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ENVIRONMENTAL ROAD & RAIL TRANSPORTATION NOISE MONITORING. A NECESSARY TOOL FOR THE PROTECTION AND REHABILITATION OF THE URBAN ACOUSTIC ENVIRONMENT

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In the last 20 years, the increasing development of road transportation networks along with other urban mass transportation networks - as light rail transit - in urban areas has an important influence on the quality of the life and the acoustic environment. The rehabilitation of the urban soundscape is now a major parameter in the rehabilitation of the quality of life. The environmental noise monitoring actions are important and necessary for the assessment of the acoustic environment and for the introduction of the most adequate mitigation measure in order to alleviate the effects of exposure to traffic noise (e.g. traffic management, smooth and uniform traffic flows, introduction of technical solution for the road noise abatement such as noise barriers, etc.). The overall approach of a complete and comprehensive monitoring scheme is important in order to process the adequate and environmental friendly operation and maintenance of the road in order to respect the noise limits defined in the relevant legislation. This paper presents a combined approach to a typical adequate road noise monitoring program based on a 10-year relevant experience in various highways and motorways in Greece. This approach is essential in order to manage effectively this complicated linear noise source. Active traffic management techniques, smooth operation, absorbing pavements, speed limits and eco-driving within the relevant strategic noise maps and action plans offer a way to provide continuous and up-to-date monitoring and assessment of road noise level.
Keywords: noise, vibration, environmental monitoring, transportation networks

1. Introduction - A brief analysis of the problem

The increasing development of road, rail and air transportation networks with emphasis to light rail transit networks in urban areas has a major consequence on the quality of the life and the acoustic environment. The rehabilitation of the urban soundscape is now a major parameter in the improvement of the quality of life. To ensure the effective protection of the acoustic environment and the successful implementation of the adequate mitigation measures, an Environmental Management Plan (EMP) needs to be initiated for each project in the framework of a comprehensive noise and vibration monitoring program including :

- all the necessary parameters, data and indicators of environmental noise (monitoring noise),
- the methods, the position, the time and the recording parameters of each acoustic event,

- the quality assurance measures and the reliability of monitoring parameters,
- the relevant actions to inform all involved decision making authorities, and
- the timetable associated with the maintenance and calibration of monitoring equipment, and relevant installations.

The structure of an adequate EMP for noise and vibration includes the identification of significant environmental parameters that will be affected by the construction and operation activities of the proposed transportation project and the expected impact on each of these, as assessed and evaluated. In Figure 1, the basic features for a comprehensive environmental acoustic management towards a successful environment protection during construction are presented.

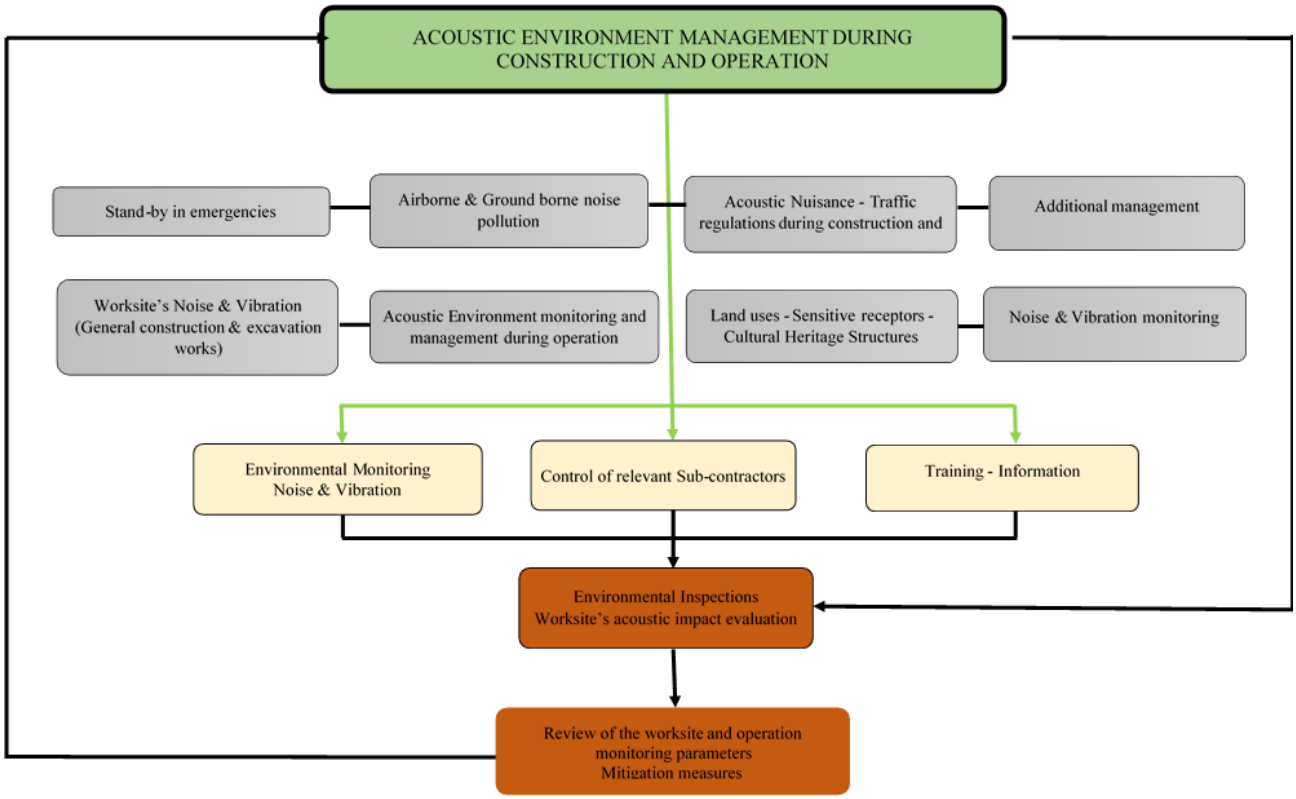

Figure 1. Acoustic environmental management during construction and operation of a major urban transportation project.

In this framework, the mapping of environmental noise as defined in the European Directive 2002/49/EC [1] is a major tool in the assessment and management of environmental noise, in order to consider the necessary noise actions. This also provides the necessary data to the European Commission (EC) and to the European Environmental Agency (EEA), on environmental noise exposure and the noise annoyance of the population of large urban centres. This tool introduces the following [2]:

- Noise assessment indicators: introduction to L_{den}, L_{day}, $L_{evening}$ and L_{night} indicators in dB(A) in environmental noise assessment issues.
- New harmonized calculation input data collection process: introduction and establishment of new collection methodology and coding (such as population data, traffic volumes, geometric elements, etc.), consultations with stakeholders, etc.
- New noise impact assessment methodology: introduction of new automated noise curves design data processing methodology using special software.
- New data processing methodology population exposure to noise.
- Investigation and best presentation selection process (with introduction of new data presentation technology and media modes combined).

- New procedures making against noise protection measures (institutional suggestions and additions, link mapping process with local noise action plans dealing with the necessary proposals for specific projects, implementation schedules them, sources of funding, etc.).
- Defining uniform acoustic environment status report (to serve as the Greek national report to the European Commission under Annex VI of Directive 2002/49/EC obligations).
- Assessment of exposure to environmental noise, through strategic noise mapping, according to the mandatory European common evaluation methods and indicators.
- Care that information is available to the public regarding the environmental noise and its effects.
- Establishment of appropriate action plans, based on the results of the noise mapping to prevent and reduce environmental noise.

2. The Greek experience

According to preliminary results from the Environmental Burden of Disease (EBD) in Europe project in six European countries [3] reported at the WHO Ministerial Conference held in Parma in March 2010 [4], traffic noise was ranked second among the selected environmental stressors evaluated in terms of their public health impact in six European countries. It estimated that some 33% of the individuals are annoyed during the daytime and a 20% have disturbed sleep at night because of the traffic noise [5, 6]. EEA has also estimated that some 20% to 40% of the urban population, (e.g. some 200-200 million inhabitants), was exposed to environmental noise levels leading to serious annoyance, speech interference and sleep disturbance. The Directive 2002/49/EC, relative to the evaluation of ambient outdoor environmental noise – now mandatory for all European cities with population superior to 100,000 – aims at the surveillance of ambient community noise is now used as a reference. Several European cities have already established environmental noise mapping and monitoring programs, as well as noise management and abatement plans in order to achieve radical reduction of the part of the urban population exposed to high noise levels [7]. However, the European Directive 2002/49/EC does not address ground borne noise and vibration especially from rail transportation networks. A recent research work [8] showed that such situation cannot longer be neglected since ground vibration and noise limits exceeded in 44% and 31% of cases respectively in a collection of recent technical ground-borne noise and vibration reports.

Since its implementation and the 1st round of Strategic Environmental Noise Mapping, the European Directive 2002/49/EC still remains highly relevant for EU policy-making as noise pollution still constitutes a major environmental health problem in Europe. However, a common approach to the noise management and harmonized data is much needed in order to provide a high-quality evidence base for understanding the issue and further developing EU environmental noise legislation introducing also ground borne and vibration issues. Regarding its effectiveness, some progress has been made towards a common approach throughout the EU, but effects materialized only partially due to the delays in adopting common assessment methodologies. However, the European Directive 2002/49/EC, on a significant level, draws attention regarding the harmful effects of noise on health. It is estimated also that the Directive is efficient with a favorable cost-benefit ratio of 1:29**,** generating added value by providing a more complete and comprehensive transport infrastructure operation.

In Greece in particular, the ongoing economic crisis resulted a decline of GDP (gross domestic product) by some 25-30% in the period 2009-2015, with the unemployment to be increased by 132%, from 11.9% to 27.6% from 2011 towards 2013. Economic recession officially started in 2008 but the consequences in the everyday life start to be obvious by 2010, when a significant reduction in traffic volumes and total vehicle kilometre travelled was recorded. Also, different travel demand patterns are followed due to user's adjustment in crisis contest and a significant reduction in fuel sales occurred. Traffic volume and environmental noise have a strong relationship,

also, and many characteristics of traffic, such as speed and heavy vehicles have significant impacts on the noise level [9].

In order to achieve a sustainable development of the city, it is important to assess the possible degradation of the acoustic environment during the construction and operation of a major urban transportation work. Environmental noise emissions and their related effects are depending both on the worksite operation (during construction works) and the transportation network operation after project's completion. In particular, urban rail public transport modes such as metro and tramway are very important for the reduction of traffic congestion and therefore the impact on the acoustic environment of this important mean of transportation, may affect the environment with noise and vibration emissions when – not correctly treated – may induce severe annoyance to the inhabitants (see for example [10, 11]). Therefore, sustainability monitoring programs are needed in order to secure the determination and the implementation of the necessary environmental mitigation measures regarding both on technical interventions and operation measures levels. It is needed to identify priorities and assess the "best" environmental friendly mitigation actions, involving the general public in order to embrace the proper actions towards environment quality based on the findings of a comprehensive environmental monitoring program. The need for environmental acoustic monitoring programs is necessary in order to clarify the possible negative impacts on the environment and the physical and psychological annoyance to inhabitants. In the Athens Ring Road (e.g. Attiki Odos motorway), the relevant monitoring programs resulted the implementation of an important anti-noise mitigation measures program as part of the relevant Noise Action Plan (2010) introducing more than 100,000m^2 of transparent noise barriers made of PMMA (polymethylmethacrylate) in approximatively 40 different locations along the motorway ensuring both aesthetic integration to the surrounding landscape as well as bird protection minimizing the effect of "visual intrusion". Additional mitigation measures introducing partial covering of two sections of the motorway are also under design – according to monitoring program results – and are expected to further enhance the rehabilitation of the acoustic environment [12].

3. A typical road environmental transportation noise monitoring program

The permanent Environmental Road Traffic Noise & Atmospheric Pollution monitoring network of Attiki Odos is based on a state of the art, monitoring network of 8 fixed stations ensuring both real time environmental noise data collection (24 hours, 7 days per week). All stations are equipped with environmental noise analysers ensuring the continuous measurement of the main EU environmental road traffic noise indices L_{day} (from 07h00 to 19h00), $L_{evening}$ (from 19h00 to 23h00), L_{night} (from 23h00 to 07h00) and L_{den} (day-evening-night equivalent level) as per the relevant European Directive 2002/49/EC (Figure 2). Each monitoring station is also equipped with an air pollutants and meteorological monitoring systems. The continuous monitoring of the airborne road traffic noise includes also an extended 24-hour noise mobile monitoring program – fully meeting the requirements of the Directive – with noise statistical analysers at a height measurement application of 3.8-4.2 m from the ground) in more than 130 selected locations along the motorway. Recently, the Attiki Odos monitoring system was fully upgraded with new – state of the art – equipment designed by 01dB-ACOEM).

A new hardware regarding noise analyzers was introduced early 2017 (e.g. Noise Monitoring Terminal CUBE by 01dB), smaller, smarter, and fully certified by German metrology institute PTB (Physikalisch-Technische Bundesanstalt) and French metrology laboratory LNE (Laboratoire National de métrologie et d'Essai) PTB class 1 type approved. All 8 CUBE noise monitoring systems are installed in a special shelter equipped with, a full air conditioning system, electrical panel with surge protection, full internal wiring, lights and voltage stabilizer for the instruments. Each NMT is connected to the wide area fibber optic network of Attiki Odos ensuring daily

publication of major EU indicators L_{den}, L_{day}, $L_{evening}$ and L_{night}. The new IT network is presented in Figure 3.

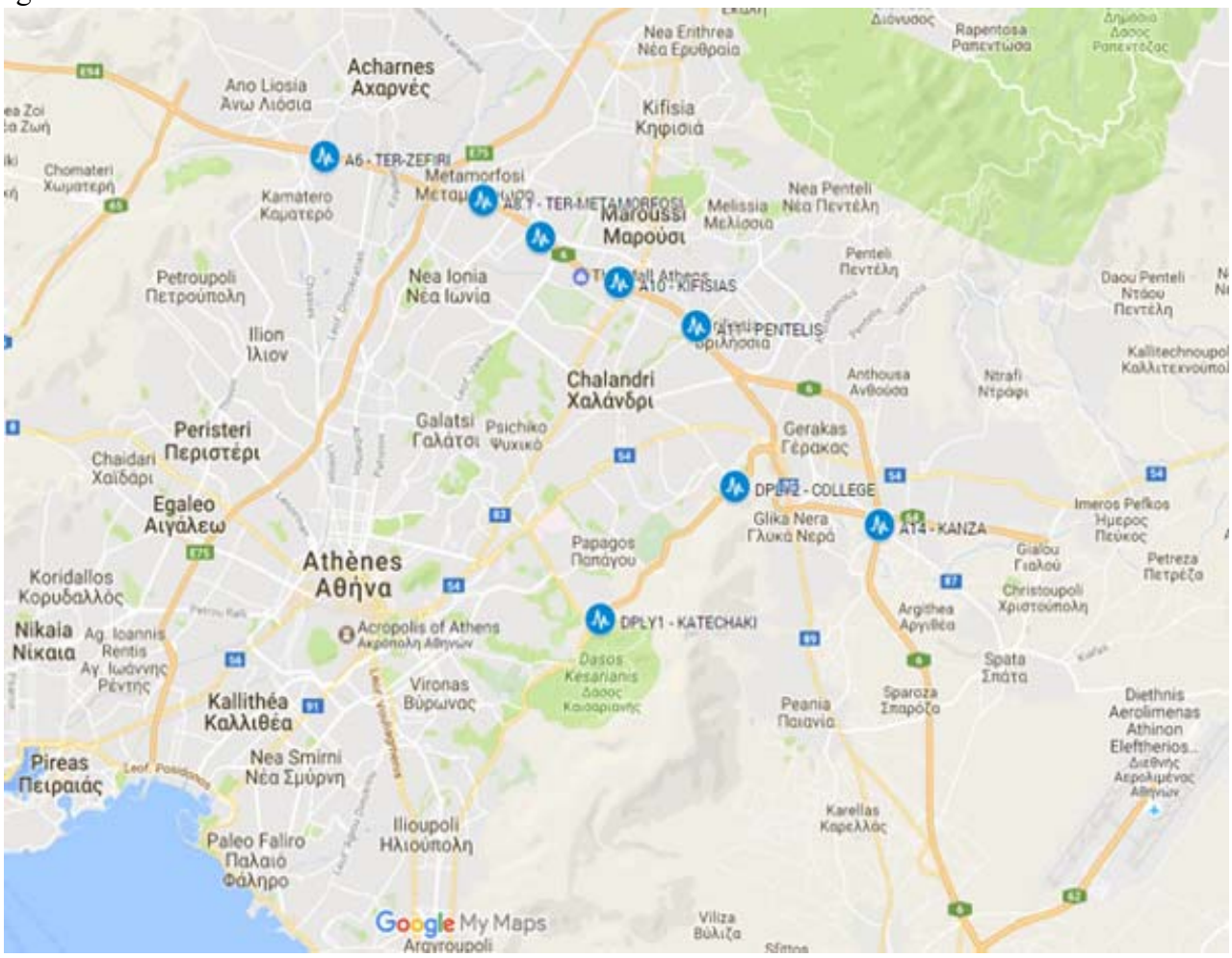

Figure 2. The Attiki Odos Noise Monitoring network.

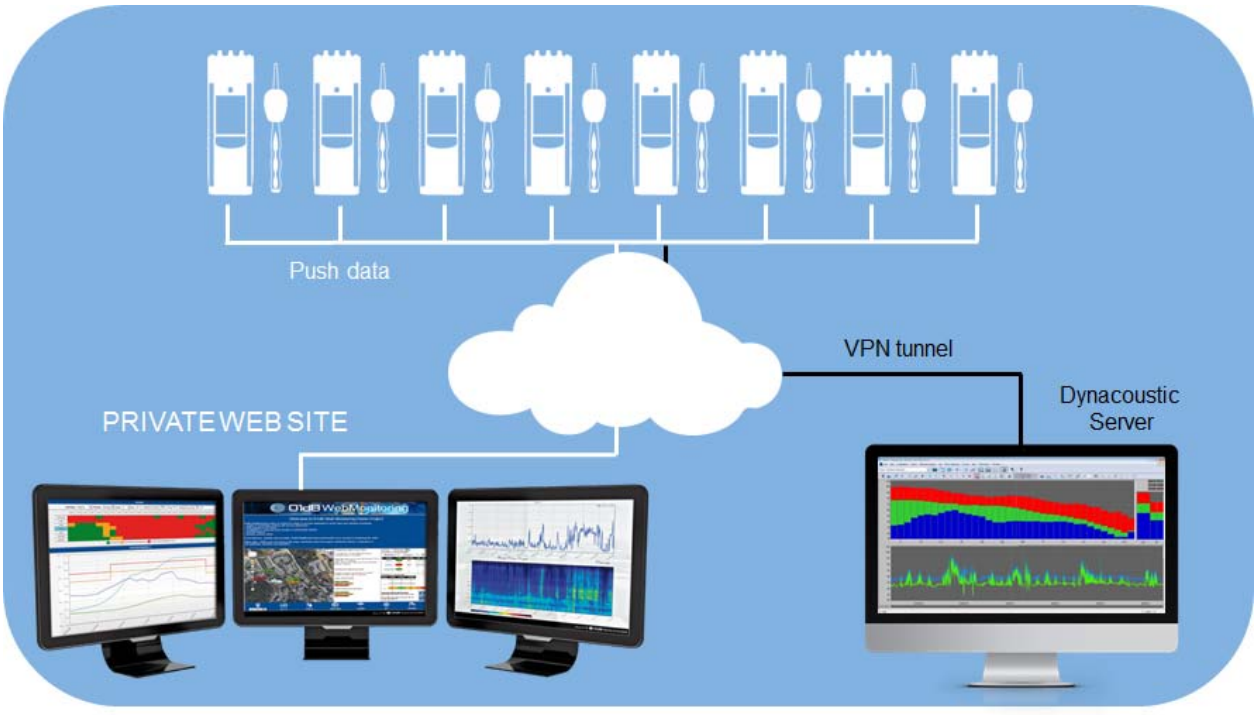

Figure 3. The new IT network of the Attiki Odos Environmental Road Noise Monitoring.

A private website (01dB Monitoring) is also foreseen in order to display data and calculations including time history and calculation per period of the major EU noise indicators (Figure 4).

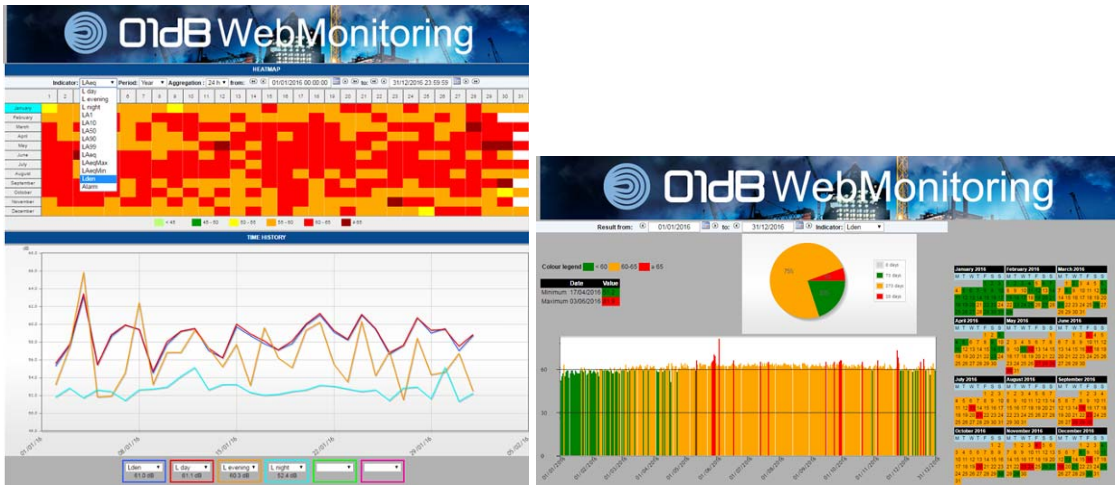

Figure 4. Noise Monitoring Website.

Regarding the mobile monitoring program, the Solo class 1 integrated sonometer is used, with VES21 – all weather protection case – in order to protect the measurement devices against external climatic conditions (like rain, temperature and humidity). A BAP21 system consisting of a stainless steel tube, a grid-supporting head, and a windscreen equipped with bird spike sis also used. The system contains a high capacity battery which will power the sound level meter during 168 hours at +20°C (the battery lifetime depends on the ambient temperature and the sound level meter set-up). The protection accessories are designed for outdoor measurements since preamplifiers and microphones are protected against any weather. The shape of the protection tube was designed also to provide BAP21 with acoustical properties compliant with the requirements of metrological precision classes (Figure 5).

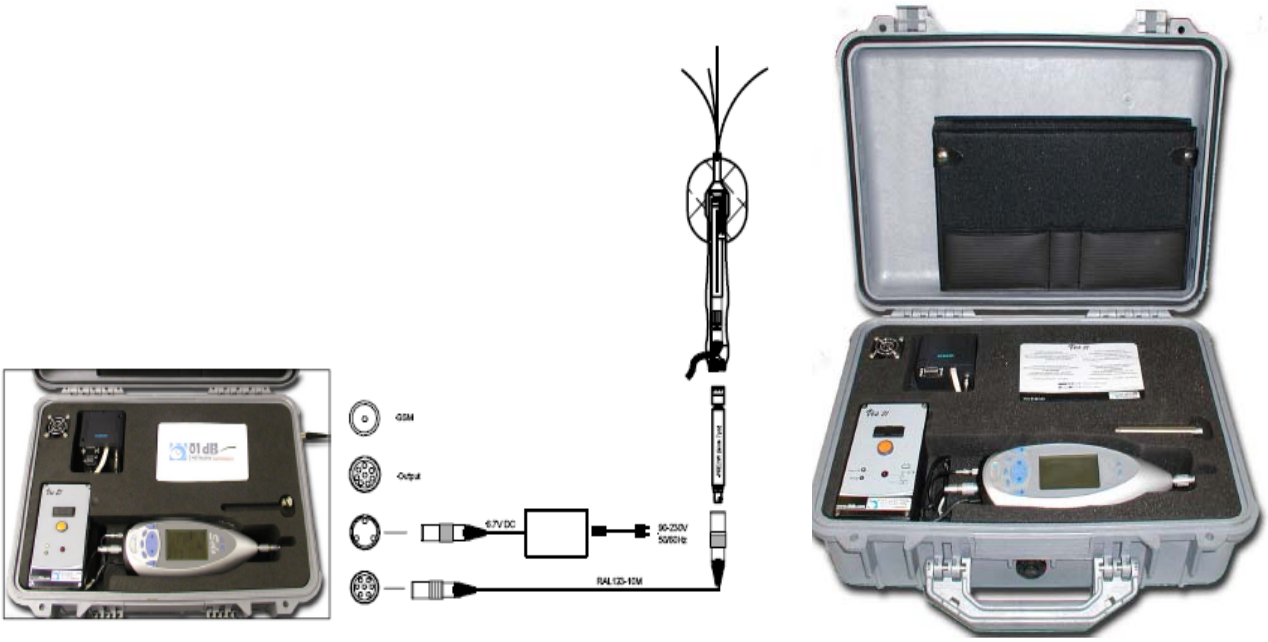

Figure 5. Solo Noise Level Meter & VES21-BAP 21 protective tools.

Based on the results of the monitoring program of the last 10 years, it seems clear that the environment noise protection is not only a matter of infrastructures, but the average user needs to contribute to the sustainability of the motorway network by driving in an environmentally friendly way. The "ecological driving" (i.e. "economical driving") project is running already in Attica Tollway in cooperation with the National Energy Center, and the Center for Renewable Energy Sources (CRES), promoting eco-driving with a view to protection of the environment. Eco-driving helps the reduction of environmental noise pollution, the minimization of accident rate and the enhancement of the road safety improvement, as well as travel time savings compared to the usual driving mode [12].

4. Discussion

The Environmental Noise Directive (END) requires from all Member States to determine the exposure to environmental noise. The main tool is the Strategic Noise Mapping and the relevant Noise Action Plans where a most needed comprehensive tool is the continuous noise monitoring. Urban transportation needs to be managed with the active participation of both national and regional stakeholders. Especially for transportation noise, considered as the principal environmental noise source, a common assessment methodology and a comprehensive monitoring program is the main basis to assess the environmental noise and the appropriate mitigation measures in order to avoid, prevent or reduce the harmful effects, due to exposure to environmental noise.

Environmental noise monitoring is the key factor to analyse and evaluate all aspects of noise (airborne and ground borne) and vibration due to both construction and operation phase of a road transportation project.

Regarding road networks, the noise emissions changes, both in level and frequency, as it propagates from the source (motorway) to a receiver (e.g. residential building), introduce decisive factors as distance, ground absorption, meteorological effects, and also natural or man-made shielding between the source and receiver. Depending on the alignment of a road and the site geometry, the first row of houses or buildings next to a road may offer shielding from noise to second and subsequent rows, therefore the outcome of a monitoring program is needed to evaluate the need of an appropriate reflective measures such as a noise barrier. The geometric design of the road alignment affects noise therefore the appropriate use of the shielding effects of embankments, cuttings, retaining walls and solid safety barriers is also to be considered by a monitoring program.

A continuous road noise monitoring program, may indicate the need for traffic calming measures in urban residential areas in proximity with major road networks. Reducing the total number of vehicles on a transport network as a travel demand management tool, by reducing the need to travel, and increasing the use of alternative modes such as public transport and/or encouraging multiple occupancy of vehicles, can be also implemented in urban areas, where the results of the monitoring program indicate relevant need.

Regarding rail noise in particular, specialized dose-response relationships are needed for new sources of noise such as high speed railways, or metropolitan underground and surficial tram and metro networks, in order to quantify the impact of additional factors such as, technical characteristics of the source, its operation mode with emphasis to speed, the implementation of quiet facades, the influence of nearby green areas, the number and distribution of high level noise events and spectral aspects (e.g. low frequency noise) [13].

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