Initial verification measurements of Dynamap predictive model

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Summary
Dynamap project addresses the question about the possibility to create a dynamic acoustic map in the city of Milan based on statistical consideration and the general observation of traffic regularity. Based on this analysis and on a limited number of monitoring stations, we developed a method for predicting the traffic noise in an extended urban area. Initial verification measurements of Dynamap predictive model are presented. Traffic and noise measurements have been performed in order to confirm both the non-acoustic parameter chosen to attribute a generic road a specific cluster membership and the noise predicted by our statistical model.

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1. Introduction

In the last decade, distributed acoustic monitoring systems started to appear in urban context, due to lowering costs of electronic components and to cheaper and smaller hardware for data transfer. Triggered by the European Directive 2002/49/EC and connected to the assessment and management of environmental noise (END) [1], this interest has grown thanks to the fact that noise maps represent a powerful tool for determining the population exposure to environmental noise. Therefore, the eventual mitigation measures has to be identified according to a realistic picture of noise distribution over urban areas. Up to now, maps of noise are normally obtained by using the vehicle flows averaged over periods of one year. A number of projects has been developed to monitor extended noise measurements such as SENSEable [2], NoiseTube [3], Smart Citizen [4], IDEA [5], Harmonica [6], EAR-IT [7] and Noisemote [8] to cite a few.

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 the capability of updating environmental noise levels through a direct link with a limited number of noise monitoring terminals. Dynamap general idea leans on the observation that roads which display similar traffic noise behavior (temporal noise profile over a whole day) can be grouped together into a single noise map [9-14]. 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 the night. The information regarding traffic noise will be taken continuously from a small number of monitoring stations (typically 24) appropriately distributed 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 [15]. From the analysis, we developed a model for predicting the traffic noise of an arbitrary road stretch within the same area. Our results are presented for a restricted pilot area, the urban Zone 9 of Milan. We separated the whole set of (about 2000) stretches into six groups, each one represented by a noise map, and gave a prescription for the locations of the 24 monitoring stations. From our analysis, it was estimated an overall error for each group of stretches (noise map), averaged over the 24 hours, of about 2 dB [16]

In this paper, we perform a preliminary check on the proper functioning and reliability of the Dynamap system in the pilot area of Milan named Zone 9 (Z9). This work is integrated in phase B7 of the "System test and fault analysis" task of Dynamap project.

2. System test and fault analysis

The monitoring activity, supporting the B7 action, has been divided into two phases:

- in the first phase, 12 acoustic measurements were carried out near the installed low-cost sensors, aimed at verifying their correct functioning;
- the second phase was focused on verifying the accuracy and reliability of the predicting model employed by the DYNAMAP system which allows to determine the traffic noise in roads characterized by specific non-acoustic parameters.

In both phases, the test measurements were performed using a standard class I sound level meter. Simultaneously to noise measurements, vehicle traffic flows recordings were also performed. Traffic measurements were also aimed at evaluating the accuracy of the traffic model used to characterize the non-acoustic parameter.

2.1 Phase 1: Monitoring stations' test

For the monitoring stations' test, the equivalent levels calculated on a 5 minutes basis has been compared with those measured by a class I sound level meter. Correlating the equivalent levels, an average overestimation was generally observed. The comparison has been performed for each of the 12 monitoring stations (two for each group of roads) as shown in Figure 1.

The recording time period was 1 h for 10 measurements and 48 h for Fara e Comasina. As is apparent, monitoring stations tend to overestimate, on average, the reference measurements of about 1 dB. This difference may be explained by the different microphone sensitivity and orientation (the monitoring station sensor directed downward and the class I sensor upward).

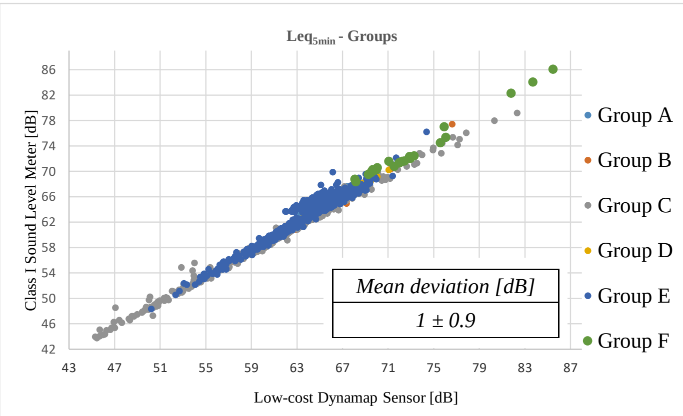

Figure 1: Comparison between the levels Leq 5 from the low-cost sensor and the class I phono meter.

2.2 Traffic flow rate

The entire Dynamap structure is based on the strict correspondence of traffic noise and vehicle flow rate [17]. In particular, the possibility to derive a noise mapping as a result of the measurements of a limited number of low cost sensors, requires that each road could be associated with a traffic flow dependent parameter. An optimal non-acoustic parameter was found in the logarithm of the total daily traffic flow rate, x = Log TT. This link was guaranteed by a traffic model provided by the Municipal agency in charge of the traffic management in Milan (AMAT). To check for the correctness of such model we performed some test measurements. The measurements were compared both with the 2012 model results and with a more recent outcome (Dec 2017) which updates the latest changes in the roads network. We performed 10 vehicle flow rate measurements, 48 hours each, that is 2 for each group of roads, excluding group F whose high traffic rate made the instrument installation impracticable (traffic counter plates). The results show that the traffic model tends to underestimate the flow rate in secondary roads and overestimate it in main roads. However, the agreement is quite good, though the deviation is higher in case of secondary roads. The updated traffic model gives better results for those streets that underwent major changes in the traffic road system. A summary of the measurements are shown in Figure 2.

Table I reports the percentage deviation of hourly traffic flow rate measurements against the 2012 and 2017 model results.

Table I. Percentage deviation of hourly traffic flow rate measurements against the 2012 and 2017 model results.

Site	*Group*	*Deviation %*	
		(2012)	*(2017)*
Via Lambruschini	A	27.37	32.98
Via M. del lavoro	A	26.90	24.35
Via Grivola	B	17.74	28.93
Via Pirelli (U6)	B	27.99	4.47
Via Fara	C	8.41	11.75
Via Baldinucci	C	14.21	10.45
Via Quadrio	D	7.05	9.77
Via Crespi	D	4.00	6.50
Via Comasina	E	4.40	11.50
Via Veglia	E	7.90	10.00

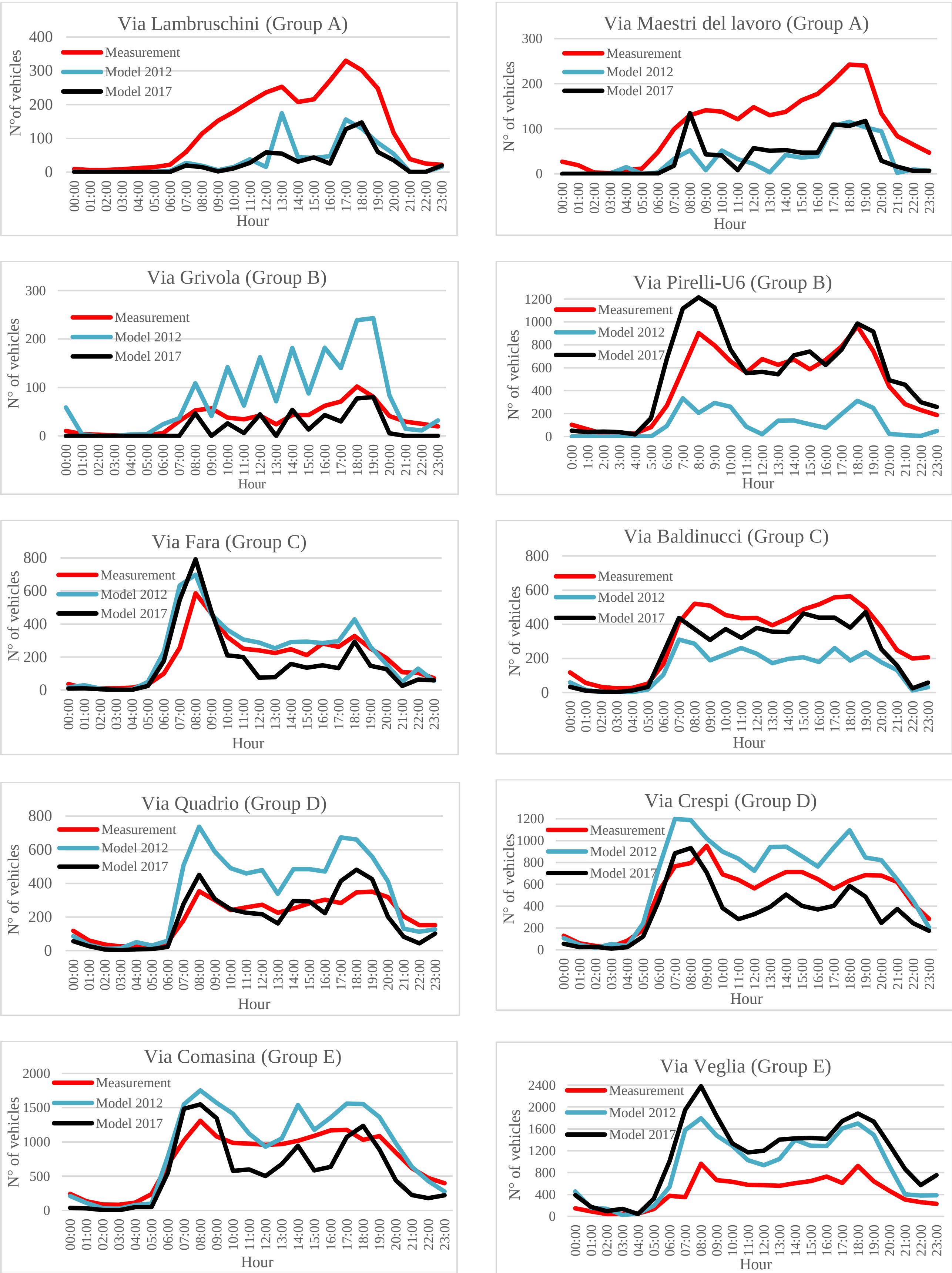

Figure 2: Measurements of hourly traffic flow rate compared to the 2012 and 2017 traffic model results

The model deviation shows a decreasing trend as the group number grows. Again, this is a direct consequence of the fact that the traffic model is mainly focused on the general traffic flow rate as a whole rather than giving specific indication on secondary, unimportant roads. Therefore, small variation on the traffic flow rates in secondary roads produces higher deviations.

2.3 Phase 2: Traffic Noise Prediction

Dynamap is based on the possibility to predict traffic noise for a given road stretch, when a direct measurement is not practicable. This capability derive from a statistical analysis performed on a sampling campaign performed on the entire road network of Milan [15]. The prediction needs to define a non-acoustic parameter, which is related to the calculations provided by a traffic flow model on each road stretch, as described above. In this case, the predicted noise for a generic road characterized by a given non-acoustic parameter results as a combination of the two typical noise profile (Clusters 1 and 2 illustrated in Figure 3), the entire sample of monitored roads have been split into as a result of a cluster analysis. This technique is a robust unsupervised tool to statistically analyze many types of data [18-21].

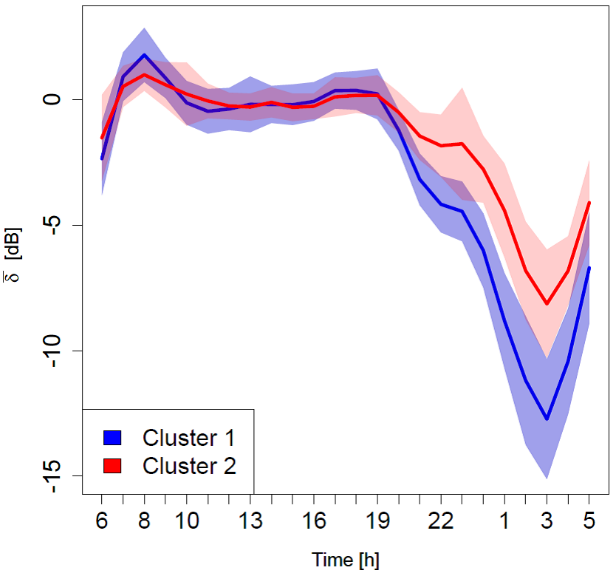

Figure 3. Mean normalized cluster profiles, $\bar{\delta}$ [dB] , for the two clusters, k = (1,2), as a function of hour h of the day. We show the corresponding dispersion (colored bands). Cluster 1 has 56 elements and Cluster 2 has 37 components. Details on the measurements and analysis related to this figure are reported in [9, 10].

In particular, 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. The corresponding distribution functions, denoted as $P_1(x)$ and $P_2(x)$, are shown in Figure 4, for the choice of x given by the logarithm of the total daily traffic flow rate x = Log (TT). Other choices of x lead to similar qualitative behavior [10, 11].

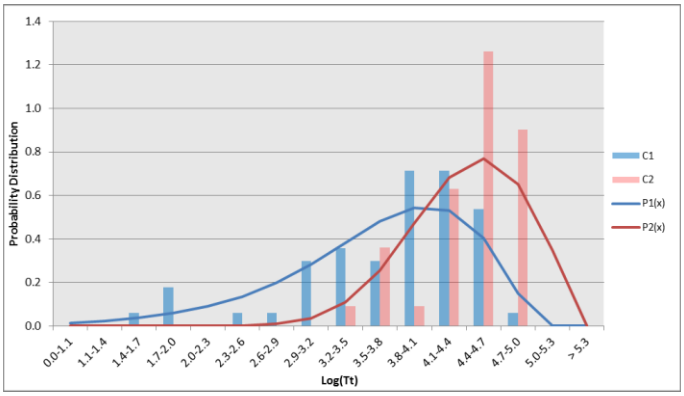

Figure 4. Distribution functions $P_1(x)$ and $P_2(x)$ for x = Log (TT) on Clusters 1 and 2, respectively. The continuous lines represent logarithmic fits to the actual histograms using the cumulative distribution functions and are used here to accurately determine $\beta_{1,2}$ using Equation (1).

As one can see from Figure 4, there is a conspicuous overlap between the two distributions, suggesting that a sharp separation into two clusters is not possible, in general. For this reason, a given value of x has components in both clusters, meaning that the temporal evolution of the noise for a given road stretch is partly due to Cluster 1 and partly due to Cluster 2. 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:

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

$$\beta_2(x) = \frac{P_2(x)}{P_1(x)+P_2(x)} \quad (2)$$

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

$$\delta_x(h) = \beta_1(x)\,\delta_{C1}(h) + \beta_2(x)\,\delta_{C2}(h) \quad (3)$$

with $\delta_{C1}(h)$ and $\delta_{C2}(h)$ representing the mean hourly values of the equivalent level (Figure 4) for both Clusters 1 and 2, respectively.

In this very preliminary phase, we predicted the noise trend profiles of those sites where the low-cost monitoring stations have been installed.

As reference noise profiles, we used data recorded by the Dynamap sensors. In order to make a meaningful comparison, we proceeded by building up a robust time profile. For this reasons, we used data recorded over a 4-week period (working days) and calculated the median of the hourly values for each site. We opted for the median, as a descriptor, because it is less affected by the presence of outliers. This procedure has the advantage of automatically eliminating any anomalous event, which can be regarded as an outlier, from the time series. Of course, such method cannot be applied to recursive events, that is those events that present periodically and that therefore the median cannot eliminate. A different approach to ANE treatment for this project has been described in [22, 24].

The total deviation over the 24 h between the normalized median-averaged measurements and the predicted normalized temporal profile is reported in Table II.

Table II. Total deviation over the 24 h between the normalized median-averaged measurements and the predicted normalized temporal profile for all the measurements sites.

Site	*Group*	*Total deviation [dB]*
Via Lambruschini	A	2.3
Via M. del lavoro	A	1.5
Via Grivola	B	2.1
Via Pirelli (U6)	B	1.2
Via Fara	C	1.3
Via Baldinucci	C	1.1
Via Quadrio	D	1.4
Via Crespi	D	0.9
Via Comasina	E	0.8
Via Veglia	E	0.4
Viale Jenner	F	0.5
Viale Stelvio	F	1.1

Table II indicates a higher deviation for via Lambruschini and via Grivola. Those two sites manifested an unusual noise trend in particular periods of the day and very difficult to predict. In general, small roads present higher vehicle variability and this is reflected on a larger error of the prediction. In addition, using the median method to eliminate unwanted noise occurrences having a random character, we do not reject periodic or systematic events. Figure 5 clearly shows these two types of events recorded in via Fara. At the top of Figure 5, the presence of systematic events is ascribable to the student exit time from a nearby school. At the bottom Figure 5, both random and periodic events are shown as derived from single daily noise measurements.

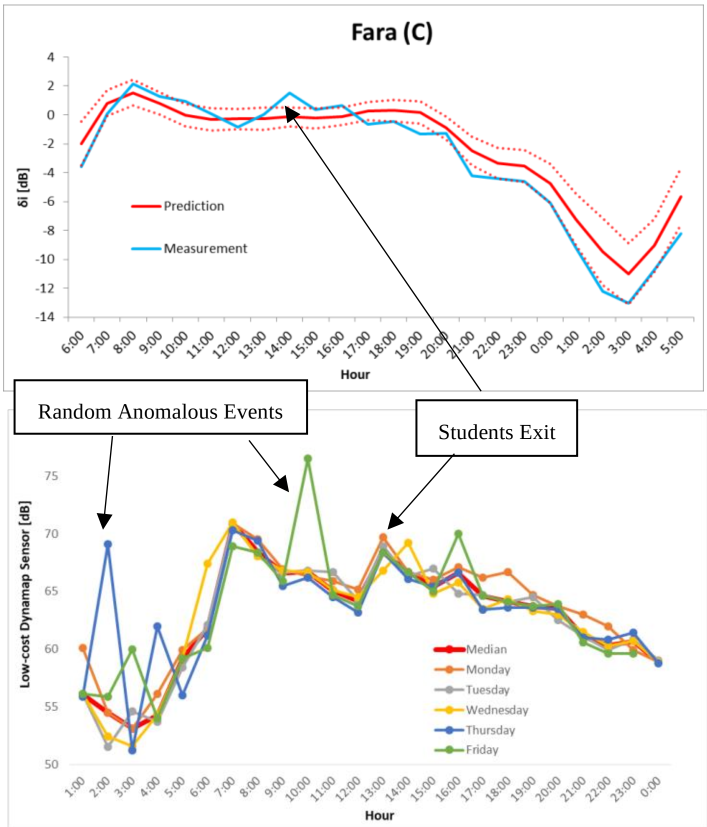

Figure 5. Top: systematic events ascribable to the student exit time from a nearby school. Bottom: both random and periodic events are shown as derived from single noise measurements (no median) in via Fara.

3. Conclusions

We showed the capability of the adopted scheme to predict with a rather good approximation (error < 2 dB with the exception of via Fara and Grivola) in 12 measuring sites (see Table II). Those sites have been chosen to be used as location for the low-cost monitoring stations in the Dynamap project. This initial verification demonstrated that it is possible to remove from the recorded time series ANEs with random character but not those of periodic nature. For this reason, an automatic ANE detection software is being tested to overcome these systematic occurrences.

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