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LIFE DYNAMAP: accuracy, reliability and sustainability of dynamic noise maps

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ABSTRACT

In 2014 the LIFE DYNAMAP project moved its first steps towards the development of a system able to detect and represent in real time the acoustic impact of road infrastructures. Aim of this project is to ease and speed up the update of noise maps that, according to the European Directive 2002/49/EC on environmental noise, shall be delivered every five years. To that end, an automatic monitoring system, based on customized low-cost sensors and a software tool implemented in a general-purpose GIS platform, was developed and built in two pilot areas located along the motorway A90 that surrounds the city of Rome (Italy) and inside the agglomeration of Milan (Italy). After more than four years working, focused on the design of the system, the development of hardware and software components, the construction and testing of the pilot systems, the project is now approaching the final step, where the accuracy, reliability and sustainability of the system will be assessed.

In this paper a general overview of the project and of the main results achieved are described.

Keywords: Noise, dynamic noise maps, real time monitoring
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

The DYNAMAP project (Dynamic Acoustic Mapping - Development of low cost sensors networks for real time noise mapping) is a LIFE project aimed to develop a dynamic noise mapping system able to detect and represent in real time the acoustic impact of road infrastructures. Scope of the project is the European Directive 2002/49/EC relating to the assessment and management of environmental noise (END) 1, 2, enforcing Member States to provide and update noise maps every five years in order to report about changes in environmental conditions (mainly traffic, mobility and urban development) that may have occurred over the reference period. However, the update of noise maps using a standard approach requires the collection and processing of many new data related to such changes. This procedure is time consuming and costly and has a significant impact on the financial statements of the authorities responsible for providing noise maps. Therefore, cheaper solutions are required in order to reduce the cost of noise mapping activities.

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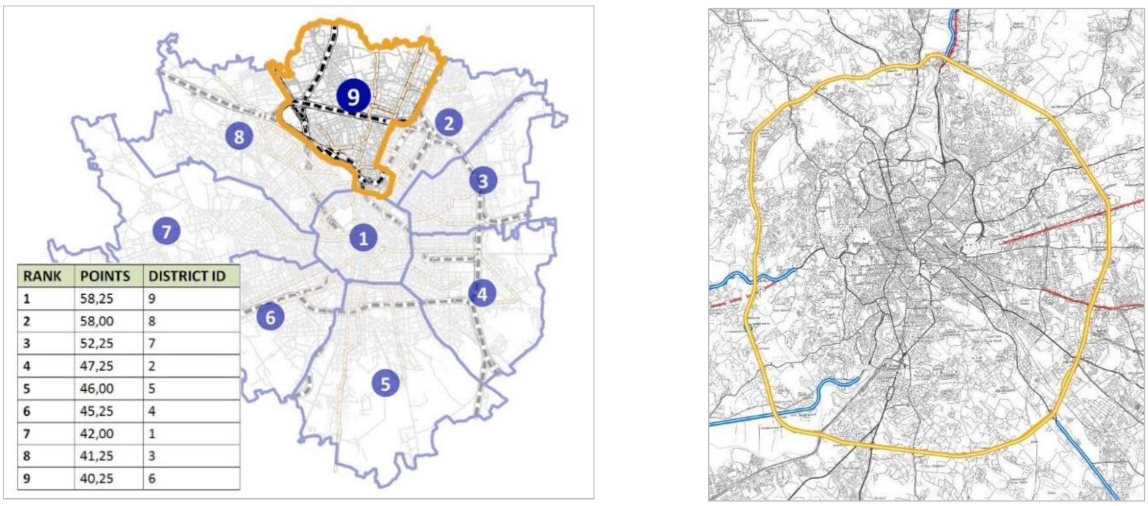
To meet such requirements and the growing demand of information about noise pollution, the Dynamap project foresees the development of an automatic noise mapping system delivering short-term (real-time dynamic noise maps), as well as long-term noise assessments (annual evaluations). Despite real time noise maps are not explicitly required by the END, their automatic generation is estimated to lower the cost of noise mapping with added significant benefits for noise managers and receivers, such as the possibility of providing updated information to the public through appropriate web tools or the opportunity to abate noise with alternative measures based on traffic control and management 3.
While this approach seems quite promising in suburban areas, where noise sources are well identified, in complex urban scenarios further considerations are needed to make the idea feasible, as it will be described in the following paragraphs.

2. THE DYNAMAP PROJECT

The Dynamap project is focused on the research and development of an automatic monitoring system, able to perform the update of noise maps in real time (dynamic noise maps) 4.
The update of noise maps is accomplished by scaling pre-calculated basic noise maps, prepared for different sources, traffic and weather conditions. Basic noise maps are selected and scaled using the information retrieved from low-cost sensors continuously measuring the sound pressure levels of the primary noise sources present in the mapping area. A complete basic noise map covering the entire survey area is calculated and saved for each source. Scaled basic noise maps of each primary source are then energetically summed-up to provide the overall noise map of the area. In this way, the need for several and expensive software license is extremely reduced and limited only to the preparation of the basic noise maps.
In order to decrease the cost of the entire mapping process, the DYNAMAP project has involved the development of customized low cost devices to collate and transmit data, and of a simple open source GIS based software application for maps scaling and sum. Such a standalone dynamic mapping software, together with low cost noise monitoring stations, makes the DYNAMAP system a very efficient and versatile noise mapping tool, virtually able to interface any existing or future noise modeling software, including the new European model CNOSSOS, which is expected to be operative for the 2022 round of END. The DYNAMAP system provides also for some unique characteristics that are not available in commercial products, like algorithms for eliminating spurious events (recognizing and masking unwanted events: i.e. occasional noise, etc.), traffic model data features, and future adaptability to other environmental parameters.



RANK	POINTS	DISTRICT ID
1	58,25	9
2	58,00	8
3	52,25	7
4	47,25	2
5	46,00	5
6	45,25	4
7	42,00	1
8	41,25	3
9	40,25	6

Figure 1. The pilot areas of Milan (left) and Rome (right).

The Dynamap system has been implemented in two pilot areas with different territorial and

environmental characteristics: an agglomeration and a major road. The first pilot area is located in the city of Milan, in the northern part of the town (district 9), where different type of roads and acoustical scenarios are present. The second pilot area is located along a major road, the motorway A90, that encircles the city of Rome.
In figure 1 a view of the two pilot areas of Milan and Rome is shown.

3. THE DYNAMAP SYSTEM

The Dynamap System is composed of a series of monitoring devices installed along the road network. Each device is able to detect the noise level, eliminate the presence of anomalous noise events through the ANED algorithm and transmit the related data to a central unit, where they are furtherly processed to update the basic noise maps (see figure 2). The update of the noise maps is achieved by scaling the basic noise maps as a function of the noise levels detected by the sensors and then summing up the scaled maps together.

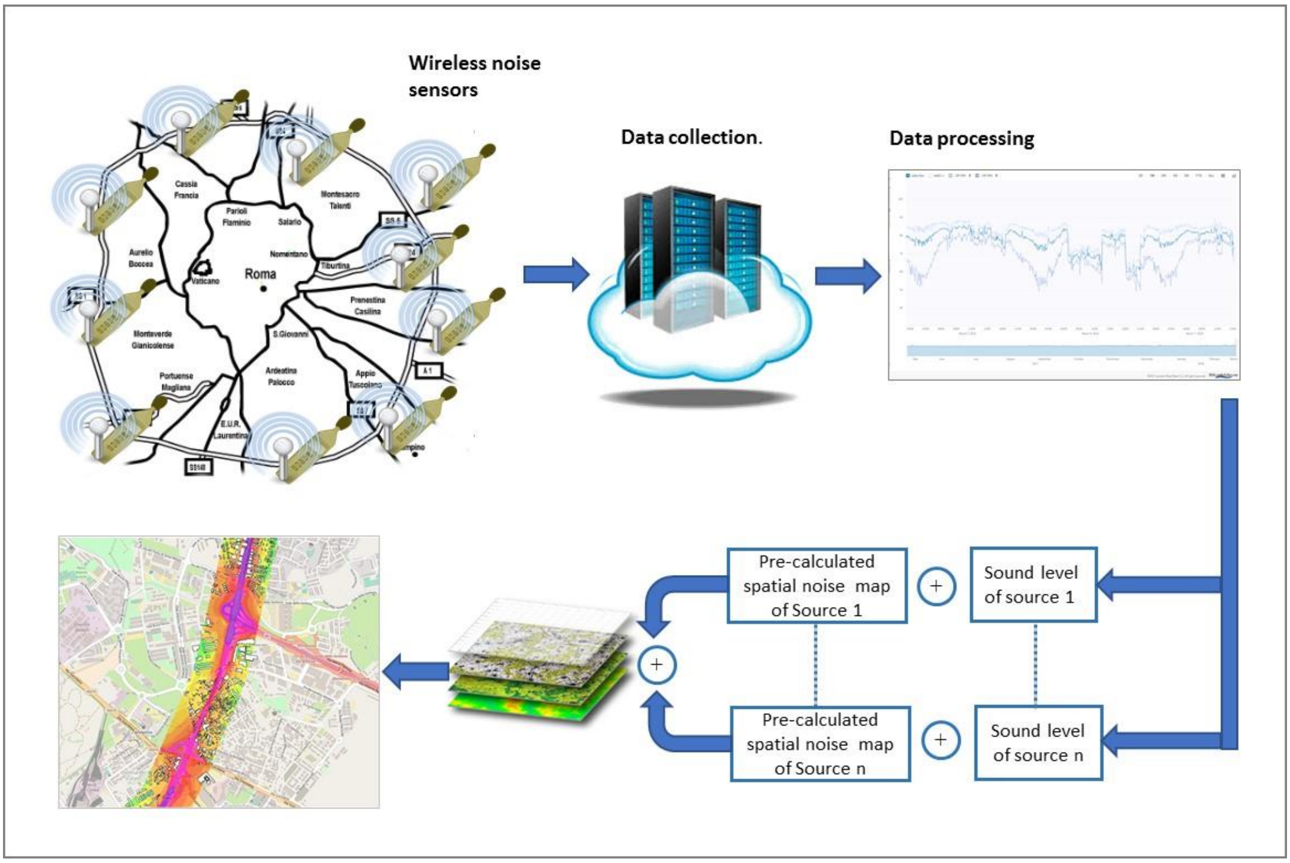


Figure 2. The Dynamap system.

To do so, a powerful open source platform is used to collect, process, view and store data.
The system has involved the design of customized hardware and software components, i.e. the low cost monitoring devices, the algorithm to detect and eliminate spurious noise events (ANED), the application to process and view data (NOISEMOTE) and the web-GIS software platform to update and report noise maps in real time.

3.1. The low cost monitoring devices

The project entailed the development of two sensor types:

- a high computation capacity sensor (HCCS), able to perform many operations, including a spectral analysis of the detected signals, to be used in complex environmental contexts;

- a low computation capacity sensor (LCCS), customized to perform a limited number of operations, to be used in simple suburban contexts, where detailed information on the noise spectrum is not necessary.

Both sensors have been designed to gather, clean up and send data to a central server, where they are analyzed, processed and used to scale the basic noise maps. The clean-up function is achieved by means of an algorithm especially developed for the project, named ANED (Anomalous Noise Events Detection). The algorithm is embedded in the monitoring device, in order to obtain a more scalable and less complex system 5.
The high computation capacity sensors are composed of low cost microphones and inexpensive embedded electronic boards, with high sound quality and 3G modems. The main advantage of this system configuration relies on the possibility of being remotely fully updated and reprogrammed. The main disadvantage of this solution stands in its high power consumption (>2-3 W), that entails a physical connection to the electric power grid, limiting its application as a stand-alone system.
A different solution was developed for the low computation capacity sensors, in order to reduce costs and make them operating also off-line with solar panels and batteries.
The data gathered by the monitoring devices are processed and published on the web through the NoiseMote application.
In figure 3 pictures of the high computation capacity sensors built for the pilot area of Rome and Milan are shown.

Figure 3. The high computation capacity sensors built for the pilot area of Rome and Milan.

3.2. The ANED algorithm

Automating the update of noise maps through the DYNAMAP system entails several consequences. One of them deals with the content of the detected noise level, that can include, in addition to the main noise source, i.e. the road traffic, the contribution of other noise sources present in the mapping area. Consequently, the resulting maps would not constitute a faithful reflection of the acoustic impact of road infrastructures 5.
For this reason, it is necessary to endow the DYNAMAP system with the ability to discern between road traffic noise and other types of acoustic events (e.g. trains, aircrafts, industries, works on the road, etc.), to exclude the latter from the noise level computation. To that end, an anomalous noise event detection (ANED) algorithm was developed. This algorithm operates on the audio stream captured by the acoustic sensors and identifies the presence of acoustic events

unrelated to road traffic, activating an alert signal to exclude the corresponding audio passages from the computation of noise levels.
The design of the ANED algorithm follows a “detection-by-classification” approach, consisting in the binary classification of sequential audio segments as either “road traffic noise” or “anomalous noise event” 5, 6.
The algorithm is able to discern three main signal categories: road traffic noise, background city noise, and anomalous events. This latter class includes 18 subtypes of events, such as people talking, music in car or in the street, or noise caused by tramways or trains, etc.
The ANED algorithm was trained, validated and tested using a data set containing samples of both road traffic and anomalous noise events achieved from an environmental noise recording campaign carried out in the two pilot areas of Rome and Milan 6.

3.3. The NOISEMOTE application

The data gathered by the monitoring devices are managed and published by a software application specifically developed for the project, named Noisemote. Noisemote is able to show real time, historical and statistical data in a timeframe defined by the user.
Real time data are updated with a time frequency of 1 s within a time interval varying from 5 to 30 minutes. On the same layer information on the device position, installation details and some pictures are shown.
The page related to historical data shows three curves: the short Leq (in the middle) and two users defined percentile levels. Data are available with or without anomalous noise events (ANEs) in different time intervals: days, weeks, months or in a time window defined by the user.
The page with statistical data reports three graphs related to the average hourly trend in a week, the monthly and the annual average values. The user can define the timeframe and the indicator to be shown among Italian and European indicators (see figure 4).
Data can be also locally saved by clicking the download button.

3.4. The web-GIS software application

The role of the GIS software application is to re-scale pre-computed partial noise maps, i.e. the basic noise maps, related to each noise source as a function of the noise levels detected by the monitoring devices, sum them together in order to achieve the updated noise map of the whole area and finally publish the results on a web site. Indeed, the system performs several tasks simultaneously: data collection and storage, maps scaling and sum, public information on the web. This implied the design of a complex data-base structure and of a bi-directional communication system between the monitoring devices and the data collection unit.
As noise maps should comply with END and national specifications, the software provides also, in addition to dynamic noise maps, a series of statistical information, such as day, evening and night data, L_{den} data, people and dwellings exposed to noise level intervals, etc. The application also reports information on the actions planned to mitigate noise levels.
As for public information and communication, two levels for accessing the system are available:

- *a high privilege access level,* reserved to authorized stakeholders, that allows to reach detailed information, such as time histories and statistics.
- *a low privilege access level*, fully open, to inform about noise levels impacting the mapped areas and ease the participation of the public in the preparation of action plans.

Since L_{Aeq} and L_{den} values, representing the average noise level over a given period on a logarithmic scale, are too complex indicators to be easily understood by the general public and authorities responsible to take ownership of noise related issues 7, a different indicator was adopted to simplify noise maps presentation. To that end, the new disturbance index, developed in the framework of the LIFE HARMONICA project, the so called Harmonica index, was applied in order to investigate its suitability to real time noise maps.

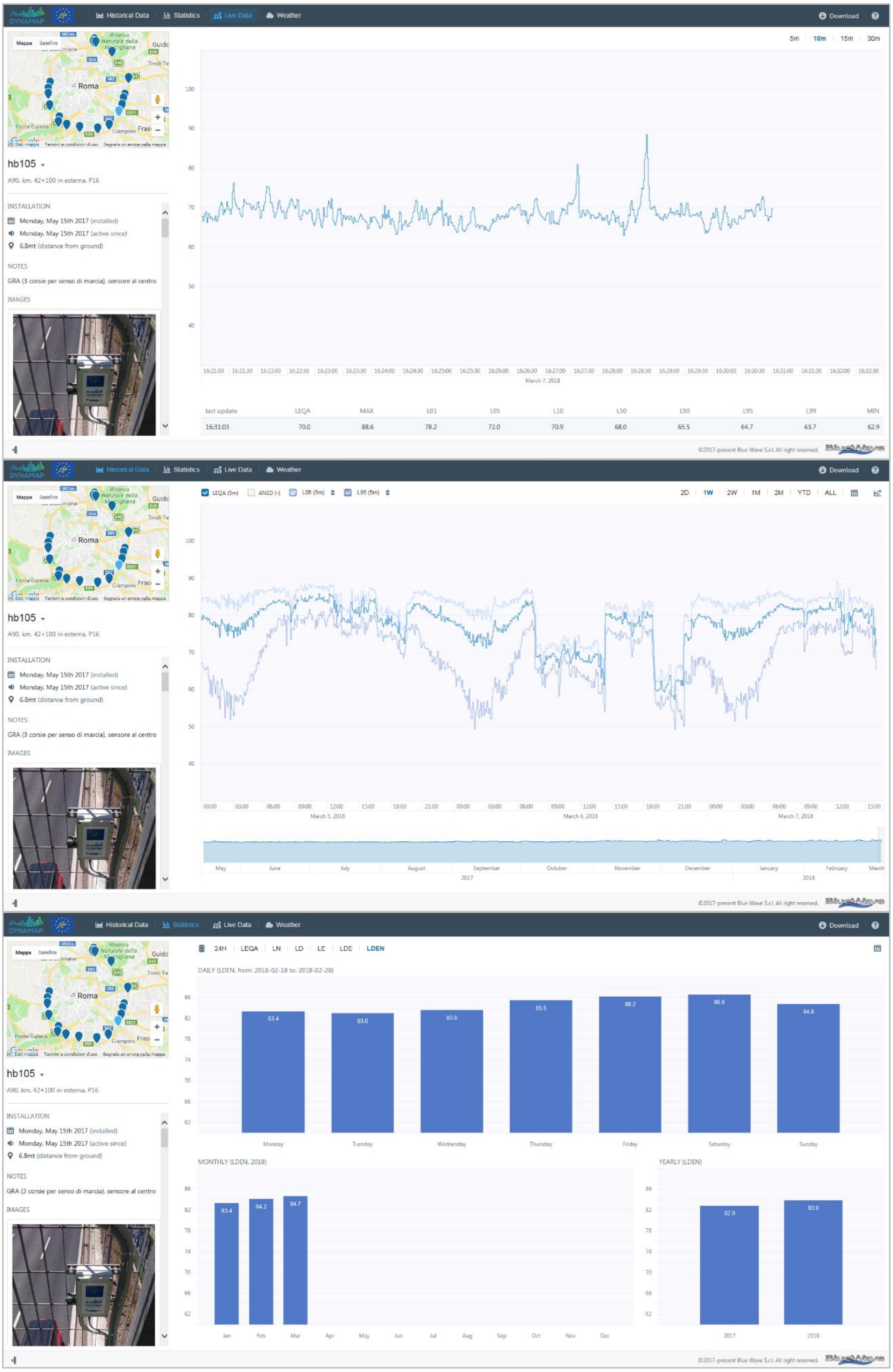


Figure 4.Screenshots of the NOISEMOTE application showing live, historical and statistical data.

4. THE PILOT AREA OF MILAN

The pilot area of Milan is located in the northern part of the town in a highly urbanized zone of the town. Given the large number of roads present in that area and, generally speaking, inside the city of Milan, a statistical approach was applied to size the monitoring network. Thus, roads having similar traffic flow conditions and, consequently, similar noise trends were grouped together after an extensive measurement campaign that involved the acquisition of noise levels from 93 monitoring stations distributed all over the city 8[11].

At the end of the design phase six groups of roads with similar traffic features and noise trends were found. For each group of roads four monitoring devices were installed, leading to a total of 24 monitoring stations. The noise signal detected by these monitoring devices is used to update the noise map. In figure 5 the six groups of roads are depicted with different colors.

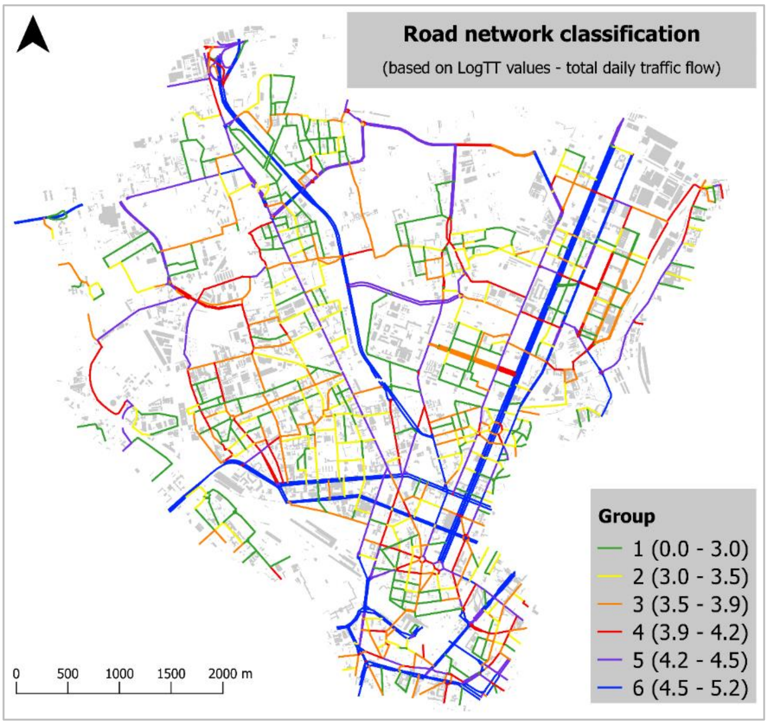


Figure 5. The six group of roads with similar traffic features and noise trends identified in the pilot area of Milan.

In the pilot area of Milan dynamic noise maps are updated with a time frequency that depends on the time of the day: 5 minutes from 7 a.m. to 9 pm; 15 minutes from 9 p.m. to 1 a.m. and 60 minutes at night, from 1 a.m. to 7 a.m. In this way it is possible to achieve more or less the same error in the estimate of the noise level.

5. THE PILOT AREA OF ROME

The pilot area of Rome is located along the motorway A90 that surrounds the city. In this case the road network was broken down into 19 elementary noise sources 9, corresponding to as many road stretches with invariant traffic trends. Therefore nineteen high computation capacity sensors (HCCS) were installed along the motorway to monitor noise levels (see figure 6).

Four low computation capacity sensors (LCCS) were also placed in parallel with the HCCS to check their ability in the detection and removal of anomalous noise events. The noise levels detected by these monitoring devices are used to update the most appropriate basic noise maps among those prepared for the area as a function of traffic and weather conditions. Since the selection of the basic noise maps depends on the time of the day (traffic distribution) and meteorological conditions, 4 weather stations were also installed to complete the system configuration. The weather stations were placed in positions corresponding to the main four wind sectors (north, south, east and west). In the pilot area of Rome noise maps are updated with a time frequency of 30 seconds from 6:00 a.m. to 10:00 p.m. At night, when traffic flow is lighter and less continuous, noise maps are updated every 5 minutes.

Figure 6. View of a HCCS installed on top of a portal.

In figure 7 and 8 portions of dynamic noise maps related to the pilot areas of Milan and Rome are shown.

6. ACCURACY AND RELIABILITY OF THE DYNAMAP SYSTEM

The Dynamap system has been tested for one year to check its accuracy and reliability. The tests included the comparison of noise levels detected by the low cost sensors with the noise levels achieved by class 1 sound level meters (SLM). During these tests the related audio signals were also recorded in order to check the ability of the ANED algorithm to discern anomalous noise events.

Test results have shown a systematic discrepancy between the low cost monitoring devices and class 1 sound level meters of about 1 dB. Such a discrepancy was not detected during laboratory tests and additional investigations are underway to identify the variables affecting the onsite microphone/device operation.

As for the ability of the devices to discern anomalous noise events, it was possible to check that the ANED algorithm can correctly detect road traffic noise with a percentage of 89%, deleting most critical ANE's, with low false alarm probability.

The experimental phase included also the comparison between the noise levels estimated by the dynamic noise maps and those detected by class 1 SLM at specific receiving points and in different weather conditions. For the pilot area of Rome this entailed also to check the accuracy

Figure 7. A portion of a dynamic noise map related to the pilot area of Milan.

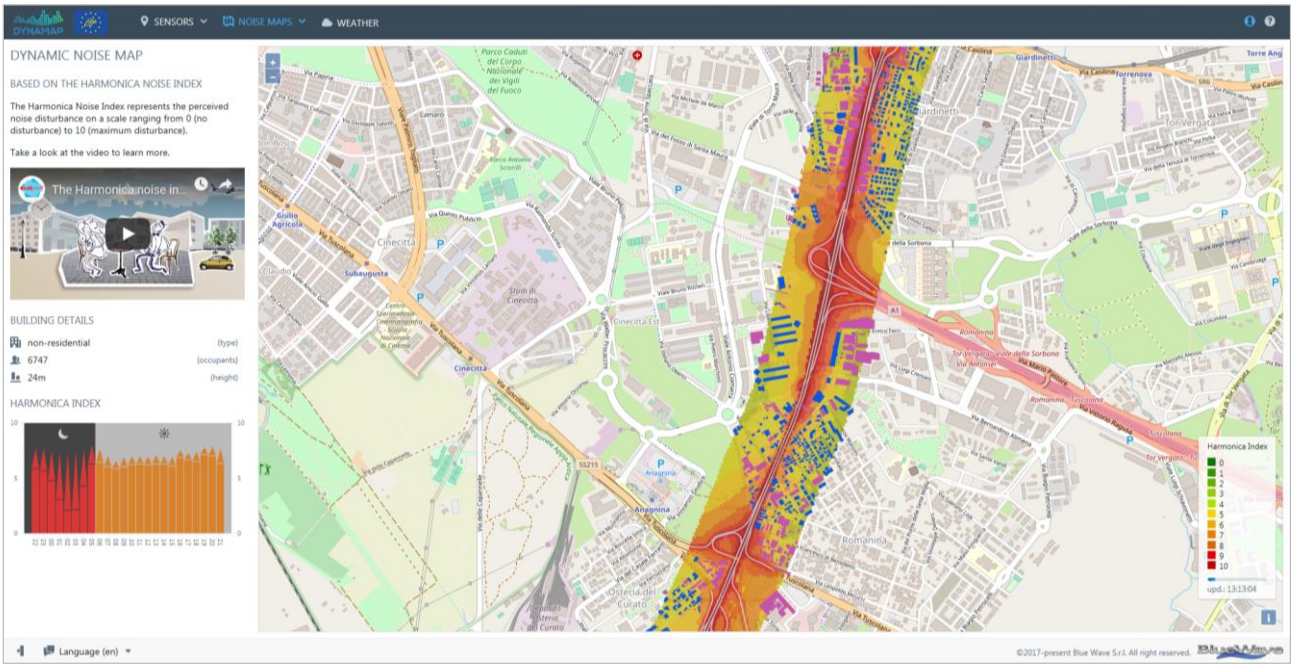


Figure 8. A portion of a dynamic noise map along the motorway A90 in Rome.

of the model developed for the selection of the basic noise maps as a function of traffic and meteorological conditions.

In this case test results have shown that the difference between estimated and measured noise levels ranges from 1 to 2.5 dB, with an average error of about 1.5 dB.

To further improve the system performance, a more detailed and accurate reconstruction of the propagation environment should be carried out. In addition, an analysis of microclimate changes at receivers points should be undertaken to evaluate the different sound propagation conditions in specific contexts.

In the pilot area of Milan, where a statistical approach was used, the validation procedure involved the comparison of estimated and measured values of 13 test sites belonging to different road groups. The experimental campaign included also some optimization activities to fine-tune the coefficients adopted to update the noise maps. In this case, test results have shown that the difference between estimated and measured noise levels the error ranges from to 2 to 4 dB at most for the cluster including minor roads. Errors are mainly due to poor information on traffic data and further investigation are under way to improve the accuracy of the system [15].
Finally, the type and number of faults events were monitored in order to estimate the system reliability. Results show a good reliability of the low cost monitoring devices with only one failure out of 54 devices installed and 3 damaged microphones.
Furthermore, an average 96% of operating time has been observed with interruptions due only to faults from the power supply grid. Standalone versions of the devices with solar panels and batteries have been also developed, in order to improve the reliability of the system and to allow the system application in areas lacking power grid connections.

7. CHECKING THE SUSTAINABILITY OF THE DYNAMAP SYSTEM

In the final part of the project an accurate analysis of costs and benefits of the Dynamap system has been accomplished. The analysis referred to a static scenario based on the implementation of traditional noise maps. The assessment was first carried out in the two pilot areas and then extended to general urban and suburban contexts.
The cost analysis let inspiration from the procedure developed in the project HEATCO 10, in which a series of steps were defined in order to ensure that all monetary inputs into the appraisal process were expressed in consistent form with each other. These include the expression of monetary data in a common unit of account (to avoid the contribution of taxes and subsidies) and in a common base year for prices and values.
The cost analysis was performed over a time horizon of 20 years, corresponding to four END cycles. The cost items related to the preparation of noise maps with both the traditional and Dynamap approach are shown in table 1.

Table 1: Cost items included in the cost analysis referred to both the traditional and Dynamp approach.

Cost item	Traditional	Dynamap
3D digital terrain and building model	■	■
Road graph, land cover data and population census	■	■
Traffic data	■	□
Noise and meteorological data (monitoring) to calibrate the model	■	
Clustering analysis		□
Monitoring system (implementation, calibration and maintenance)		■
Data transmission and storage		■
Noise map preparation (model setting, calibration and calculations)	■	
Basic noise maps preparation		■
Data preparation according to END requirements	■	

□ *Applicable only in urban scenarios.*

In this table personnel costs are not included, as they mainly depends on companys wages, and only external costs have been considered. As it can be seen basic input data are the same in both the traditional and Dynamap approach. The differences mainly deal with peculiar information and applications, such as traffic data, noise and meteorological monitoring for model calibration, noise and meteorological monitoring for real time noise map update, noise maps preparation (traditional noise maps or basic noise maps), clustering analysis (only for urban scenarios). In the Dynamap system the time and work effort needed to deliver output data according to END requirements is not

included, as they are automatically prepared in the right format by the Dynamap software platform.
The results of this analysis show that the Dynamap system performs a cost reduction by approximately 32% in suburban scenarios. Costs abatements are mainly due to the elimination of periodical service contracts to monitor the road network and prepare the noise maps.
The results related to urban scenarios are not still available, but a lower cost reduction is expected, due to the statistical procedures needed (cluster analysis) to group the different road types.
The reduction of costs in noise mapping activities is not the only benefit expected from the implementation of the Dynamap system. Many other advantages can be ascribed to the system, such as the automation of noise mapping activities, the immediate and compliant provision of output data, the continuous noise monitoring and model calibration, that allows to achieve more accurate and reliable results, the possibility of undertaking noise mitigation measures in real time based on traffic control and management, the capability of filtering, through the ANED algorithm, the noise contribution of other interfering noise sources. The system also includes user friendly interface to present noise mapping results to the public and easy communication tools to foster public participation in the preparation of action plans.

8. CONCLUSIONS

The Dynamap project is a five years long project, aimed at developing a dynamic noise mapping system, able to detect and represent in real time the acoustic impact of road infrastructures. To do so, the project has involved the development of low cost sensors and tools for the management, processing and reporting of real time noise maps and the design and implementation of two demonstrative systems in the cities of Milan and Rome.
After more than three years working, focused on the design of the system and the development of hardware and software components, many interesting results have been achieved in the effort to simplify the system and reduce its cost as much as possible. These include, among the others, the preparation of statistical models to size the monitoring network in urban and suburban environments, the identification and definition of the method to update the noise maps in real time, the design of low cost monitoring sensors, the implementation of algorithms to remove anomalous events from the noise level, the development of software applications to scale and sum the basic noise maps, provide statistical information and ease the participation of the public in the preparation of the action plans.
The Dynamap system has been tested for one year to check its reliability, effectiveness and efficiency. Test results have shown that in suburban areas the average error between estimated and measured noise levels is about 1.5 dB. In urban areas, when a statistical approach was used, the error ranges from to 2 to 4 dB at most for the cluster including minor roads. Further efforts are in progress to improve the accuracy of the noise maps also in urban areas.
An in depth analysis was also performed to check the cost and efficiency of the system. This analysis shows that in suburban areas Dynamap allows to achieve a cost reduction of 32% with respect to the cost of traditional noise mapping activities and that several benefits can be ascribed to the system in terms of possible future applications. The results of the cost/benefit analysis in urban areas are not available yet, but less favorable outcomes are expected, due to the major complexity of the noise environment.

Acknowledgement
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