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MANAGING ENVIRONMENTAL NOISE BY BRINGING TOGETHER CONTINUOUS MONITORING AND SIMULATION MODELS

Luis Conde Santos[1*] **André Carvalho**[2] **Jorge Preto**[1]
Paulo Valério[1] **Cristina Leão**[1] **Guilherme Covas**[2]
[1] dBwave.i - Acoustic Engineering, SA, Oeiras, Portugal
[2] Instituto de Soldadura e Qualidade, Oeiras, Portugal

ABSTRACT

Assessment of environmental noise is commonly done by either performing measurements, long or short-term, or by calculating noise by means of acoustic models. These methods, although satisfactory for long-term planning or for noise limit compliance assessment, may not be suitable as a basis for an environmental noise management and control system, especially if one wants to be able to act upon the noise sources almost in real time. This paper addresses the implementation of environmental noise management systems based on continuous monitoring together with simulation models, which seek to combine real-time information from monitoring stations, installed close to the noisy activity, with information from an acoustic model that allows to predict sound levels at a distance, typically near sensitive receivers. Monitoring data is processed and made available by a digital platform, with the capacity to detect and classify noises, and that can generate alarms in quasi-real time, making it possible to take immediate action to reduce noise emission. The monitoring data is fed into the acoustic model to adjust noise sources emission for a best-fit with the measured levels. Examples of application are presented, namely the case of a racetrack and the case of a construction site.

Keywords: *Environmental Noise, Noise Management, Permanent Monitoring, Digital Platform.*

**Corresponding author*: luis.conde@dbwave.pt.

1. INTRODUCTION

A common method for assessing environmental noise generated by a noisy activity is to carry out noise measurements near potentially affected sensitive receptors, which can be carried out by sampling or continuously over several days (e.g. 48 hours). Another method is by developing an acoustic model of the noisy activity (e.g. a factory) and its surroundings and use it to calculate noise levels at the sensitive receptors and, in a more comprehensive way, noise maps throughout the surroundings. These methods, although applicable in many cases, have some limitations as a basis for an environmental noise management and control system, and are even totally inadequate in situations where there is great variability or unpredictability in the noise emitted by the activity and/or where there is a need for real-time monitoring of the noise of the activity.

In fact, in the context of rapid changes in society and the technologies at its disposal, the methods and technologies used in the assessment and management of environmental noise have evolved slowly, failing to keep up with the real paradigm shifts that have been occurring around them. dBwave, an acoustic engineering company of the ISQ Group, seeking to address this type of issues, has developed and has been applying continuous noise monitoring methodologies, for more or less extended periods (from 48 hours to several weeks), with manual analysis of the recordings in post-processing, methodologies that are currently insufficient, consuming a lot of time, not allowing remote access to the data during monitoring, nor any real-time control of the activity or noisy source that is being monitored and that are only identified a posteriori.

2. MIRA – AN INTELLIGENT PLATFORM FOR ENVIRONMENTAL NOISE MONITORING

To respond to the afore-mentioned challenges, dBwave and ISQ joined efforts to develop an innovative solution, named MIRA, which focuses on continuous, unaccompanied noise monitoring, by means of type 1 sound level meters which communicate with an integrated digital platform with automations to identify specific sounds or noises, as well as the generation of alerts and daily reports of measurements made. MIRA aggregates different modules, all interconnected by a robust architecture, which allows the integration and centralization of several existing technologies, as well as new ones developed with innovative and differentiating characteristics. It thus seeks to respond to the needs identified in the market, in sectors such as industry, construction, transport infrastructures, municipalities and musical and sports performances [1].

MIRA platform is designed to allow flexibility, performance, scalability and ease of use, with the main focus on the ability to scale depending on the traffic that is occurring at the time. For this purpose, a cloud service is used that allows flexibility of the contracted computing capacities according to the need of the moment. This aspect is critical because it allows us to guarantee great security in the quality and responsiveness of the service, but also control the associated costs, since these are directly related to the number of equipment/work to be carried out at any given time.
Figure 1 illustrates the various existing modules and how they communicate with each other.

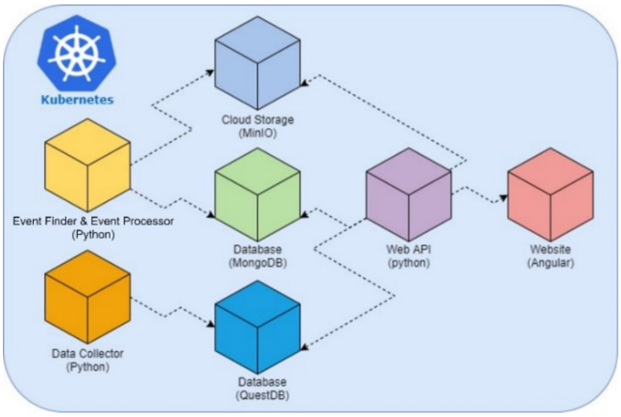


Figure 1. MIRA Architecture Schematic.

3. NOISE MANAGEMENT WITH PERMANENT MONITORING AND SIMULATION MODELS

As far as we know, the first time the approach to environmental noise management with the integration of noise mapping and monitoring techniques was proposed, goes back to 1999 [2]. Since than substantial developments have taken place, such as the technique of Dynamic Noise Mapping, extensively addressed in the European project LIFE DYNAMAP [3].

One of the areas in which permanent monitoring and noise simulation models have long been combined is that of noise management and monitoring systems around airports [4]. For example, in Portugal, Noise Monitoring Systems (in continuous operation) are installed with the aim of monitoring and controlling noise levels, with a special focus on those generated by aircraft, at Humberto Delgado, Francisco Sá Carneiro, Faro and Madeira airports. Simulations/forecasts are also carried out, through the regular preparation of Noise Maps, which are integral elements of the noise monitoring reports of these airports. Real data associated with aircraft movements in the reference periods (flight tracking technology) are used, allowing greater accuracy of the results obtained.

This paper addresses environmental noise management systems based on permanent monitoring and simulation models, in which it is sought to combine real-time information from monitoring stations, installed near the noisy activity, with information from an acoustic model that allows predicting sound levels at a distance, typically near sensitive receivers. The monitoring data is processed and made available by a digital platform, with the capacity to detect and classify noise, feeding the acoustic model for assigning sound power to the noise sources present.

4. EXAMPLES OF APPLICATION

4.1 Environmental noise management of a Racetrack

4.1.1 Background

In the specific case of motorsport tracks, as in other situations (airports, industries) the problem generally arises that, although the objective is to control and limit noise near sensitive receptors, in practice it is not possible to control the noise generated by the racetrack based on monitoring near these receptors. In fact, there are almost always other sources of noise present, such as road, air, rail traffic, animal noise, etc., and it is not possible to attribute the noises monitored at these points to the specific noise of the racetrack alone. On the other hand, the high number of sensitive receivers to be analyzed could make it unfeasible to install permanent monitoring equipment in all of them.

In this context, many automotive circuits have implemented Noise Management Plans, often based on the imposition of limits on the noise emission of vehicles and their control, either through static tests (at 50 cm and 45º from the exhaust), or drive-by tests (20 m from the track) [5], as well as monitoring systems, such as the Circuit de Spa-Francorchamps, in Belgium[1], using one or more trackside monitoring points and others near potentially more affected sensitive receivers, then seeking to correlate the noise recordings near the sensitive receivers with the trackside recordings, thus seeking to rule out noise that does not originate from circuit activity. In other cases, the approach is to monitor the noise inside the circuit, near the track, and calculate the relationship between the sound level near the source and the sound level near the sensitive receivers, which in practice can be done with an acoustic model of the circuit and its surroundings [6].

Some noise indicators have been developed for automobile circuits such as the Lap Equivalent Level (LEL) and the Race Equivalent Level (REL), the first defined as the L_{Aeq} of the noise received at a given point due to a lap of the track by a single vehicle, and the second as the L_{Aeq} of the noise received at a given point due to the set of vehicles during a race [7].

4.1.2 The Estoril Racetrack

Inaugurated on June 16, 1972, the Estoril Circuit has had some layout changes throughout its history, and the track currently has the following main technical characteristics:

- Runway length (centerline): 4,182.7 m
- Ideal Length of the Route: 4,140.4 m
- Runway Width: between 10 and 18 m
- Total turns: 13
- Longest Straight (Finish Line): 985.7 m

[1] Webpage of the Spa-Francorchamps circuit: http://www.francorchamps-acoustique.be/index.aspx

Figure 2. Example of preliminary noise measurements for the development of the acoustic model, during a classics race.

4.1.3 Elements of the noise management system

This case study refers to the environmental noise management and control system implemented at the Estoril Circuit. The system is intended to control the noise emission of all private and corporate events (i.e., other than official sports competitions and respective training), and is essentially based on the following elements:

Event planning and emission control procedures:

- Pre-setting the maximum noise emission levels of vehicles for each event, as well as the maximum number of vehicles that may circulate simultaneously on the track, and previously inform the organizers of these events;
- Systematic pass/fail inspection of all vehicles, before the start of the event, according to a standard procedure (noise level measured at 50 cm and 45 º from the exhaust pipe outlet, at 3/4 of the maximum engine speed);
- Planning of the events for each month in such a way as to avoid concentration of noisiest events in the same month and try to mix them with less noisy events (e.g. alternating track days for motorcycles and for electric cars).

Environmental noise monitoring network, consisting of:

- 3 permanent continuous monitoring stations for ambient noise, weatherproof, consisting of type 1 sound level meters, duly approved in Portugal and subject to annual metrological control, installed within the limits of the circuit, strategically placed to determine the noise emission of the various sections of the circuit;
- Integrated digital platform, MIRA, which receives, stores, and processes the data transmitted by the monitoring stations, namely relevant noise indicators for environmental noise assessment (L_{Aeq}, L_d, L_{den} and

others, including analyses in 1/3 octave), with capacity to generate reports, make information available via the web to those responsible for the circuit, as well as detect specific characteristics of the noise, such as exceeding pre-programmed thresholds and generating alarms for the user.

<u>Acoustic simulation model of the circuit and the surrounding area</u>, developed based on 3D cartographic information, including the digital terrain model, buildings and other obstacles, as well as the layout of the track, which constitutes the specific noise source, divided into a number of segments according to their characteristic sound emission levels. The model allows relating the following variables, involved in the activity of the circuit:

- Maximum permitted noise levels within 0,5 m of vehicle exhaust, taking into account the number of simultaneous vehicles on the track;
- Noise emitted by each segment of the runway, based on the developed acoustic simulation model;
- Noise levels measured at the 3 permanent monitoring stations;
- Specific and background noise levels in the most critical sensitive receivers, to verify the noise nuisance criterion of the Portuguese Noise Regulations.

The environmental noise management and control system includes the preparation of monthly reports with the results of permanent monitoring at the 3 points, respective detailed analysis, identification and individualized calculation of the noise generated in private and corporate events, estimation of the acoustic impact at sensitive receivers, with evaluation of the applicable legal criteria (maximum exposure and nuisance) for a monthly evaluation period. Also, an annual report is produced, synthesizing and systematizing the information from the monthly reports, and making an annual assessment of noise emissions, control and monitoring measures implemented, and evaluation of the applicable criteria.

4.1.4 Noise monitoring network

Monitoring stations have been installed at the following points:

- PM1: "Airton Senna Parabolic" Curve
- PM2: Finish line (Stand B)
- PM3: “Chicane” Curve

Location and example of results are depicted in the next figures.

Figure 3. Location of the monitoring points.

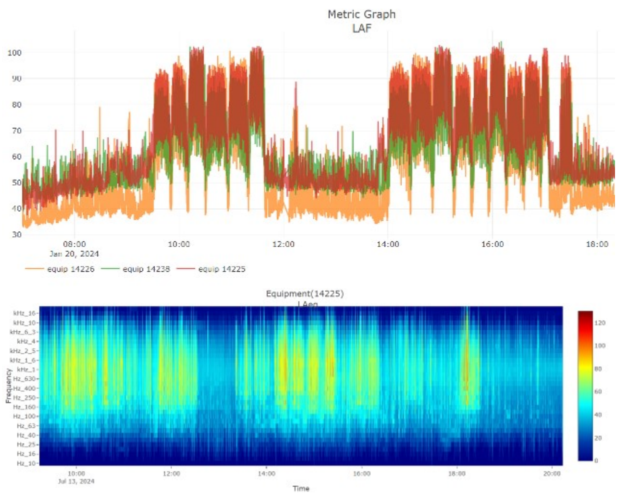
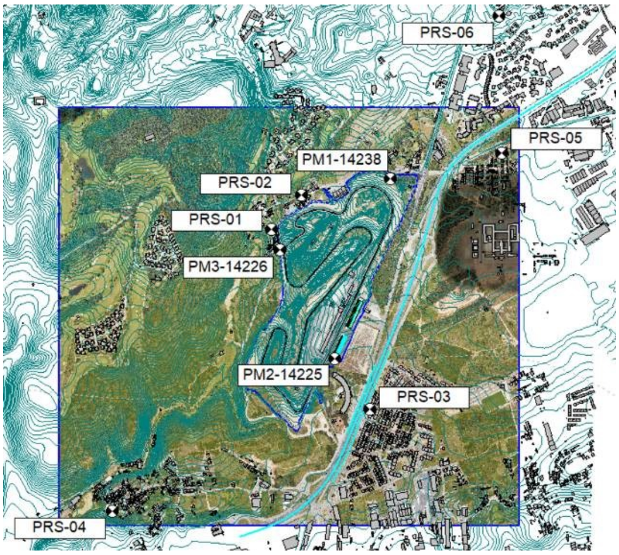


Figure 4. Examples of records on MIRA platform.

4.1.5 Acoustic Model

The acoustic model developed for the Estoril Circuit and surrounding area is shown in the following figure. The model was developed using CadnaA software and is used to calculate the specific noise of the events recorded each month, next to the defined sensitive receptors. For this purpose, the sound power emitted by each segment of the track is optimized for a best-fit between measured and calculated sound levels at the receivers, thus obtaining a model which is calibrated by continuous monitoring.



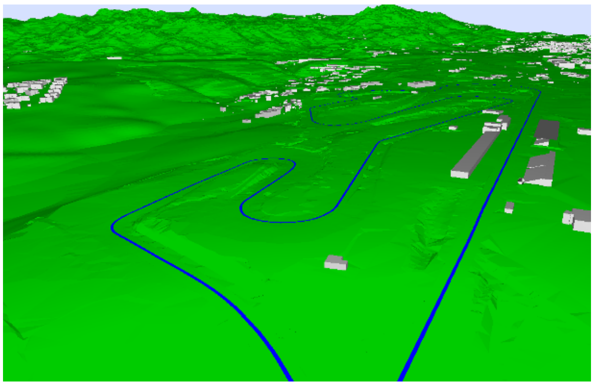


Figure 5. Images of the acoustic model, seen in plan (above) and in 3D view (below).

4.1.6 Evaluation procedure

Taking into account the assumptions of the circuit noise management system, the following compliance assessment procedure has been defined:

- Monitoring of L_d values (L_{Aeq} of the daytime period) for the days with private/corporate events that occurred in the month and calculation of the respective logarithmic average;
- Monitoring of L_d values on days with no activity in the circuit, as a reference for residual noise, and calculation of the respective logarithmic average;
- Extrapolation of the residual noise values obtained above to the closest sensitive receptors or with sound environment characteristics similar to the monitoring points (the so called "image points" according to Procedure 2 of Note 8 of the Practical Guide for Environmental Noise Measurements, published by the Portuguese Environment Agency (APA));
- Calibration of the model to adjust, at the monitoring points, with the values of the logarithmic mean of the L_d values recorded during the private/corporate events;
- Calculation of the specific noise by the model, at points representative of the areas with sensitive use in the circuit envelope;
- Definition of the limits to be applied to the differential of the nuisance criterion, taking into account the quotient between the number of days in the month with private events and the total number of days in the month (for example, in a given month in which there are private events in 9 out of 30 days, the regulatory quotient q = 30% is calculated, so correction regarding the duration of the activity will be D = 2, the regulatory limit to be considered is then 5+2 = 7 dB(A), in the daytime);
- Analysis of the results to verify the criteria of nuisance and of maximum exposure.

4.1.7 Noise control procedures

Within the scope of the noise management system, control procedures have been implemented for private/corporate events which, since its entry into operation in January 2024, have been adjusted according to the results obtained with monitoring. The main procedures currently in force are the following:

<u>Prior Inspection of Vehicles:</u>

All vehicles participating in private events are subject to systematic inspection prior to the start of the event, by measuring 50 cm from the exhaust, at 3/4 of the maximum engine speed and with the sound measured at a 45-degree angle to the tailpipe outlet. Purely electric vehicles (which do not have exhaust) are excluded.

The emission limit set for most private events has been 100 dB(A), and any vehicle that fails this inspection is prohibited from entering the track. The limits are announced in advance to the promoters of the events, and in the future there may be greater or lesser restrictions on emission levels, as is the case in other international circuits [5], taking into account aspects such as:

- Maximum number of vehicles on the track at the same time;
- Number of events scheduled for the month (in a month with many scheduled events, it may be necessary to restrict emissions further, at least in some of them);
- Event schedules;
- Vehicle and event type in question.

The results of all emission measurements are presented as an annex to the monthly report.

<u>Generation of automatic alarms for the motorsport marshals:</u>

Taking into account the experience of several months of monitoring, and the identification of some of the most critical points, an alarm was programmed for one of the monitoring stations, with the following trigger configuration: LAeq (5 min) > 85 dB(A). Thus, if this alarm is triggered during a race, the responsible marshal is notified and, depending on the conditions of the race/event, will act accordingly: for example, by forcing a reduction in speed in the most critical area of the track, through the use of signal flags.

<u>Opening hours</u>

The Estoril Circuit only operates during the day – typically not occupying the full period. In addition and depending on possible noise management needs of private events, schedules may be adjusted for some events (e.g. noisier events).

4.2 Noise management of a large construction project

4.2.1 Background

Construction noise can affect the physical and mental health of construction workers as well as of the people in the surrounding area and has been reported as one of the main reasons for complaints and disputes that cause delays and cost overruns for construction projects. Several studies have been conducted in the subject of construction noise management, and a comprehensive investigation of the current state of the art in this area was presented in the article by Mir et al. [8].

4.2.2 The Ruby line of Porto metro

The Ruby Line (H) of the Porto Metro is a line under construction that will connect Casa da Música, in Porto, to Santo Ovídio, in Vila Nova de Gaia.
Line features

- The new line will add 6.3 kilometers to the Metro do Porto network, with buried sections, on the surface and on viaduct;
- The project is funded by the Recovery and Resilience Plan (RRP);
- The investment is around 379.5 million euros;
- The work involves the construction of tunnels, 8 stations, 5 ventilation and/or emergency wells, a connection branch at both ends of the line (for the injection and removal of vehicles and track to carry out the reversal of vehicles, viaducts, a new bridge over Douro river and reformulation of the urban space (including roads).

Social, economic and environmental impact

- The Ruby Line will bring social, economic and environmental benefits quantified at 1.7 billion euros

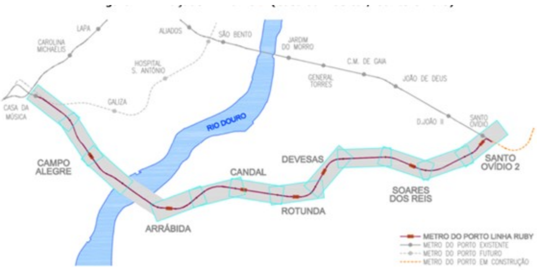


Figure 6. Simplified plan of the Ruby line.

The project was subjected to an Environmental Impact Assessment procedure, which laid out a set of requirements relative to noise and vibration planning and management during the construction phase. With respect to noise, a management plan was established with the following main steps:

- Identify the sensitive receivers potentially affected and the noise requirements and limits applicable to the project;
- Survey ambient noise levels before construction begins at a number of points nearby the various construction sites involved in the project;
- List all relevant noise sources and noisy activities that will be present on the sites, for each scenario of the construction process, and develop an acoustic model to simulate the various scenarios and the expected noise levels in the nearby sensitive receivers, including residential building façades;
- Propose and implement noise mitigation measures at the source (e.g. less noisy machines, acoustic enclosures), at the propagation path (e.g. noise barriers) or at the receivers (e.g. façade insulation);
- Install continuous noise monitoring stations, at over 20 points and throughout the entire duration of the construction works, connected to a web platform, with capacity of sending automatic exceedance alarms to the various parties involved and information to help identifying the related sources and, also, correlate them to the acoustic model of the site – this enables, works in the first place, to check if the exceedance is related to the construction and, if yes, provide information to quickly take action and correct the exceedance;
- Provide regular noise reports, during the various construction phases and for all construction sites.

4.2.3 Acoustic simulations for various sites and scenarios

For each site, a comprehensive study was carried out before starting the construction works, including a characterization of the construction process, with its successive phases, each involving its specific noise sources, with corresponding sound power levels and working times, and topographic changes (excavations), and, for each phase, simulations were carried out with the acoustic model to check for compliance with noise limits and to test noise abatement measures.

For example, for a typical metro station construction, the following phases were simulated:

- Demolitions, Affected Services and Excavations;
- Excavation of the Tunnel + Coatings
- Internal Structures;
- Urban Insertion and Landscaping

The figures below illustrate the acoustic simulations of two of the construction sites, at a particular phase of the construction process.

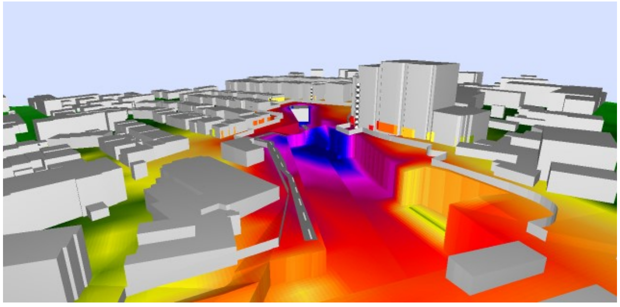


Figure 7. 3D noise map for the Santo Ovidio station.

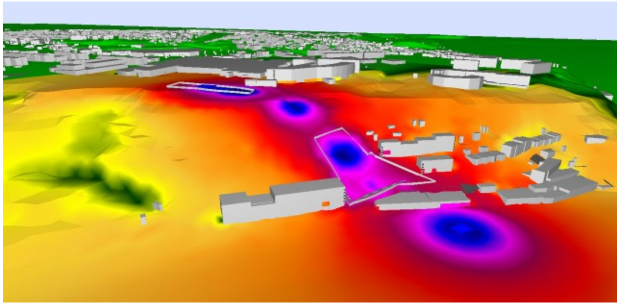


Figure 8. 3D noise map for the south bank side of the bridge over Douro river.

4.2.4 Noise monitoring

At the time of writing this paper, the construction works haver recently started, and the first 3 monitoring stations have just been installed – it is planned that over 20 will need to be working simultaneously, distributed by various sites, as the construction works proceed.

These monitoring stations are being connected to MIRA platform, for automatic reporting and alarm generation. Source detection and correlation with the acoustic simulation models of each site is envisaged and is expected to be tested in the near future.

Next figure shows photos of the noise monitoring stations already installed on site.

Figure 9. Photos of noise monitoring on one of the construction sites.

5. CONCLUSIONS

In this communication, the problem of implementing environmental noise management systems based on permanent monitoring and simulation models was presented, in which it is sought to combine real-time information, from monitoring stations installed next to or within the noisy activity, with an acoustic model that allows predicting sound levels at a distance, typically next to sensitive receptors. The integrated digital platform MIRA, developed by dBwave, which allows the management, communication, registration and analysis of environmental noise monitoring networks, was briefly described and its application was illustrated, together with a simulation model, in the development of an environmental noise management and control system for a racetrack and for a construction site. These were analysed in more or less detail, describing the constituent elements of the system, with emphasis on the monitoring network and the simulation model, as well as describing the procedures for evaluating and controlling the noise generated by the noisy activities. In the case of the circuit, from the experience of 15 months of operation of the system, it can be concluded that it has proved to be very useful, functional and adaptable to different conditions and needs, making it an effective tool in the management and control of circuit noise. In the case of the construction site, although the monitoring part of the project has just started, the almost one year experience with the development and practical application of the simulation models has been proven very useful, helping in the definition and adoption of abatement measures, in the approval and licensing of the construction sites by the authorities and, also, in the acceptance of the unavoidable nuisances by the affected population.

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