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DYNAMAP project: procedure for noise mapping updating in urban area

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ABSTRACT

The main goal of Dynamap project, as for the urban case study, is to produce a dynamic noise map within a given area of the city of Milan containing about 2000 road arches, by using 24 continuous measuring stations. This map will be dynamically updated at an interval varying from 5 minutes to 1 hour. The reliability of the mapping process for a complex urban context is related to the fact that the vehicle flow patterns are supposed to be very regular, in function of the use of different roads. In the first phase of the project, nearly 100 road arches have been monitored for a period of at least 24 hours and have been statistically aggregated in two clusters, depending on their noise level profiles. Then the analysis of the distribution of a non-acoustic parameter -which depends on the vehicular flows- allowed to attribute a specific noise profile to a road not present in the database. The total amount of road arches has been finally divided into six groups to better distinguish the different noise trends. Four monitoring stations have been planned to be installed for each group, selecting the most representative arches. For each group of roads, a basic noise map covering all the pilot area has been calculated with an acoustic software. In this paper the procedure for the updating of the pre-calculated basic noise maps in the starting operational phase of Dynamap is discussed. The process is based on the average of the noise level variations calculated at the monitoring stations, according to two different procedures. The absolute equivalent noise level at a certain time interval for an arbitrary receiver point in the urban pilot area can be obtained by properly summing the six acoustic maps updated values.

Keywords: Noise, Traffic, Acoustic Maps I-INCE Classification of Subjects Number(s): 76.

1. INTRODUCTION

Dynamap is based on the idea of finding a suitable set of roads which display similar traffic noise behavior (temporal noise profile over a whole day) so that one can group them together into a single noise map [1-5]. Each map thus represents a group of road stretches whose traffic noise will be updated periodically, typically every five minutes during daily hours and every hour during night. The information regarding traffic noise will be taken continuously from a small number of monitoring stations (typically 24) distributed appropriately over the urban zone of interest.

To achieve this goal, we have performed a detailed analysis of traffic noise data, recorded every second from 93 monitoring stations randomly distributed over the whole urban area of the City of Milan (Fig. 1) [6]. From the analysis, we develop a model for predicting the traffic noise of an arbitrary road stretch within the same area. Our final results are presented for a restricted area, the urban Zone

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9 of Milan (Fig. 2). We have separated the whole set of (about 2000) stretches into six groups, each one represented by a noise map, and give a prescription for the locations of the future 24 monitoring stations. From our analysis, it is estimated that the mean overall error for each group of stretches (noise map), averaged over the 24 hours, is about 2 dB.

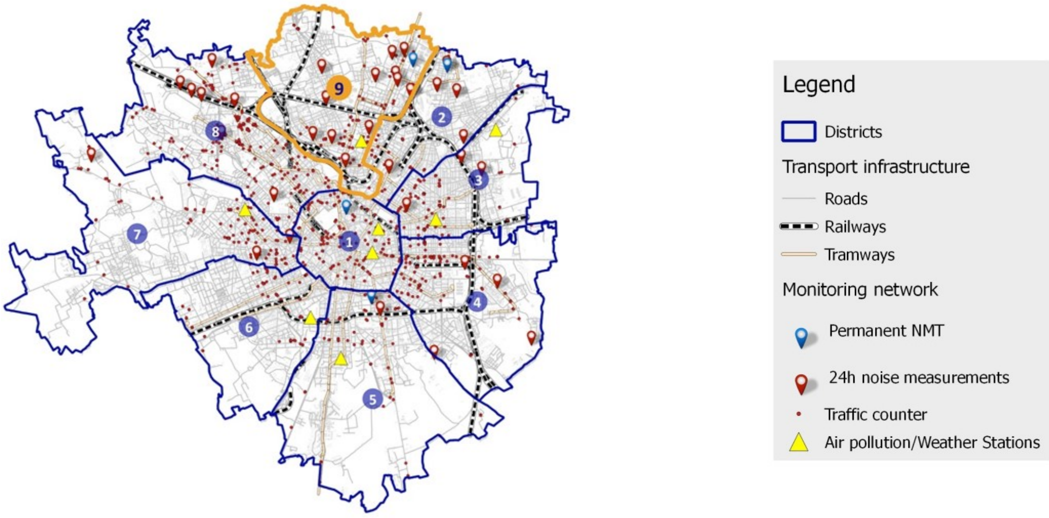

Figure 1: Urban areas of the city of Milan indicating the 9 urban districts. The different explanatory items are reported to the right side of the figure. Here, our interest is in the Zone 9, in the northern part of the city.

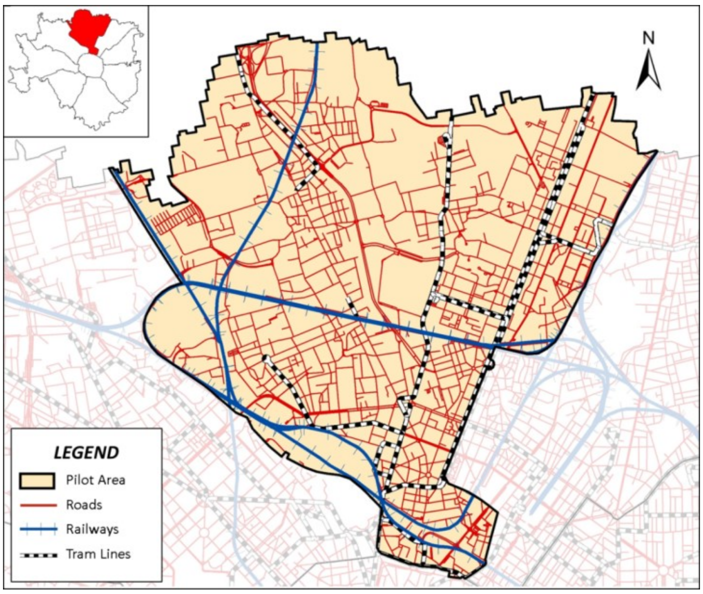

Figure 2: The Urban zone 9 of the city of Milan which is the pilot area chosen for the deployment of the acoustic sensors for the functioning of Dynamap. In the latter, the number of recording stations has been fixed at 24.

The analysis of hourly traffic noise from the 93 monitoring stations have been performed using standard clustering techniques (see [1,2]), yielding two clusters, here denoted as Cluster 1 and 2. Within each Cluster, each road stretch displays similar time noise dependences, which are different for each cluster. The corresponding mean normalized acoustic equivalent levels for each cluster C_1 and C_2 as a function of the hour h of the day are denoted as $\delta_{C1}(h)$ and $\delta_{C2}(h)$, respectively. In order to predict traffic noise for a given road stretch within Dynamap, we need to define a non-acoustic parameter which we denote generically as x and is related to model calculations of the traffic flow on that road stretch. Here, we choose x to be given by the logarithm of the total daily traffic flow rate $x = Log(T_T)$. 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 obtained from each one of the noise Clusters 1 and 2, denoted as $P_1(x)$ and $P_2(x)$, respectively. The idea of the method is to evaluate the probability β_1 that x belongs to Cluster 1, and $\beta_2 = 1 - \beta_1$ that it belongs to Cluster 2. The values of $\beta_{1,2}$ are given by the relations,

$$\beta_1(x) = P_1(x)/(P_1(x)+ P_2(x)) \quad \text{and} \quad \beta_2(x) = P_2(x)/(P_1(x)+ P_2(x)). \tag{1}$$

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

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

One important requirement for the location of monitoring stations is that the corresponding road stretches, where they are positioned, have values of x covering essentially all the relevant x values of the urban zone under consideration. To check this, the distribution function of x for the zone 9 (Z9) of Milan has been determined and compared with the P(x) obtained from the stretches where the monitoring stations were positioned. The results [5] suggest that the choice of station locations is appropriate, which are more or less scattered over the same range of x as the ones for Z9.
It is found that $0<x<5.5$, so we have divided the total interval of x into six parts, each one containing a similar number of road stretches each. The corresponding intervals of x defining each group g=(1-6) are reported in Table 1. In the same Table, we display the corresponding mean values of $\beta_{1,2}$ which can be seen as an illustration of the type of values typical of each group, since they have been obtained from the 93 recording stations over the whole City of Milan. The way in which the actual values of $\beta_{1,2}$ can be calculated will be explained in the following Section.

Range of x	**0.0 – 3.3**	**3.3 – 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

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

Finally, it is to be noted that each group g will have an associated acoustic map which is updated in real time, according to the 24 measurements of traffic noise registered by the 24 recording stations in Z9. The traffic noise is recorded at the time scale of one second and the data is aggregated to obtain the Leq at 5 min. Filtering of the noise data is performed in order to eliminate anomalous noise events. The update of the acoustic maps is performed every 5 min, but a type of moving average can be implemented yielding an effective update time of 1 min. For our present purposes, we discuss the case of updating the maps every 5 mins only.

In what follows, we discuss in Sect. 2 the initialization procedure required to start the implementation of the maps. For this purpose, we use two different methods of implementation and discuss them in detail. The associated mean and median values of the Leq5min are discussed in order to decide when their variations should be discarded, or kept for evaluating the average quantities of interest. In Sect. 3 we present the concluding remarks.

2. INITIALIZATION OF DYNAMAP AND ITS IMPLEMENTATION

2.1 Starting operation of Dynamap from the four stations in each group g: $\delta^{\tau}_{g,j}(t)$

In this Section we discuss how *Dynamap* can be brought to operation from the very beginning. The 24 stations (index *i=1-24*) have been chosen so that there are 4 stations (index *j=1-4*) in each one of the six groups (index *g=1-6*) of road stretches on which the pilot Zone 9 of Milan has been divided. For example, we can have that (i=3,16,19,24) belong to group *g*=1, (i=1,2,7,17) to *g*=2, etc. For each group *g*, we then have the correspondence of (*g*,j) with *i* using the notation M(*g*,j)=*i*. In this example one has: M(1,1)=3, M(1,2)=16, M(1,3)=19, M(1,4)=24. While for g=2 we find: M(2,1)=1, M(2,2)=2, M(2,3)=7, M(2,4)=17.

An acoustic map has been associated to 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 30 milliseconds resolution, which will be integrated, after filtering the anomalous events, in 1 second equivalent noise level. Then the signal needs further integration to obtain $L_{eq\tau,i}$ over a predefined temporal interval τ (τ=5,15,60 min). The operator thus 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 = nτ and n is an integer, defined according to,

$$\delta^{\tau}_{g,j}(t) = L_{eq\tau,M(g,j)}(t)_{(\text{measured})} - L_{eqref,M(g,j)(\text{calculated})}\,, \tag{3}$$

where $L_{eqref,\,M(g,j)\,(\text{calculated})}$ is a reference value calculated from the acoustic map of group g (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 temporal ranges within the day are conventionally chosen as,

τ=5min for(7:00-21:00), τ=15min for (21:00-1:00), τ=60min for (1:00-7:00).

Once all the $\delta^{\tau}_{g,j}(t)$ values have been obtained, the six acoustic maps can be updated corresponding to each group g by averaging the variations in Eq. (3) over the four values j in each group, according to,

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

The variations $\delta^{\tau}_{g,j}(t)$ originated from the (g,j)th station must remain bounded within the group acceptance interval [$Q^{\tau}_{1,g}(t) - 1.5 \cdot \mathrm{IQR}^{\tau}_{g}(t)$, $Q^{\tau}_{3,g}(t) + 1.5 \cdot \mathrm{IQR}^{\tau}_{g}(t)$], where IQR^{τ}_{g} is the interquartile range (see Fig. A.1, in Appendix) obtained as the difference between the 75th ($Q^{\tau}_{3,g}(t)$) and 25th ($Q^{\tau}_{1,g}(t)$) percentiles calculated at the same time t (of duration time τ) of the day for all $\delta^{\tau}_{g,j}(t)$. These quantities will be obtained initially from the data recorded over the previous 10 working days (running or moving averages) during the operation of *Dynamap*. The proper number of days required to obtain reliable results (for IQR, Q_1 and Q_3 for each group and time t) will be determined by the Bicocca Team (during the Action B7) once the system has generated sufficiently statistics. In the case in which a variation $\delta^{\tau}_{g,j}(t)$ falls outside the group acceptance interval (A.I.), the contribution of the (g,j)th station is considered to be an outlier and it is not included in Eq. (4). Then, the average is performed over the remaining active stations. In this way, the acoustic maps can be updated. In the extreme case in which more than 12 of the stations of the whole network (for instance two stations per group fail to remain within the A.I.) have exceeded their acceptance intervals, we are in the presence of a global network extreme event, and therefore their data cannot be rejected but need to be included into the updating procedure of the maps. The number of excluded stations (here initially taken as 12) will be reconsidered during the development of the Action B7.

2.2 Clustering of the 24 recording stations: $\delta^{\tau}_{C1,2}(t)$

In the following, we discuss a second procedure for updating the acoustic maps based on a 2-Cluster expansion scheme which should be more accurate as it uses all the 24 stations to determine $\delta^{\tau}_{g}(t)$ simultaneously. The clustering method can be implemented once the 24 stations have been working during 10 consecutive working days, in order to record the noise data before proceeding to the clustering analysis and thus their separation into two Clusters, 1 and 2. This can be done within Action B7 as mentioned above. That

is, from each station, we need to record $L_{eq\tau,i}(t)$ and obtain sufficiently accurate mean values for each interval of time τ. The Bicocca Team will perform the clustering calculation.
Once the compositions of Cluster 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 in Cluster 2, $k_2=(1,\ldots,N_2)$, such that $N_1+N_2=24$), we need to rearrange the variations obtained from Eq.(1) 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,

$$\delta^{\tau}_{C1}(t) = \frac{1}{N_1} \Sigma^{N_1}_{k1=1} \delta^{\tau}_{C1,k1}(t), \qquad \text{and} \qquad \delta^{\tau}_{C2}(t) = \frac{1}{N_2} \Sigma^{N_2}_{k2=1} \delta^{\tau}_{C2,k2}(t), \tag{5}$$

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. Here, the allowed ranges of variation of $(\delta^{\tau}_{C1,k1}(t), \delta^{\tau}_{C2,k2}(t))$ are determined similarly as in Eq. (4) using $[Q^{\tau}_{1,C1,2}(t) - 1.5 \cdot \mathrm{IQR}^{\tau}_{C1,2}(t),\ Q^{\tau}_{3,C1,2}(t) + 1.5 \cdot \mathrm{IQR}^{\tau}_{C1,2}(t)]$, calculated for all stations (k_1,k_2) within each cluster C_1 and C_2, respectively. Then, the mean variation $\delta^{\tau}_{g}(t)$ associated to each group g can be calculated by taking the formula,

$$\delta^{\tau}_{g}(t) = \bar{\beta}_1(\bar{x}_g)\ \delta^{\tau}_{C1}(t) + \bar{\beta}_2(\bar{x}_g)\ \delta^{\tau}_{C2}(t) \tag{6}$$

where the parameters $\bar{\beta}_1(\bar{x}_g)$ and $\bar{\beta}_2(\bar{x}_g)$ for each group g, which have been illustrated in Table 1 for the whole city of Milan) will be provided by the Bicocca Team at a later stage. Here, the value $\bar{x}_g$ represents the mean non-acoustic parameter associated to group g, and $\bar{\beta}_1(\bar{x}_g)$ and $\bar{\beta}_2(\bar{x}_g)$ the corresponding probabilities to belong to Cluster 1 and 2, respectively. Again, in the extreme case in which more than 12 of the stations of the whole network (for instance 6 stations per Cluster fail to remain within their A.I.'s) have exceeded their acceptance intervals, we are in the presence of a global network extreme event, and therefore their data cannot be rejected but need to be included into the updating procedure of the maps. The number of excluded stations (here initially taken as 12) will be reconsidered during the development of the Action B7.

2.3 Leq at time t for arbitrary receiver point a: $Leq^{a}_{\tau}(t)$

Let us discuss next the way in which the absolute $Leq^{a}_{\tau}(t)$ at time t for an arbitrary receiver point *a* can be obtained from the measured values of $\delta^{\tau}_{g}(t)$ using either Eq. (4) or Eq. (6). The first quantity we need to know is the value of $L_{eqref(g,a)}$ at the receiver point *a* due to the noise produced by roads in the group g, which is provided by the calculated (CADNA) acoustic map. The absolute $Leq^{a}_{\tau}(t)$ at location *a* at time t=nτ can then be estimated by,

$$Leq^{a}_{\tau}(t) = 10 \cdot Log\ \Sigma^{6}_{g=1} 10^{\frac{\mathrm{Leqref}(g,a)+\delta^{\tau}_{g}(t)}{10}}. \tag{7}$$

3. CONCLUSIONS

In conclusion, we have discussed a procedure for starting and implementing the six acoustic maps (one for each group g) of Dynamap for the Zone 9 of the City of Milan. This procedure considers three time intervals during the day: T_h=(07:00 - 21:00), (21:00 - 01:00), (01:00 - 07:00), associated with the three discretization times τ= (5, 15, 60) min, respectively. We have presented two methods for evaluating the variations $\delta^{\tau}_{g}(t)$ [dB], one in which their average is performed over the four stations within each group g, and a second method which uses the corresponding values $\bar{\beta}_1(\bar{x}_g)$ and $\bar{\beta}_2(\bar{x}_g)$ for each group g. Finally, we have presented the general formula for obtaining the absolute $Leq^{a}_{\tau}(t)$ at time t for the update time τ at an arbitrary receiver point a.

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Appendix: **Note on calculation of IQR.**

In this Appendix, we briefly summarize the main properties of mean and median values, which are relevant to our present purposes [7].

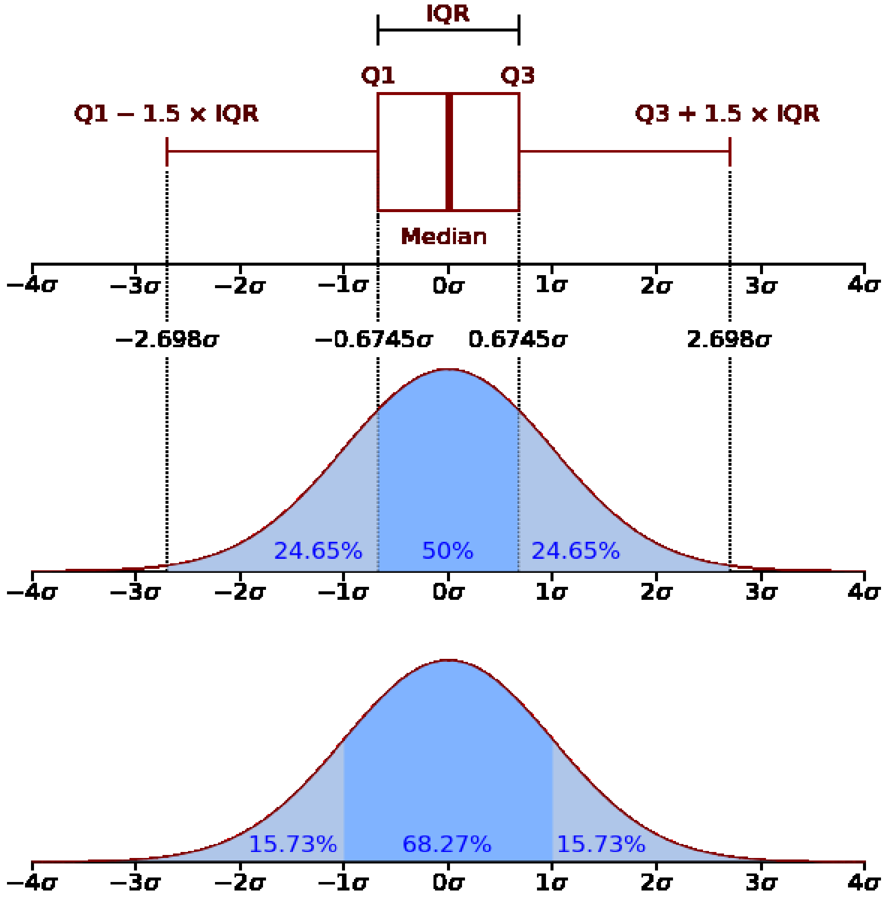

Figure A.1: Boxplot and a probability density function (PDF) of a Normal $N(0,\sigma)$ distribution.

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