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# Optimization of Dynamap noise mapping predictive scheme in Milan urban area

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**ABSTRACT**

**Dynamap, a co-financed project by the European Commission through the Life+ 2013 program, aims at developing a dynamic approach to noise mapping based on a limited number of noise monitoring stations. Dynamap is based on the idea of finding a suitable set of roads that display similar traffic noise behaviour so that one can group them together into a single noise map. The applicability of Dynamap is based on an available non-acoustic information on each road segment of the area under study. According to the chosen non-acoustic parameter, each road stretch presents a noise temporal profile that could be described as a combination of the two main noise behaviour. Each group of roads can, therefore in principle, be represented by the same acoustic map. For the effective implementation of Dynamap, we, initially, decided to divide the entire range of available non-acoustic parameter into six intervals, called groups, each one described by a noise base map and described by four monitoring sensors. The noise in a given location is therefore predicted by a combination of the six acoustic base noise maps whose variation (dynamic feature) are provided by the monitoring stations. In this paper, we discuss a second procedure for updating the acoustic maps based on a two-cluster expansion scheme performed directly over the noise recorded by the 24 monitoring sensors.**

**Keywords:** Traffic Noise, Noise Mapping, Environment
**I-INCE Classification of Subject Number:** 30

## 1. INTRODUCTION

Since the publication of the European Directive 2002/49/EC, a number of project have been devoted to the assessment and management of environmental noise especially in the form of noise mapping [1-7]. Dynamap [8], a co-financed project by the European Commission through the Life+ 2013 program, aims at developing a dynamic approach to noise mapping based on a limited number of noise monitoring stations.

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This approach has been implemented in a pilot area of the city of Milan (Zone 9, illustrated in Figure 1), consisting of about 2000 road arches and using 24 continuous monitoring sensors [9].

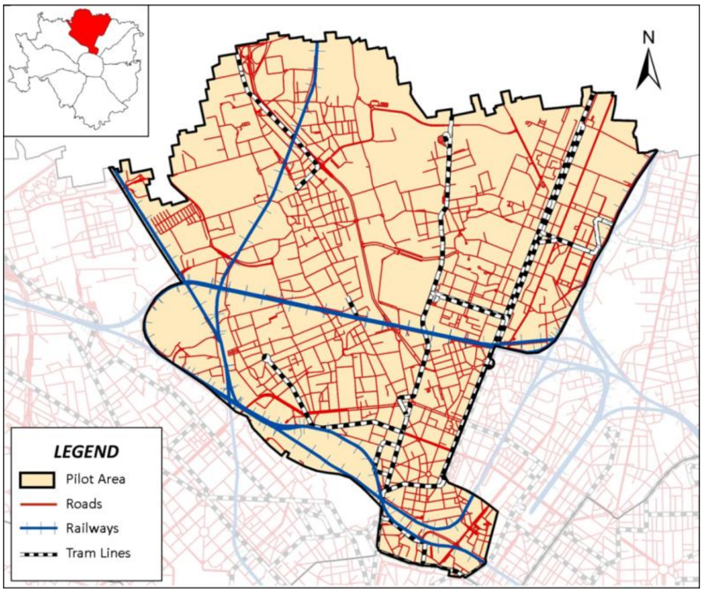


**Figure 1.** District 9 of the city of Milan, the pilot area chosen for the implementation of Dynamap.

For a complex urban context, the suitability of the mapping process is related to the fact that vehicle flow patterns are typically quite regular, allowing them to be classified using essentially two main clusters of different road traffic behaviours [10-12]. In references [13-14], each cluster was also cross-checked with a non-acoustic information in order to assign each road segment to the correspondent noise cluster. As non-acoustic parameter, x, we chose the logarithm of the total daily traffic flow rate, $x = \text{Log}(T_T)$.

The analysis of the distribution of the non-acoustic parameter (which depends on vehicular flows) within each cluster allows for the attribution of a specific noise profile to each road within the entire urban zone. In this way, all road arches can be divided (for convenience of representation) into six groups to cover the entire area of interest [14]. The 24 monitoring sensors have been distributed homogeneously in all the six groups. Therefore, each group can be, reasonably, described by the same noise base map and updated from the information retrieved by four monitoring sensors (four noise sensors in each group). The noise in a given location is, therefore, predicted by a combination of the six acoustic base noise maps whose variation (dynamic feature) is provided by the monitoring stations themselves. The process for updating the pre-calculated six base noise maps is based on the average of noise level variations of the monitoring stations, according to two different procedures. A first procedure has been extensively described in [15] together with the latest results on Dynamap reliability [16-18].

In this paper, we discuss a second procedure for updating the acoustic maps based on a two-cluster expansion scheme performed directly over the noise recorded by the 24 monitoring sensors distributed over the six identified groups of roads.

## 2. DYNAMAP NOISE MAPPING PROCEDURE

The 24 stations (indexes i = 1–24) have been chosen so that there are four stations (index j = 1–4) in each one of the six groups, indexed ($g_1$, …, $g_6$), that the pilot area (Zone 9) of Milan has been divided into (see Figure 2).

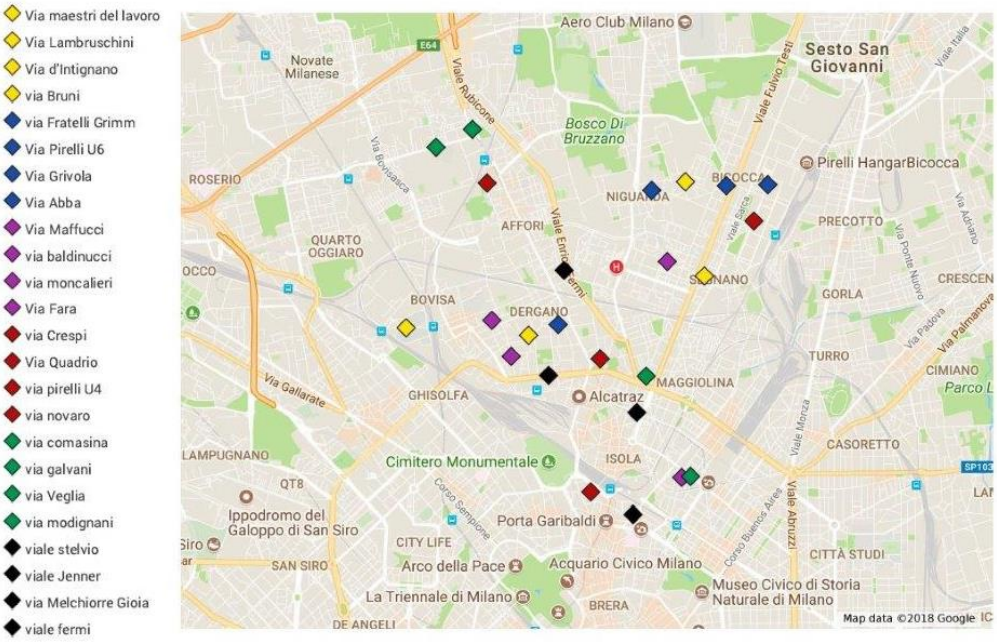


**Figure 2**. Locations of 24 monitoring noise stations in the pilot area Zone 9 of Milan. The inset on the left side of the figure reports the names of the streets of each monitoring station. The same colour refers to stations belonging to the same group g.

### 2.1. Updating Operations of Dynamap

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. The noise signal from each station *i* is filtered from any anomalous events not belonging to road traffic noise prior its integration to obtain $L_{eq\tau,i}$ over a predefined temporal interval τ (τ = 5, 15, 60 min) [19-21]. 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*τ and *n* is an integer, defined according to

$$\delta^{\tau}_{g,j}(t) = L_{eq\tau,M(g,j)}(t)_{(\text{measured})} - L_{eqref,M(g,j)}(T_{ref})_{(\text{calculated})} \quad (1)$$

where $L_{eqref,\, M(g,j)\,(\text{calculated})}$ is a reference value calculated from the acoustic map of group *g* (the CADNA model) at the time interval $T_{ref}$ = (08:00–09:00) at the point corresponding to the position of the *M*(*g*, *j*)-th station. The CADNA software 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, thus representing a reference static acoustic map. Here, we have chosen the reference time $T_{ref}$ = (08:00–09:00) for convenience, since it displays rush-hour type of behaviour. The temporal ranges within the day are 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).

### 2.2. Average over the Monitoring Stations in each group: 1st method

Once all the $\delta_{g,j}^{\tau}(t)$ values have been obtained, the six acoustic maps can be updated corresponding to each group $g$ by averaging the variations in Equation (1) over the four values $j$ in each group, according to [15]:

$$\delta_{g}^{\tau}(t) = \frac{1}{4}\Sigma_{j=1}^{4}\delta_{g,j}^{\tau}(t). \tag{2}$$

### 2.3. Clustering of the 24 Monitoring Stations: 2nd method (new procedure)

In the following, we discuss a second procedure for updating the acoustic maps based on the two-cluster expansion scheme, which uses all the 24 stations to determine $\delta_{g}^{\tau}(t)$ simultaneously. The clustering method to be implemented requires sufficient noise data to be analyzed. That is, from each station, we need to record $L_{eq\tau,i}(t)$ and obtain sufficiently accurate values for each interval of time τ. Then, the clustering calculation can be performed. The available dataset considered spans from November 13th 2018 to February 5th 2019. From this dataset, we excluded all Christmas festivities, weekends, rainy and windy days and for each monitoring sensor we calculated its median. For this preliminary analysis, we chose two time resolutions, τ, constant for all the day: $\tau = 60$ and 5 minutes. The results of the analysis, performed on the 24 median profiles, are reported in figures 3 and 4.

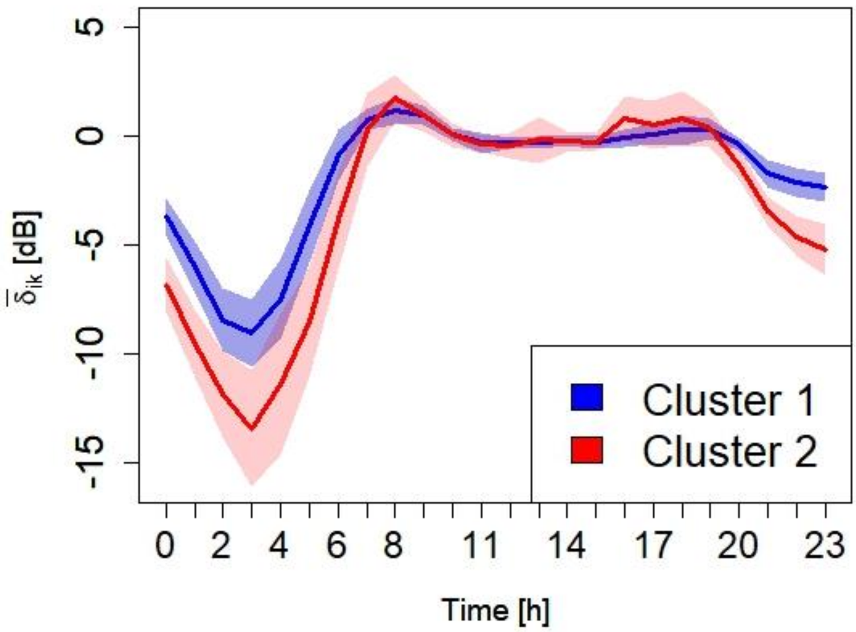


**Figure 3**: Mean normalized cluster profiles, $\bar{\delta}_{ik}$, and the corresponding error band. Time resolution $\tau = 60$ minutes.

From this analysis, it appears very clearly the robustness of the clustering method of the 24 monitoring sensors (both for : $\tau = 60$ and 5 minutes). In fact, the 24 sensors result perfectly distributed in the two clusters mimicking the trend obtained with the original sampling measurements taken over the entire city [9-13]. In Table 1, the information regarding the monitoring sensors together with their cluster membership are reported.

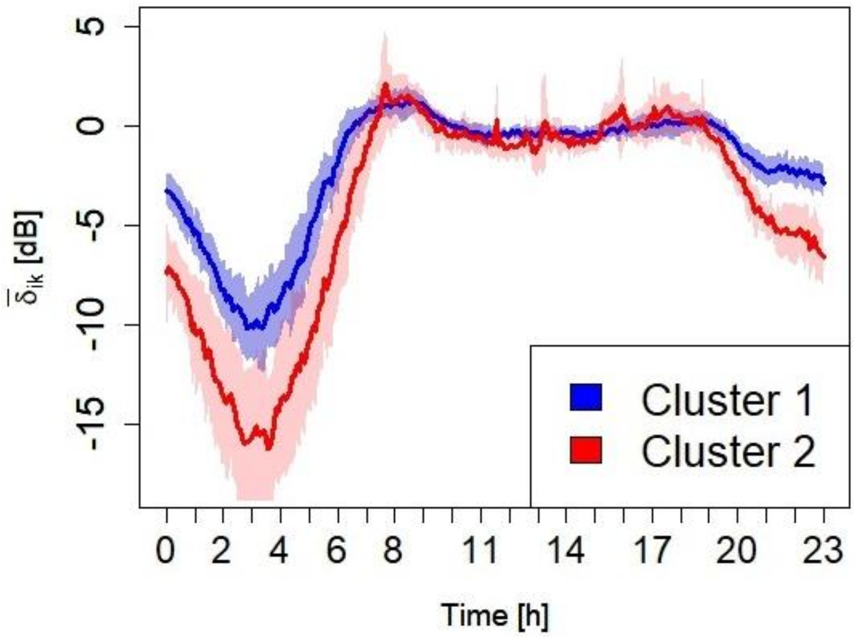


**Figure 4.** Mean normalized cluster profiles, $\bar{\delta}_{ik}$, and the corresponding error band. Time resolution $\tau =$ 5 minutes.

| Sensor Code | Group | x = Log($T_T$) | Cluster |
|---|---|---|---|
| hb 135 | $g_1$ | 2.892099 | 2 |
| hb 137 | $g_1$ | 1.904066 | 2 |
| hb 139 | $g_1$ | 1.13 | 2 |
| hb 144 | $g_1$ | 2.944705 | 2 |
| hb 108 | $g_2$ | 3.06 | 1 |
| hb 124 | $g_2$ | 3.496278 | 2 |
| hb 125 | $g_2$ | 2.687232 | 2 |
| hb 145 | $g_2$ | 3.415341 | 2 |
| hb 115 | $g_3$ | 3.581817 | 1 |
| hb 116 | $g_3$ | 3.5947 | 2 |
| hb 120 | $g_3$ | 3.736355 | 1 |
| hb 133 | $g_3$ | 3.7468 | 2 |
| hb 121 | $g_4$ | 4.06 | 1 |
| hb 127 | $g_4$ | 3.902877 | 2 |
| hb 129 | $g_4$ | 3.94 | 1 |
| hb 138 | $g_4$ | 4.193578 | 2 |
| hb 106 | $g_5$ | 3.902877 | 1 |
| hb 123 | $g_5$ | 4.300392 | 1 |
| hb 136 | $g_5$ | 4.206915 | 1 |
| hb 151 | $g_5$ | 4.398055 | 1 |
| hb 109 | $g_6$ | 4.746 | 1 |
| hb 114 | $g_6$ | 4.575 | 1 |
| hb 117 | $g_6$ | 4.846 | 1 |
| hb 140 | $g_6$ | 4.7005 | 1 |

**Table 1.** Monitoring sensor information: code, group membership, non-acoustic parameter, x = Log($T_T$) and cluster membership according to the performed analysis (12 sensors belong to Cluster 1 and 12 to Cluster 2).

**2.4. New Updating Procedure**

Once the compositions of Clusters 1 and 2 have been found (meaning that there are $N_1$ stations in Cluster 1, $k_1 = (1, \ldots, N_1)$, and $N_2$ stations in Cluster 2, $k_2 = (1, \ldots, N_2)$, such that $N_1 + N_2 = 24$), we need to rearrange the variations obtained from Equation (2) according to the indices $C_{1,k1}$ and $C_{2,k2}$, which we denote as $\delta^{\tau}_{C1,k1}(t)$ and $\delta^{\tau}_{C2,k2}(t)$ within each cluster, $C_1$ and $C_2$. Then, we calculate the mean variations, $\delta^{\tau}_{C1}(t)$ and $\delta^{\tau}_{C2}(t)$, for each cluster according to,

$$\delta^{\tau}_{C1}(t) = \frac{1}{N_1}\sum_{k1=1}^{N_1} \delta^{\tau}_{C1,k1}(t) \quad (3)$$

$$\delta^{\tau}_{C2}(t) = \frac{1}{N_2}\sum_{k2=1}^{N_2} \delta^{\tau}_{C2,k2}(t)$$

where $C_{1,k1}$ and $C_{2,k2}$ are the $N_1$ and $N_2$ indices of stations belonging to Cluster 1 and Cluster 2, respectively. In figure 5, the histograms and density function, $P_1(x)$ and $P_2(x)$ for Cluster 1 and 2 are illustrated as a function of the non-acoustic parameter, $x = \mathrm{Log}(T_T)$. $P_1(x)$ and $P_2(x)$ represent the "probability" that a road with a given x belongs to Cluster 1 and 2, respectively.

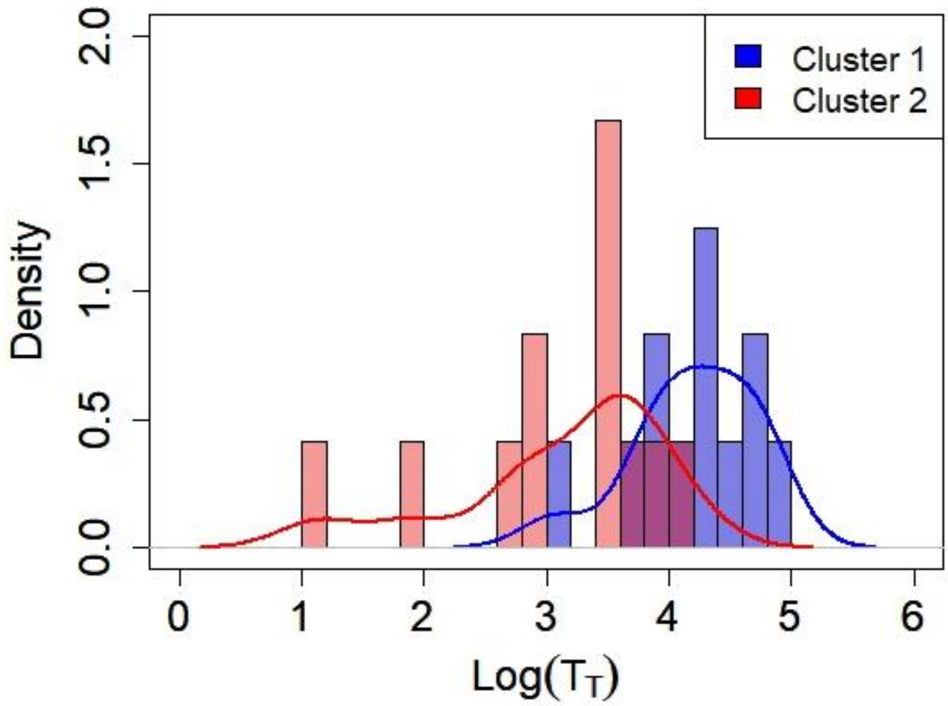


**Figure 5.** Histograms and probability distributions, $P_1(x)$ and $P_2(x)$, as a function of the non-acoustic parameter, $x = \mathrm{Log}(T_T)$, for Cluster 1 and 2. Bin size is 0.2.

Due to the large superposition of the two cluster distributions $P_1(x)$ and $P_2(x)$, we can consider a linear combination between the two mean normalized cluster profiles to describe the noise behaviour of a road with a given value of x. The weights ($\alpha_1$, $\alpha_2$) of the linear combination can be obtained, for each value of x, using the relations: $\alpha_1 = P_1(x)$ and $\alpha_2 = P_2(x)$. Therefore, the values of $\alpha_{1,2}$ represent the "probability" that a given road characterized by its own value of x belongs to the corresponding Cluster, 1 and 2. As one can see, the resulting hourly behaviour of the noise for that road is a linear combination of the mean noises measured for Cluster 1 and 2, denoted respectively as $\delta^{\tau}_{C1}(t)$ and $\delta^{\tau}_{C2}(t)$. By denoting as β, the normalized values of $\alpha_{1,2}$, we obtain:

$$\beta_1 = \frac{\alpha_1}{\alpha_1+\alpha_2}$$

and (5)

$$\beta_2 = \frac{\alpha_2}{\alpha_1+\alpha_2}.$$

The mean variation $\delta_g^\tau(t)$ associated with each group $g$ can be calculated using the formula

$$\delta_g^\tau(t) = \bar{\beta}_1(\bar{x}_g)\,\delta_{C1}^\tau(t) + \bar{\beta}_2(\bar{x}_g)\,\delta_{C2}^\tau(t). \quad (4)$$

Here, the value $\bar{x}_g$ represents the mean non-acoustic parameter associated with group $g$, and $\bar{\beta}_1(\bar{x}_g)$, $\bar{\beta}_2(\bar{x}_g)$ the corresponding probabilities to belong to Clusters 1 and 2, respectively.

## 2.5. Noise level at an Arbitrary location

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 either Equation (2) or Equation (4). 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. 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 $\delta_g^\tau$(t):

$$Leq_\tau^a(t) = 10 \cdot Log \sum_{g=1}^{6} 10^{\frac{\text{Leqref}(g,a)+\delta_g^\tau(t)}{10}}. \quad (5)$$

This operation provides what we called the "scaled map" (dynamic map).

## 3. CONCLUSIONS

In this paper, we presented a second procedure for updating the acoustic maps in the framework of Dynamap project. It is based on a two-cluster expansion scheme performed directly over the noise recorded by the 24 monitoring sensors distributed over the six groups of roads, the whole District 9 of the urban area of Milan has been split into.

The 24-h noise profiles recorded by 24 the monitoring sensors cover a period from November 13th 2018 to February 5th 2019. From this dataset, we excluded all Christmas festivities, weekends, rainy and windy days. In order to get robust noise profiles, we calculated, for each sensor, its median. The cluster analysis showed that the 24 sensors are perfectly distributed in the two clusters, thus mimicking the trend obtained with the original sampling measurements taken over the entire city. From the probability distribution, $P_1$(x) and $P_2$(x), we can update the acoustic map of the pilot area of Milan (using Eqs. (4) and (5)) that is based on a two-cluster expansion scheme.

## 4. ACKNOWLEDGEMENTS

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