DYNAMAP: a new approach to real-time noise mapping

Giovanni Zambon, Fabio Angelini, Roberto Benocci, Alessandro Bisceglie
Department of Earth and Environmental Sciences, University of Milano Bicocca, piazza della Scienza 1, 20126 Milano, Italy

Simone Radaelli, Paola Coppi
AMAT S.r.l., via Grazia Deledda 9/A, 20127 Milano, Italy

Patrizia Bellucci, Annalisa Giovannetti, Raffaella Grecco
ANAS S.p.A., via della Stazione di Cesano 331, 00123 Cesano di Roma (Roma), Italy

Summary
The usual approach to real-time noise mapping consists in implementing a localized noise monitoring network that continuously collects noise data and transmits them to a data center where a noise model software runs. The role of the noise model software is to re-scale some pre-computed partial noise maps according to the measured data and to sum the new re-scaled partial maps together, in order to obtain the whole area noise map to be published and continuously updated on a web site. At the moment the application of real-time noise map systems is limited to small areas because of the high cost of noise monitoring stations and long time needed to run and manage the system. A new approach to real-time noise mapping will be developed in DYNAMAP (DYNamic Acoustic MAPping), a co-founded project in the framework of LIFE 2013 program. The main features of this project are to define a statistically-based method to optimize the choice and the number of monitoring sites, and to automate the noise mapping process using the information retrieved from a low cost monitoring network. Preliminary results and a case study, referring to a small sample of roads of the city of Milan, will be presented.

PACS no. 43.50.+y

1. Introduction

The project aims at developing a dynamic noise mapping system able to detect and represent in real time the acoustic impact of road infrastructure. Scope of the project is the European Directive 2002/49/EC (END) relating to the assessment and management of environmental noise. In particular, the project refers to the need for noise maps to be updated every five years, as stated in the END.
The updating of noise maps using a standard approach is time consuming and costly and has a significant impact on the financial statements of the authorities responsible for providing noise maps, such as road administrations and local or central authorities.
To facilitate the updating of noise maps and reduce their economic impact, noise mapping can be automated by developing an integrated system for data acquisition and processing, able to detect and report in real time the acoustic impact of noise sources. The system will be composed of low-cost sensors measuring the sound pressure levels emitted by the noise sources and of a software tool based on a GIS platform for real-time noise maps updating. While this approach seems quite promising in areas where noise sources are well identified, such as those close to main roads, in complex scenarios, such as in agglomerations, further consideration is needed to make the idea feasible.
In this project, two demonstrative systems will be designed and implemented along a major road (the large ring road in Rome, Italy) and in the agglomeration of Milan (Italy) to check and test the feasibility of updating noise maps in real time.

2. Objectives

The main objectives of the projects are to:

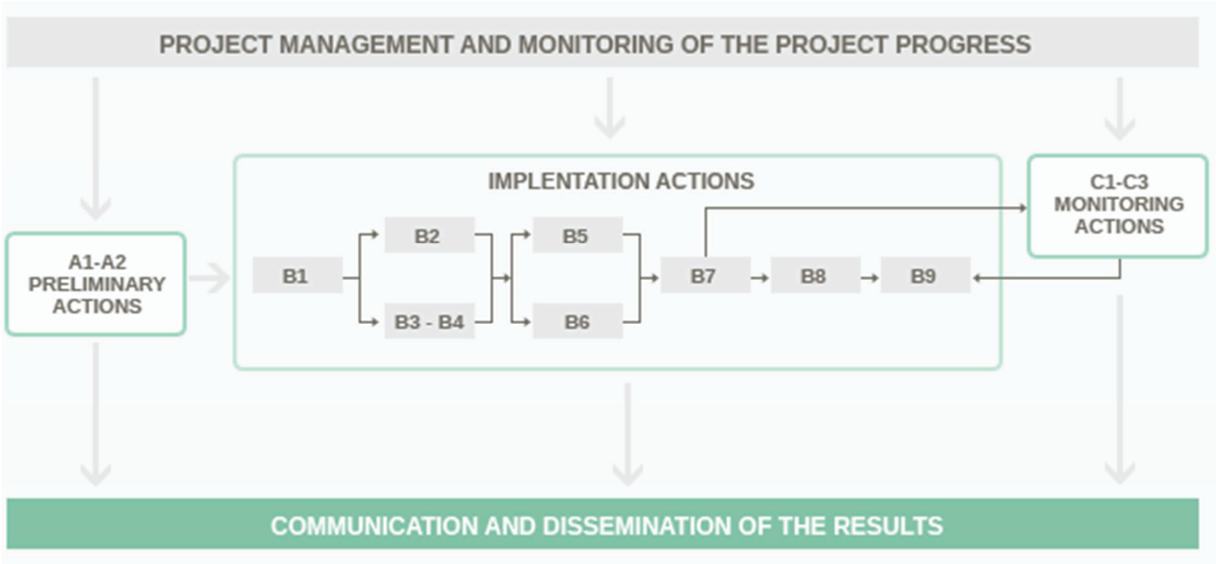

Figure 1. The main 14 actions of the project

- automate the noise mapping process using the information retrieved from a low-cost monitoring network;
- develop low-cost sensors and communication devices to collect the information needed to update noise maps in real time;
- implement and test the system in two sites with different characteristics: an agglomeration and a major road;
- demonstrate that the automation process will lead to a significant reduction in the resources needed to update noise maps (time, costs and dedicated personnel);
- improve and ease public information through different system access levels to provide user-friendly information;
- check the possibility of improving the system with additional information to report multiple environmental data dynamically (air quality, meteorological conditions, etc.).

3. Project structure

The project will be accomplished through four main steps:

1. Development of low-cost sensors and tools for managing, processing and reporting real-time noise maps on a GIS platform.
2. Design and implementation of two demonstrative systems in the cities of Milan and Rome. The first will cover a significant portion of the agglomeration of Milan, while the second will be located along a major road surrounding the city of Rome.
3. Systems monitoring for at least one year to check criticalities and analyse problems and faults that might occur over the test period. The test results will then be used to suggest system upgrades and extend implementation to other environmental parameters.
4. Provision of a guideline for the design and implementation of real-time noise mapping.

These four steps will be implemented through 14 main actions:

Two Preparatory Actions (A1-A2) regarding: collecting information on the state of the art of real-time noise mapping, analysing the road networks and locating the areas where the demonstrative systems will be implemented, acquiring information on the pilot areas.

Nine Implementation Actions (B1-B9) regarding: sizing the monitoring network, developing hardware and software, implementing and testing the system in the pilot areas, providing a guideline to real-time noise mapping.

Three Monitoring Actions (C1-C3) regarding: assessing public response and user ability in consulting and managing the system, evaluating costs and benefits, providing future visions on system applications.

Five more actions have been planned for dissemination and project management, including the arrangement of public events.

Actions will be accomplished by seven beneficiaries, among road administrations (ANAS, the Italian Road Administration), local authorities (Milan Municipality and AMAT), universities (University of Milan “Bicocca” and University of Barcelona “La Salle”) and private companies (ACCON and BLUE WAVE).

ANAS will lead the project, provide management skills and resources to implement the system on a major road, monitor public response and user ability in consulting and managing the system, in conjunction with AMAT and the Milan Municipality.
The MILAN MUNICIPALITY and AMAT will coordinate dissemination actions and provide resources to implement the system in the city of Milan.
The UNIVERSITIES OF MILAN and BARCELONA will mainly provide skills for sizing the monitoring network, developing processing algorithms, testing the system, and drawing up the guidelines.
BLUE WAVE and ACCON will provide skills in hardware and software development, and system installation and maintenance.

4. Preparatory action A2

Action A2 concern analysis of road networks and location the areas where the demonstrative systems will be implemented.
The feasibility of real time noise mapping will be demonstrate through a case study application in two different typology of sites.
The definition of a methodology for pilot area selection is a preliminary action of Dynamap project .
As regard urban context, the selection of the pilot area was carried out using a multi criteria procedure applied to nine territorial districts of Milan Municipality.
The procedure consists of a ranking system based on scores to be assigned to the districts of Milan Municipality. Partial scores are assigned to each area according to a series of descriptive attributes related to territory and mobility features, noise monitoring systems and air quality/weather stations availability, criticality of the area in terms of noise levels, presence of other noise sources, and the access to communication channels (Wi-Fi access points). All data were retrieved from public administrations and collected into a Geographic Information System (GIS), so as to support and automate the selection process.
The scores assigned to variables are then weighted using some coefficients. The total score of each zone is finally obtained by adding the resulting values for each variable.
The final output is a ranking list, achieved sorting the total scores associated to the district zones.
Milan district number nine resulted to be the highest score one and so it was selected as urban pilot area for the Dynamap project. District nine is located in the north part of Milan and it has a population of about 180.000 citizens; 40.000 citizens are exposed to Lden values higher than 70dB(A) according to END strategic noise map.
Figure 2 shows graphically the layers used to classify the nine districts and the location of district nine.

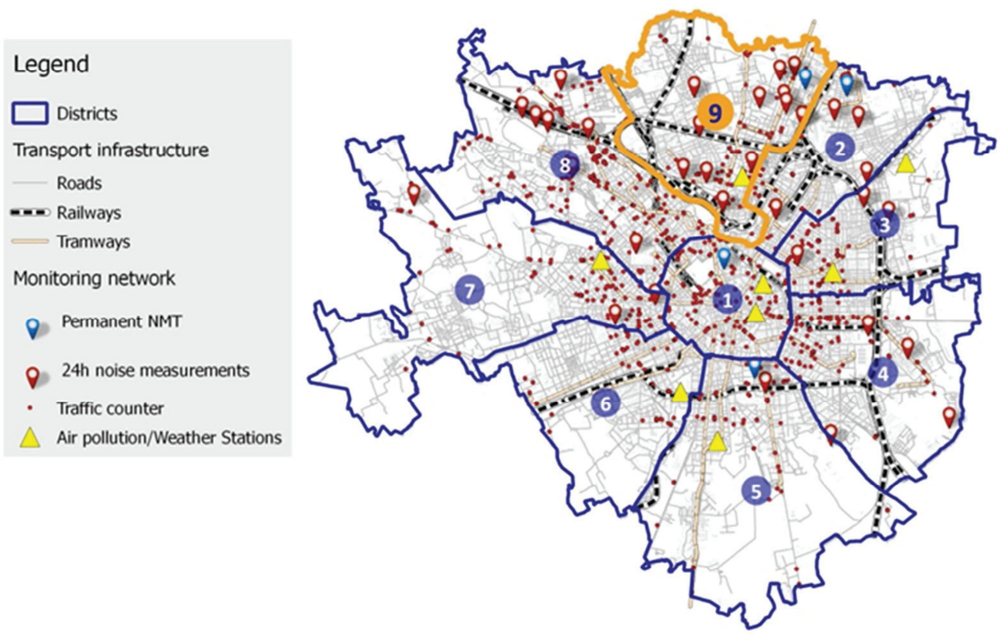

Figure 2. Layers used to characterize Milan Municipality districts

Suburban pilot area, along the ring road surrounding the city of Rome, will be composed of many test sites, chosen from four representative noise scenarios such as:

A. single road (A90 Motorway);
B. additional crossing or parallel roads;
C. railway lines running parallel or crossing A90 motorway;
D. a complex scenario including multiple connections.

To select the sites where the DYNAMAP sensors will be placed, a GIS tool was accomplished to collect and process information related to the 67 critical areas identified by ANAS Action Plan in the first and second round of the END.

The tool provides for the creation of four ranking lists of critical areas, corresponding to the four suburban scenarios A to D. The ranking lists were based on a priority index associated to each critical area, that takes into account the following main information:

- noise levels;
- population density;
- number of buildings (dwellings) and amount of people exposed to noise.

Other information were necessary, such as the presence of additional noise sources, the availability of further devices, communication networks and electric power connections. The tool was implemented in a GIS environment, through an algorithm based on the following five steps:

Step 1: preparation of the pilot area;
Step 2: filtering of critical areas missing connection to the power grid and communication channels;
Step 3: selection of critical areas with traffic counting devices;
Step 4: identification of critical areas with additional noise sources;
Step 5: sites classification.

The final number of sites will be defined on the basis of the amount of sensors necessary to calibrate and update the maps, taking into account that a maximum of 25 sensors was foreseen to be installed.

5. Implementation Action B1 (sizing the monitoring network)

The functional road classification does not usually reflect the actual use of roads which generally depends on the road activity, its use in the urban context, its width, the presence of reflecting surfaces, obstacles, type of paving, etc. However, for a better description of the real behavior of noise in complex scenarios such as the mobility network of the city of Milan, we approached the problem considering an agglomeration method based upon similarities among the 24-h continuous monitoring of the hourly equivalent LAeqh levels. Upon normalization [dB] (i = 1, ……, 24 h; j = 1, ……, 58), where 58 represents the total number of monitored sites, values provide a tool to group together roads following the same vehicular dynamics. For this reason, an unsupervised hierarchical clustering algorithm was applied to group together patterns found to be "similar" to one another [CC]. Figure 3 shows the results for the mean cluster profiles, , and the corresponding ± standard deviation, in the case of two (left), three (center) and four (right) clusters.

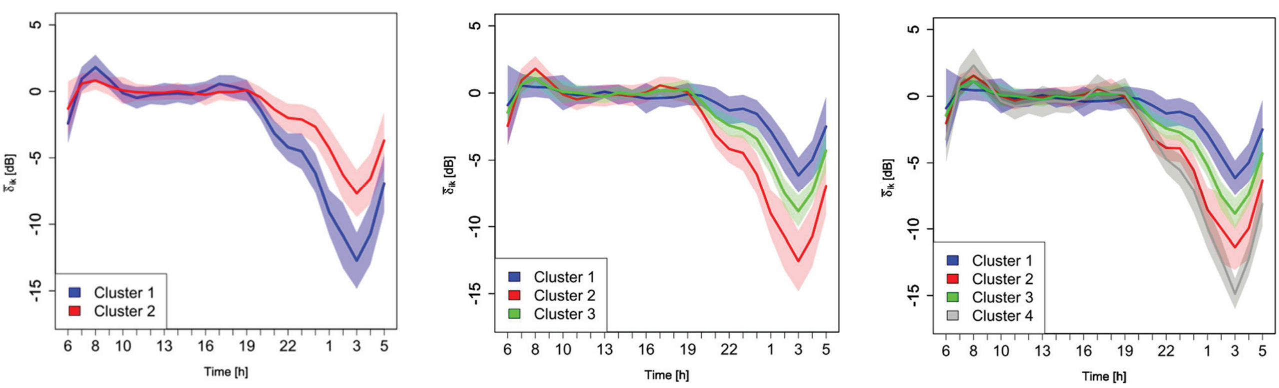

Figure 3. Mean cluster profiles, $\overline{\delta}_{ik}$, and the corresponding ± standard deviation, in the case of two (left), three (center) and four (right) clusters.

Increasing the number of clusters we can observe a better discrimination. This result is, however, not useful if compared with non–acoustical parameters describing the obtained groups. Considering as non-acoustical parameter the vehicle flow rate at rush hour, the histogram and probability density displayed in Figure 4 provide meaningful results in terms of cluster composition, just for the two-cluster results (left). The other two results (center and right of Figure 4) present an overlapping over a wide range of vehicle flow rate,
thus making any distinction among clusters extremely difficult.
Figure 5 presents the box plots of different non-acoustic parameters obtained for the two hierarchical mean cluster profiles. Here, we considered as non-acoustic parameters, besides the vehicle flow rate at rush hour, the night minimum vehicle flow rate, the equivalent vehicle flow rate at rush hour, the equivalent mean daily traffic (MDT), the ratio between road capacity and the mean daily traffic and, finally, the difference between vehicle flow rate at rush hour (Rh) and the vehicle flow rate between the time interval 15-16 h. The results show that only the first two box plots do not cross and, therefore, represent the best choice among the studied parameters. In particular, a vehicular flow rate at rush hour of 2000 vehicles/hour can be considered as threshold between the two profiles, that is roads featuring lower values (< 2000 vehicles/hour) can be associated with cluster 1, whereas for higher flow rates (> 2000 vehicles/hour) to cluster 2. For the night minimum vehicle flow rate parameter the threshold value between the clusters is around 40 vehicles per hour.

6. Conclusions

In this work the general outline of the Dynamap project and the first results were shown. In particular clusters that best represent all the roads of the Milan agglomeration and the non-acoustic parameter that best represents the roads belonging to each of the identified clusters (rush hour) have been identified. Pilot areas in which the project will be realized have been selected both for the Milan agglomeration and the Rome ring road.
The project is expected to provide seven main deliverables:

1) development of low cost sensors - The project includes the development of low-cost sensors to measure the noise levels generated by the sources included in the mapping areas
2) development of a software tool for dynamic noise mapping - Data retrieved from sensors will be sent to a data management system, through a dedicated software application for real-time data management and processing.
3) implementation of two demonstrative systems - The system will be installed and tested at two different sites: the first located within the agglomeration of Milan (Italy) and the second along a major road surrounding the city of Rome (Italy)
4) test results of the systems - The system will be tested for one year in order to assess its reliability, detect and solve problems, determine its accuracy and calculate the uncertainty associated with noise maps
5) system upgrade feasibility - The possibility of strengthening the system with applications for dynamic reporting of integrated environmental impacts (noise, air quality, meteorological conditions, etc.), will be analysed
6) test results on public response and user ability in consulting and managing the system - The software tool will be structured with different data access levels assigned to authorised users. The tool will be tested to check public response and user ability in consulting and managing the system
7) dissemination - The project will provide for an extensive dissemination campaign based on traditional and web communication channels, such as conferences, seminars, workshops, papers, a dedicated internet site, social networks, smart-device applications and fora.

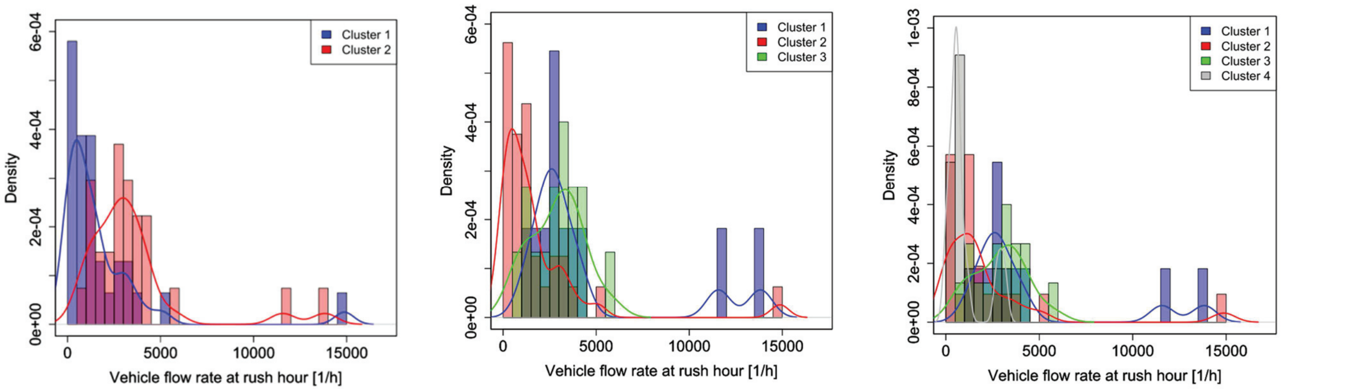

Figure 4. Histogram and probability density vs. vehicle flow rate at rush hour for the hierarchical two (left), three (center) and four (right) cluster results.

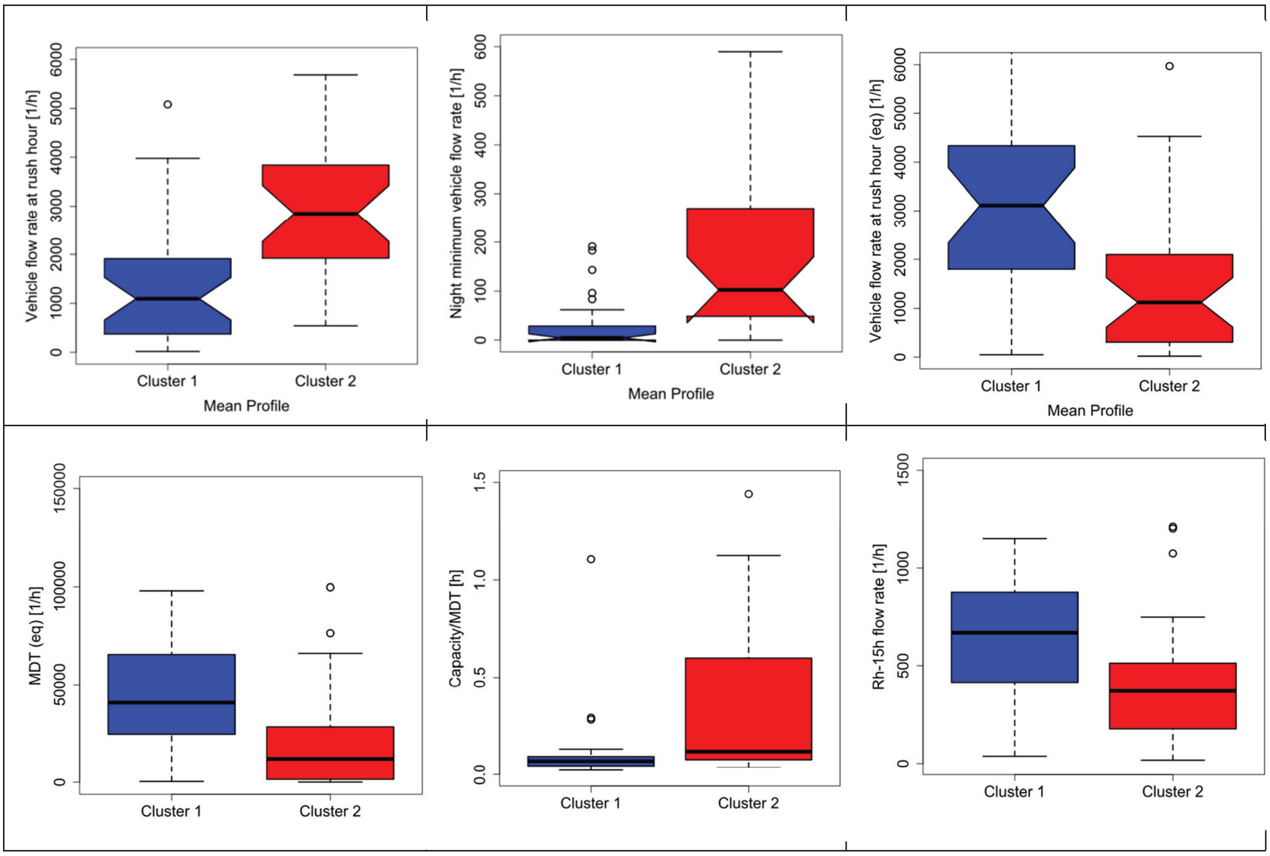

Figure 5. Box plots of different non-acoustic parameters for the two hierarchical mean cluster profiles.

Acknowledgement

This research has been partially funded by the European Commission under project LIFE13 ENV/IT/001254 DYNAMAP.

References

[1] J. H. Ward: Hierarchical Grouping to Optimize an Objective Function, Journal of the American Statistical Association 58, 236–244, 1963.

[2] J. M. Barrigon, V. Gomez, J. Mendez, R. Vilchez, J. Trujillo, *A categorization method applied to the study of urban road traffic noise*, J. Acoust. Soc. Am., **117**, 2844-2852, 2005.

[3] F. Angelini, A. Bisceglie, G. Brambilla, V. Gallo, G. Zambon, *Campionamento spaziale stratificato per il rumore da traffico stradale: un'applicazione alla rete viaria di Milano*, Atti AIA 2012, Roma, 2012.

[4] P. Bellucci, N. Corbo, D. Fernandez, A. Giovannetti, *"Applicazione di procedure GIS per lo screening della rete stradale ANAS"* – 12° onferenza Italiana Utenti ESRI, Roma 27-28 Maggio 2009.