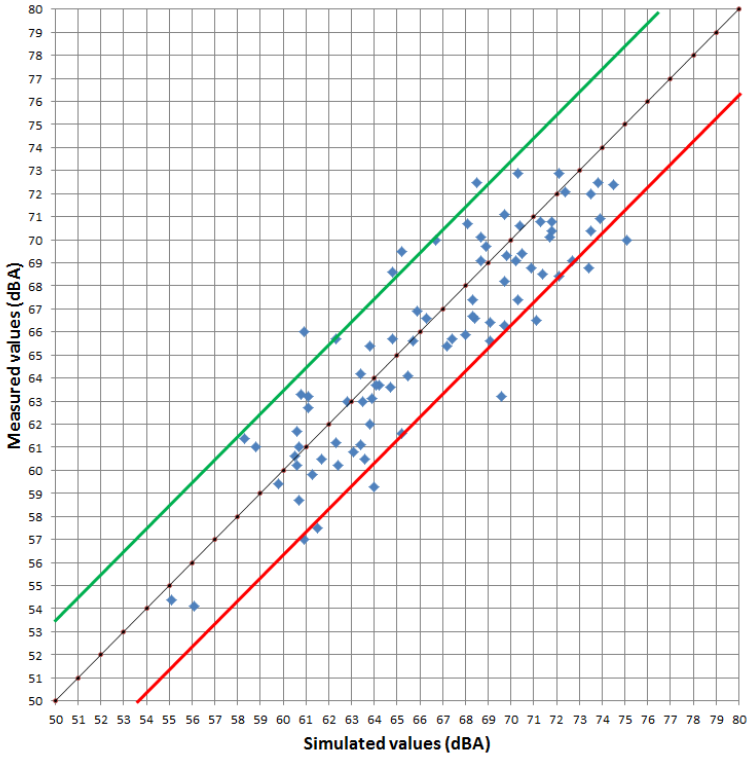

Illustration 5. Road traffic model validation graphic

From the result obtained, it is concluded that the uncertainty value of the traffic model of the Strategic Noise Map is ± 3.5 dB (A). With this validation process and the implementation of a Quality Assurance Procedure which includes a number of quality control protocols to manage specific aspects of the process, the final Noise Mapping results show good quality and precision [15].

3.3. Dynamic Noise Map

Unlike the Strategic Noise Map, the Dynamic Noise Map of the city of Badajoz allows you to consult the noise levels existing in each point of the city at different times of the day and for the different days of the week, since it is linked to the levels measured in real time by the 17 fixed sensors distributed throughout the agglomeration.

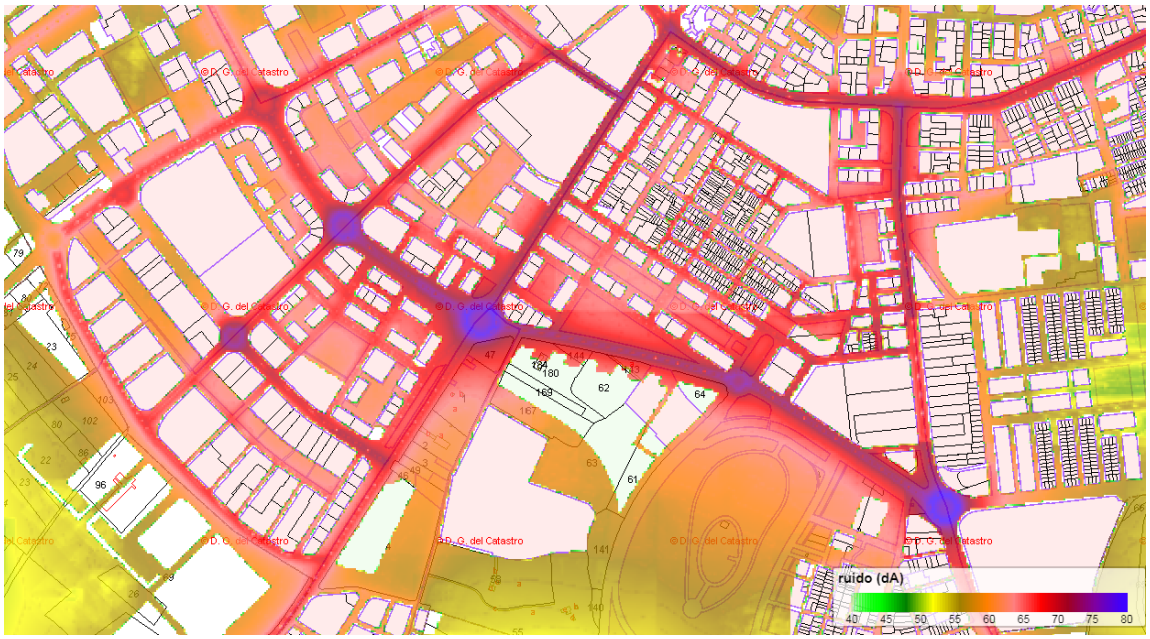

Illustration 6. Dynamic Noise Map

One of the advantages of a noise management tool based on a dynamic map is that it allows the evaluation of the corrective measures performed during the action plans, and with the previous work described in stages 1-4.

In total 132 distributed sensors have been created:

- 17 real noise monitoring equipment.
- 28 virtual traffic sensors, related to the values coming from the real instruments.
- 7 virtual sensors related to the real values for the sources associated with pedestrian streets.
- 20 virtual sensors related to real values and virtual traffic sensors that allow separating sources in measurement points with more than one noise source.
- 60 virtual sensors associated with leisure activities in the downtown area.

Every hour, automatically, LAeq1h values are calculated for each sensor, with the relationships established according to the previous classification. In addition, the user has access to the following services:

- Individual request of Ld, Le, Ln, Lden maps of a given day.
- Individual request of the time map of a specific date and time.

3.4. Web Services

As a municipal management tool, the project has been integrated into a web on noise pollution that allows the following actions:

- Publishing the contents specified by the municipal technicians.
- User management.
- Management of the sensors belonging to the city.
- Data query of the sensors installed in the city, as well as the data of the equipment in graphic form by means of its location on the map.

One of the objectives of the web is the realization of Action Plans against noise and comprehensive environmental management policies for the management of Acoustically Saturated Zones and Special Acoustic Protection Areas [16].

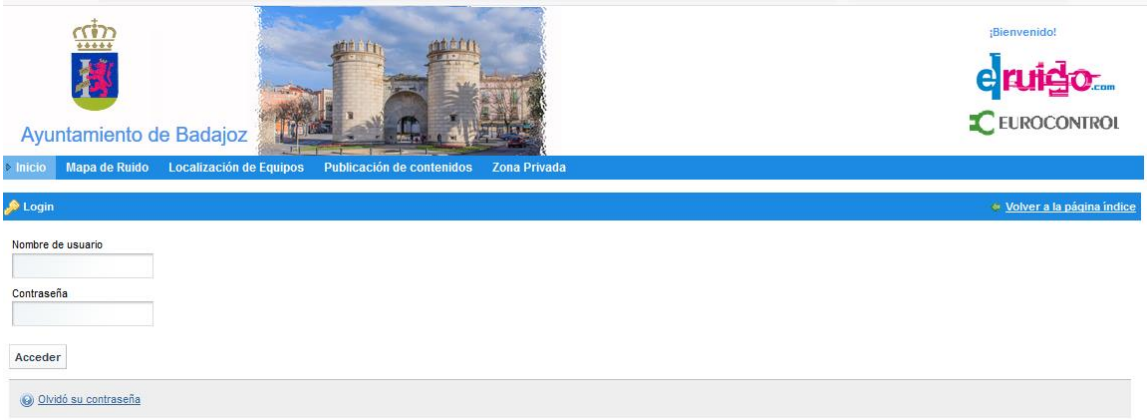

Illustration 7. Municipal web portal for noise management

The interface available in the City Council is an application from which technicians can make different utilities thanks to the Web Services generated for the viewer:

- Sensors noise levels inquiry.
- Consult dynamic noise map requests for Ld, Le, Ln and Lden
- Total Dynamic Noise Maps and traffic and leisure sources inquiry.
- Specific areas of the city inquiry.
- Strategic Noise Maps inquiry.
- Manual requests and calculation of the map.
- Daily animation of the Dynamic Noise Map.

4. CONCLUSIONS

Throughout the article the process has been described by means of which a joint project of Strategic Noise Map and Dynamic Noise Map has been carried out through 1-year monitoring stations and short-term noise tests, with the aim of validating and calibrating the calculation model. The dynamic noise map can discern between different types of noise sources, due to the extensive knowledge of the reality of the city.

In order for municipal technicians to use these results to address environmental noise management policies, the project has been integrated into a municipal web portal.

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