INTER-NOISE 2018
Impact of Noise Control Engineering
26-29 AUGUST
CHICAGO, ILLINOIS

Preliminary results of Dynamap noise mapping operations

Roberto Benocci[a)]
Fabio Angelini[b)]
Marco Cambiaghi[c)]
Alessandro Bisceglie[d)]
Hector Eduardo Roman[e)]
Giovanni Zambon[f)]
Dipartimento di Scienze dell'Ambiente e della Terra (DISAT), Università di Milano-Bicocca
Piazza della Scienza 1
20126 Milano, Italy

Rosa Ma Alsina-Pagès[g)]
Joan Claudi Socoró[h)]
Francesc Alías[i)]
Ferran Orga[l)]
GTM - Grup de Recerca en Tecnologies Mèdia, La Salle - Universitat Ramon Llull
C/Quatre Camins, 30
08022 Barcelona, Spain

ABSTRACT

DYNAMAP, a European Life project, aims at developing a dynamical acoustic map of large urban areas such as the city of Milan based on a limited number of noise monitoring stations. Generally, traffic noise, recorded as time series by field monitoring stations, is affected by the presence of Anomalous Noise Events (ANEs), which are extraneous to the regular vehicle noise. A dedicated algorithm integrated in the DYNAMAP sensors helps the identification and removal of ANEs from the time series in real time. Traffic noise data from the distributed monitoring stations, each one representative of a group of roads sharing similar characteristics (e.g. traffic flow), are used to build-up a dynamic noise map. An evaluation of the reliability of this procedure is performed by comparing the map prediction and in-field measurements. Preliminary results of this activity are presented.

[a)] email: roberto.benocci@unimib.it
[b)] email: fabio.angelini@unimib.it
[c)] email: m.cambiaghi8@campus.unimib.it
[d)] email: alessandro.bisceglie@unimib.it
[e)] email: eduardo.roman@mib.infn.it
[f)] email: giovanni.zambon@unimib.it
[g)] email: ralsina@salleurl.edu
[h)] email: jclaudi @salleurl.edu
[i)] email: falias @salleurl.edu
[l)] email: forga @salleurl.edu

1 INTRODUCTION

Dynamap is a European Life project, which aims at developing a dynamical acoustic map in a large urban area such as the city of Milan and the motorway surrounding Rome. Many project have been addressed to study and represent real-time noise maps [1-7], mostly prompted by the European Directive 2002/49/EC addressed to the assessment and management of environmental noise (END) [8].

Dynamap new concept for the city of Milan is based on the idea that a limited number of real-time noise measurements can be used to build up a noise map representative of a large urban area.

The method has been applied to Zone 9 of the city of Milan consisting of about 2000 road arches, using 24 continuous measuring stations [9]. The underlying idea that the traffic noise source of a street generally depends on its use in the urban context, suggested a stratified sampling approach aimed at optimizing the number of monitoring sites [10-11]. Two general behaviors (clusters) have been observed by statistically analyzing the hourly noise level profiles [12]. Such scheme has also been confirmed by studying the vehicle flow pattern [13]. In order do attribute to each road stretch a noise behavior, as that found by analyzing the sampled traffic noise, each cluster was also cross-checked with an available non-acoustic information [14]. According to the chosen non-acoustic parameter, each road stretch presents a noise temporal profile that could be describes as a combination of the two main mean cluster noise profiles. To simplify the procedure, we separated the whole set of (about 2000) stretches into six groups, each one represented by typical traffic noise behavior and gave a prescription for the locations of the 24 monitoring stations [15]. Generally, traffic noise, recorded as time series by field monitoring stations, is affected by the presence of anomalous noise events (ANEs), which are extraneous to the actual vehicle noise. A dedicated algorithm integrated in Dynamap sensors helps the identification and removal of ANEs from the time series prior their use in the map formation [16-17]. An evaluation of the reliability of the dynamic noise map procedure is performed by comparing the map prediction and in-field measurements. Very preliminary results of this activity are presented.

2 GENERAL SCHEME OF DYNAMAP PROJECT

In order to predict traffic noise for a given road stretch, when a direct measurement is not practicable, we need to define a non-acoustic parameter, which we denote generically as x and is related the traffic model developed by the Milan municipal agency for mobility, environment and territory (Agenzia Mobilità Ambiente e Territorio, AMAT). The model provides mean hourly traffic flow for each road stretch n in the entire city. The hourly behavior of the traffic noise for a given road stretch n, characterized by a value x_n, can be described in terms of the distribution functions of the variable x, $P(x)$, obtained from the roads belonging to Clusters 1 and 2 (as obtained in previous papers [12-13]). The corresponding distribution functions, denoted as $P_1(x)$ and $P_2(x)$, are shown in Figure 1, for the choice of x given by the logarithm of the total daily traffic flow rate $x = \mathrm{Log}(T_T)$.

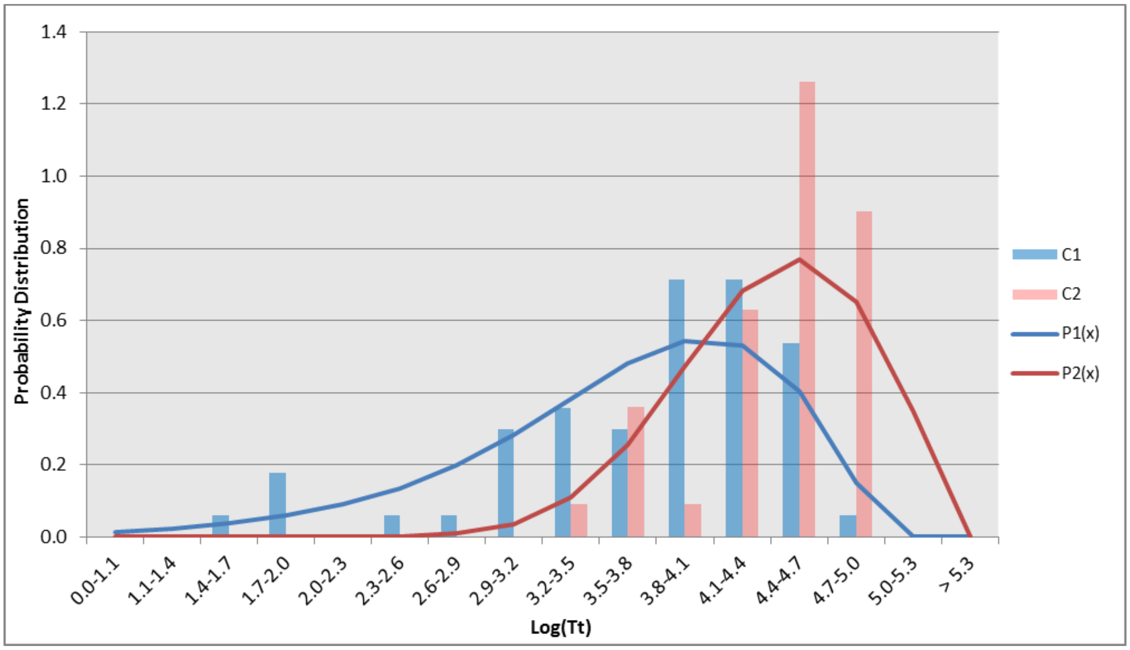

Fig. 1 – Distribution functions $P_1(x)$ and $P_2(x)$ for $x = \log(T_T)$ on Clusters 1 and 2, respectively. The continuous lines represent logarithmic fits to the actual histograms using the cumulative distribution functions and are used here to accurately determine $\beta_{1,2}$ using Equation (1).

As one can see from figure 1, there is an overlap between the two distributions. This might suggest that for a given value of *x*, the temporal evolution of the noise for a given road stretch can be thought as a combination of Cluster 1 and Cluster 2 profiles. The idea of the method is to evaluate the probability β_1 that *x* belongs to Cluster 1 and the probability $\beta_2 = 1 - \beta_1$ that it belongs to Cluster 2. The corresponding values of β are given by the following relations:

$$\beta_1(x) = \frac{P_1(x)}{P_1(x) + P_2(x)} \qquad (1)$$

$$\beta_2(x) = \frac{P_2(x)}{P_1(x) + P_2(x)}.$$

Using the values of $\beta_{1,2}$, we can predict the hourly variations $\delta_x(h)$ for a given value of *x* according to:

$$\delta_x(h) = \beta_1(x)\, \delta_{C1}(h) + \beta_2(x)\, \delta_{C2}(h) \qquad (2)$$

with $\delta_{C1}(h)$ and $\delta_{C2}(h)$ representing the mean hourly values of the equivalent level for both Clusters 1 and 2, respectively [15-17].

The implementation of Dynamap makes use of 24 monitoring stations. In this case, the station locations have been distributed to match the empirical distribution of the chosen non-acoustic parameter in Z9 ($\log(T_T)$ total daily traffic flow) [15]. For this reason, we have divided the entire range of the non-acoustic parameter values into (arbitrarily) 6 groups, so that each one contains approximately the same number of road stretches, thus representing a uniform distribution of locations. This decision was prompted by practical reasons about the number of acoustic maps that will be handled in the actual implementation of Dynamap. The corresponding groups of roads for Z9 are displayed in Figure 2.

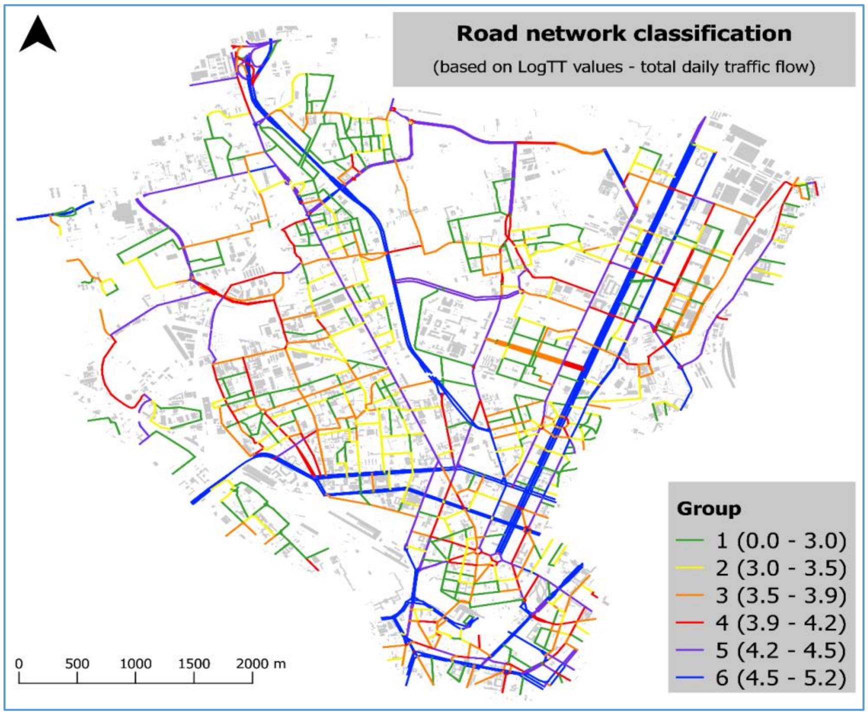

Fig. 2 - The six groups of road stretches (different colors) for the actual implementation of Dynamap in Zone 9. In the inset, we report the intervals of x values (corresponding to the non-acoustic parameter $log(T_T)$) within each group.

Once we have determined the 6 groups of *x* values (Table 1), the acoustic map of each group will be obtained by using the mean probability values within each group. They read

$$\bar{\beta}_1(\bar{x}_g) = \frac{P_1(\bar{x}_g)}{P_1(\bar{x}_g) + P_2(\bar{x}_g)}$$
$$\bar{\beta}_2(\bar{x}_g) = \frac{P_2(\bar{x}_g)}{P_1(\bar{x}_g) + P_2(\bar{x}_g)} \quad (3)$$

where $\bar{x}_g$ is the mean value of x within group g. The values of $\bar{\beta}_{1,2}$ for each group are reported in Table 1 (cf. Figure 2).

Table 1 - Mean values of $\bar{\beta}_1$ and $\bar{\beta}_2$ for the six groups of $x = log(T_T)$ within Zone 9.

Range of *x*	**0.0–3.0**	**3.0–3.5**	**3.5–3.9**	**3.9–4.2**	**4.2–4.5**	**4.5–5.2**
$\bar{\beta}_1$	0.99	0.81	0.63	0.50	0.41	0.16
$\bar{\beta}_2$	0.01	0.19	0.37	0.50	0.59	0.84

3 ADAPTATION OF THE ANOMALOUS EVENTS RECOGNITION ALGORITHM

The Anomalous Noise Event Detector (ANED) has been conceived as a two-class classifier that labels input audio signals between two acoustic categories, that is, Road Traffic Noise (RTN) and Anomalous Noise Events (ANEs), which are any sound event extraneous to the actual regular vehicle noise (e.g. sirens, horns, birdsongs, etc.) [18]. The classification system has two main stages: the first is audio parameterization, which represents each audio frame of 30 ms by a cepstral-based coefficient vector, and the second is a binary classifier that follows a two-level decision scheme to output a binary RTN/ANE decision every second. The original implementation of the ANED [18] to run in-real time on a low-cost acoustic sensor is currently being redesigned to take into account the new context of real-life network operation after the deployment of the wireless acoustic sensor network (WASN) in the two pilot areas of Milan and Rome. Some previous studies were carried out using audio samples gathered in other locations where the sensors were to be finally placed [18, 19], e.g. next to the street and not where the sensors are actually deployed (façade). The audio database that was used for this preliminary ANED validation (here named as *preliminary* audio database) contained samples from two types of environments (urban and suburban). In the urban scenario of the city of Milan, a labelled database composed up to 4 hour and 24 minutes of RTN and ANE was generated: ANE represented about 12.2% the total recorded time [20]. However, the Milan recordings were supposed to model mostly daytime noise patterns, which were obtained during two working days. Here, the most relevant ANEs were attributed to music, people talking and sounds of tramways and trains [16].

The first tests were conducted with the ANED trained using the dataset obtained in the recording campaign [20]; nevertheless, nighttime data and the different location of the sensors led to low accuracy results in the algorithm performance. In the aim of adapting the ANED to the characteristics of the final WASN, audio data obtained from 24 low-cost acoustic sensors from the network has been considered. These sensors allow high computational capacity to detect the ANE within the RTN in real time. It is important to highlight that the recording conditions have been changed with regard the preliminary recording campaign, not only by the fact that more recording locations have been added, but also due to the different placement of the sensors, moved from streets to the façades.

Data from two days were recorded (one working day and one weekend day) at a regular basis of 20 minutes per hour, 24 hours a day, for each one of the 24 sensors of the WASN deployed in the district 9 of Milan. The sensors saved both raw audio data and the corresponding ANED decisions, being previously trained with the preliminary acoustic dataset from the recording campaign. The purpose of this experiment was studying to what extent the preliminary ANED version was able to generalize to the new context across all the 24 sensors deployed in Milan. From the analysis of the results, it was concluded that the preliminary ANED obtained poor classification performance, showing an especially critical behavior during night periods, when a large number of false alarms of ANE were produced. From that analysis, we observed that the RTN during night periods was different from the noise profiles obtained during the daily recordings of the initial database. Moreover, the changes in performance of the detection of errors found during daytime can be attributed to the differences in the recording conditions (e.g. substantial changes in sensors location). However, we leave for future work the detailed analysis of this issue.

After obtaining these results, the initial dataset was discarded for the trainings of the ANED running in the deployed WASN. Labelling was conducted over the recordings in the WASN. The 50% of the available audio files were labelled by subjective listening by five trained listeners; for more details, see [21]. The process consisted on labelling the ANE boundaries and discarding the time regions where it was difficult to make a reliable decision (regions marked as complex

regions). In addition, log-based spectrograms and preliminary ANED output decisions were used as references to accelerate the labelling process. This process allowed us to observe more types of ANE than in the preliminary audio database: house and car alarms; church bells; beep of a van when move backwards; sound of blinds; some new sounds related to people like steps, breathing, coughing and trolley wheels; repair works on the street and some related sounds (drills, hammers and saws), sounds of glass, sounds produced when garbage trucks collects its cargo.
The audio analysis performed within the WASN produced as output a total of 116 hours and 22 minutes of labelled audio. Of this 11.3% are ANEs and 87.7% RTN; the ratio of the initial dataset has been maintained. Future work will be focused on exploiting these new data to retrain and validate the ANED to improve its operation within the acoustic sensor network.

4 DESCRIPTION OF DYNAMAP OPERATIONS

The 24 stations (indexes i = 1–24) have been chosen so that there are 4 stations (index j = 1–4) in each one of the 6 groups, indexed (g_1, …, g_6), the pilot Zone 9 of Milan has been divided into. An acoustic map has been associated with each group g, so that all road stretches within a group are represented by the same acoustic map. Operatively, each station i records a noise signal at a 30 ms resolution, which will be integrated, after filtering the anomalous events, in a 1 s equivalent noise level [16-17]. The signal then needs further integration to obtain $L_{eq\tau,i}$ over a predefined temporal interval τ (τ = 5, 15, 60 min). Thus, we get 24 $L_{eq\tau,i}$ values every τ min, each one corresponding to a recording station i. To update the acoustic maps, we deal with variations $\delta^{\tau}_{g,j}(t)$, where the time t is discretized as $t = n\tau$ and n is an integer, defined according to:

$$\delta^{\tau}_{g,j}(t) = L_{eq\tau,M(g,j)}(t)_{(measured)} - L_{eqref,M(g,j)}(T_{ref})_{(measured)} \tag{4}$$

where $L_{eqref,\,M(g,j)\,(measured)}$ is a reference value representing the daily updated L_{eq} at the time interval T_{ref} = (08:00–09:00) at the point corresponding to the position of the $M(g, j)$-th station. Here, we have chosen the reference time T_{ref} = (08:00–09:00) for convenience, since it displays rush-hour type of behavior. The temporal ranges within the day have been conventionally chosen as:

τ = 5 min for (07:00–21:00);
τ = 15 min for (21:00–01:00);
τ = 60 min for (01:00–07:00).

Once all the $\delta^{\tau}_{g,j}(t)$ values have been obtained, the 6 acoustic maps can be updated corresponding to each group g by averaging the variations in Equation (4) over the four values j in each group, according to:

$$\delta^{\tau}_{g}(t) = \frac{1}{4}\Sigma^{4}_{j=1}\delta^{\tau}_{g,j}(t). \tag{5}$$

In this way, the acoustic maps can be updated.

5 DYNAMIC NOISE MAP CONSTRUCTION AND ITS VALIDATION

Let us discuss next the way in which the absolute level $Leq_{\tau}^{a}(t)$ at time t for an arbitrary location point a can be obtained from the measured values of $\delta_{g}^{\tau}(t)$ using Equation (5). The first quantity we need to know is the value of $L_{eqref(g,a)}$ at the point a due to the noise produced by roads in the group g, which is provided by the calculated (CADNA) acoustic base map. CADNA model provides mean hourly L_{eq} values over the entire city of Milan at a resolution of 10 m, given a set of input traffic flow data. $L_{eqref(g,a)}$ thus represents a reference static acoustic map at T_{ref} = (08:00–09:00). The absolute level $Leq_{\tau}^{a}(t)$ at location a at time $t = n\tau$ can then be obtained by properly adding the contribution of each base map with its variation δ_{g}^{τ}:

$$\mathrm{Leq}_{\tau}^{a}(\mathrm{t}) = 10 \cdot \mathrm{Log} \sum_{g=1}^{6} 10^{\frac{\mathrm{Leqref(g,a)} + \delta_{g}^{\tau}(\mathrm{t})}{10}}. \quad (6)$$

This operation provides what we call the “scaled map” (dynamic map).

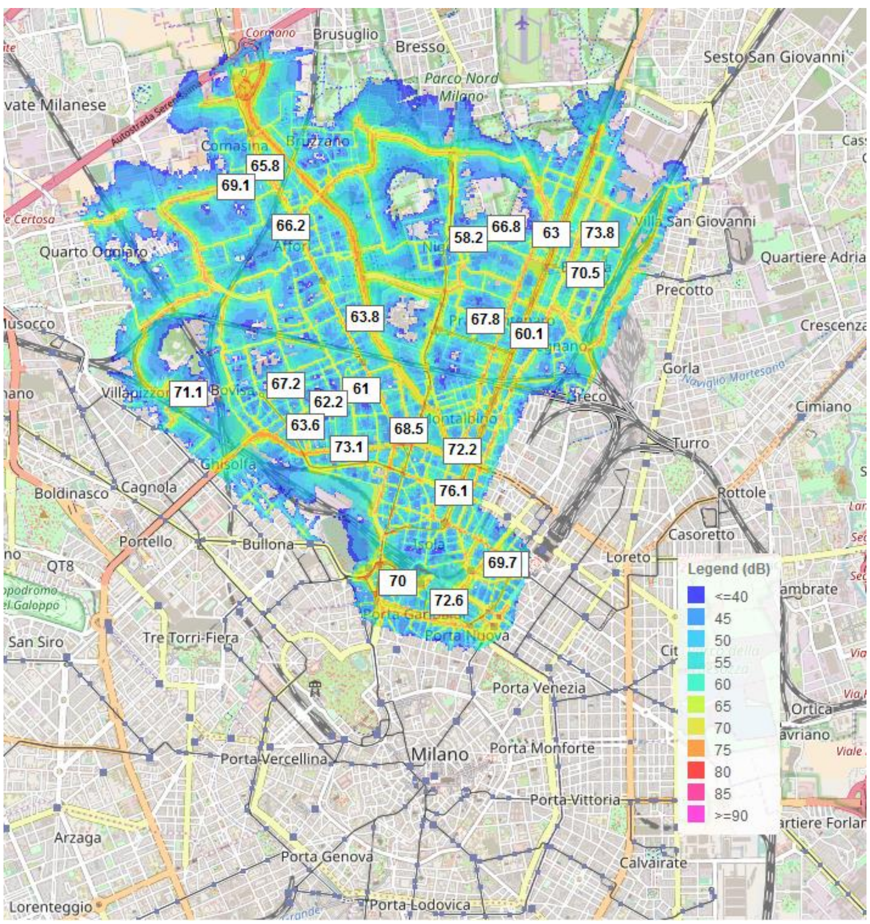

Fig. 3 – Snapshot of the dynamic noise map active on Zone 9. In the insets, the actual noise monitoring station levels are displayed.

A preliminary validation of the described procedure has been done by comparing the measurements in one site and the prediction of the dynamic map.

Both data have been previously cleaned up from eventual anomalous events, as described in section 3. The present available data refer to the sites showed in table 2. Both measurements have 24-h duration. The site, Via Ciaia, belongs to group g_3 whereas Via Majorana to group g_5. Table 2 contains the local reference noise values (Leq ref.) to be applied in eq. (6). These are the results of energetically adding the local reference noise values corresponding to each group (map).

Table 2 – Reference values for the test site Via Ciaia and Via Majorana.

Site a	Leq ref. (dB)	X / Group	Leq ref. (1,a) (dB)	Leq ref. (2,a) (dB)	Leq ref. (3,a) (dB)	Leq ref. (4,a) (dB)	Leq ref. (5,a) (dB)	Leq ref. (6,a) (dB)	Mean deviation (dB)
Via Ciaia	63.6	3.5814 / 3	41.0	56.1	62.7	20.8	31.7	28.7	2.3±2.7
Via Majorana	68.5	4.3003 / 5	29.7	26.0	32.2	29.1	68.5	33.4	1.7±1.1

The last column of table 2 contains the mean deviation (± standard deviation) between the predicted and measured noise profile.
In figures 4 and 5, we report the comparison between the map prediction as derived from eq. (6) and the test-site measurement for Via Ciaia and Via Majorana. The mean deviation is of about 2.3 ± 2.7dB and 1.7±1.1 dB, respectively.

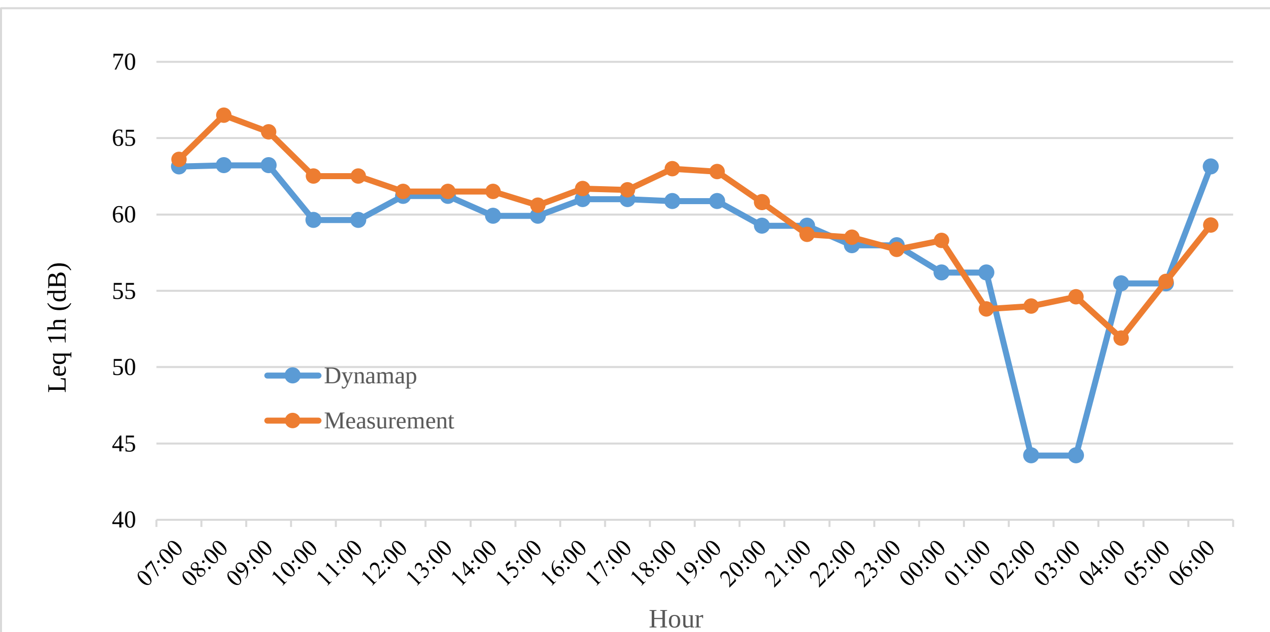

Fig. 4 – Comparison between the map prediction and the test-site measurement, Via Ciaia.

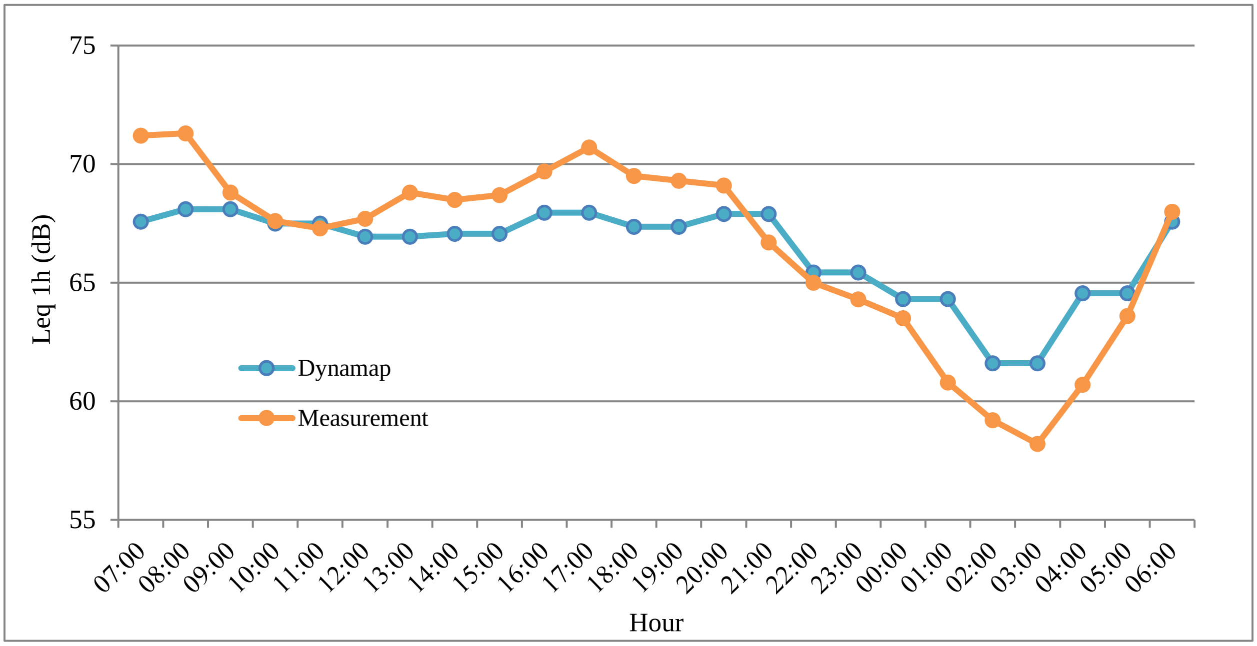

Fig. 5 – Comparison between the map prediction and the test-site measurement, Via Majorana.

Particularly critical is the choice of the reference value, which derives from a calculation procedure. Further investigation is needed to reduce the discrepancy between prediction and measurements.

6 CONCLUSIONS

In this paper, the general scheme of Dynamap project is presented with particular emphasis to the pilot area of Milan city. The initial noise sample measurements has been arranged into two clusters of roads sharing the same noise dynamics. A non-acoustic parameter has been found to well correlate the noise and traffic behavior. The distribution of such parameter into the about 2000 road arches of the pilot area allowed to assign each of them to a combination of the two-cluster behavior. For convenience, the whole range of variability of the non-acoustic parameter has been split into 6 groups so that each road belonging to a specific group behaves in the same way (same noise dynamics). Therefore, we derived 6 acoustic basic maps, one for each group. The dynamics is contained in the noise variations as recorded by the 24 field monitoring stations equally distributed in the 6 groups. The recorded data, cleaned from non-traffic related noises by means of a dedicated algorithm, have been used to build-up a dynamic map as that illustrated in figure 3. In specific sites, we compared the map outcome with measurements performed with a class I phono meter. Preliminary results seem to be reasonably in agreement. Further tests need to be performed in order to better estimate and reduce the prediction error.

7 ACKNOWLEDGEMENTS

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

8 REFERENCES

1. Dustlab (2011). SENSEable Pisa project. [Online.] available: http://www.senseable.it/

2. BrusSense (2009). Noisetube project. [Online.] available: http://www.noisetube.net

3. FabLab Bcn (2012). Smart citizen project. [Online.] available: https://smartcitizen.me/

4. Ghent University (2008). IDEA project. [Online.] available: http://www.idea-project.be/

5. Bruitparif (2011). Harmonica project. [Online.] available: http://www.noiseineu.eu/

6. Uninova (2011). Ear-it project. [Online.] available: http://www.ear-it.eu/

7. Bluewave (2010). Noisemote system [Online.] available: http://www.noisemote.com

8. EU Directive (2002), Directive 2002 /49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise, Official Journal of the European Communities, L189/12, July 2002.

9. G. Zambon, R. Benocci, A. Bisceglie, H.E. Roman, P. Bellucci, "The LIFE DYNAMAP project: Towards a procedure for dynamic noise mapping in urban areas", Appl. Acous., **124**, 52-60, (2017). DOI: 10.1016/j.apacoust.2016.10.022

10. J.M. Barrigon Morillas, V. Gomez Escobar, J.A. Méndez Sierra, R. Vílchez Gomez, "Study of noise in a small Spanish Town", Int. J. Acoust. Vib., **7**, 231–237 (2002).

11. J. Romeu, S. Jimenez, M Genescà, T. Pamies, R. Capdevila, "Spatial sampling for night levels estimation in urban environments", J. Acoust. Soc. Am., **120**, 791–800 (2006).

12. X. Sevillano, J. Claudi Socoró, F. Alías, P. Bellucci, L. Peruzzi, S. Radaelli, P. Coppi, L. Nencini, A. Cerniglia, A. Bisceglie, R. Benocci, G. Zambon, "DYNAMAP – Development of low cost sensors networks for real time noise mapping", Noise Mapping, **3**, 1, (2016).

13. M. Smiraglia, R. Benocci, G. Zambon, H.E. Roman, "Predicting Hourly Traffic Noise from Traffic Flow Rate Model: Underlying Concepts for the DYNAMAP Project", Noise Mapp., **3**, 130–139(2016).

14 G. Zambon, R. Benocci, A. Bisceglie, H. E. Roman, "Milan dynamic noise mapping from few monitoring stations: Statistical analysis on road network", Proc. of the 45th INTERNOISE, Hamburg, Germany, (2016).

15. G. Zambon, H.E. Roman, M. Smiraglia, R. Benocci. Monitoring and prediction of traffic noise in large urban areas (Review), Applied Sciences (Switzerland) **8** (2), (2018).

16. F. Orga, J.C. Socoró, F. Alías, R.M. Alsina-Pagès, G. Zambon, R. Benocci, A. Bisceglie, "Anomalous noise events considerations for the computation of road traffic noise levels: The DYNAMAP's Milan case study", Proc. of the 24th ICSV, London, UK, 23–27 July 2017.

17. G. Zambon, R. Benocci, F. Orga, R.M. Alsina-Pagès, F. Alías, J.C. Socoró, "Real-time urban traffic noise maps: The influence of anomalous noise events in Milan pilot area of Dynamap", Proc. of the 46th INTERNOISE, Hong Kong, China, 27–30 August 2017.

18. J. C. Socoró, F. Alías, R. Ma Alsina-Pagès, "An anomalous noise events detector for dynamic road traffic noise mapping in real-life urban and suburban environments", Sensors, **17** (10), 2323, (2017)

19. J. C. Socoró, X. Albiol, X. Sevillano, F. Alías "Analysis and automatic detection of anomalous noise events in real recordings of road traffic noise for the life Dynamap project", Proc. of the 45th INTERNOISE, Hamburg, Germany, (2016).

20. F. Alías, J. C. Socoró, "Description of anomalous noise events for reliable dynamic traffic noise mapping in real-life urban and suburban soundscapes", Applied Sciences, **7**(2),146, (2017).

21. J. C. Socoró, R. Ma Alsina-Pagès, F. Alías, F. Orga, "Adapting an Anomalous Noise Events Detector for Real-Life Operation in the Rome Suburban Pilot Area of the DYNAMAP's Project", Euronoise 2018, Crete, Greece, (2018).