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ANOMALOUS NOISE EVENTS CONSIDERATIONS FOR THE COMPUTATION OF ROAD TRAFFIC NOISE LEVELS: THE DYNAMAP'S MILAN CASE STUDY

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Dynamic noise maps are computed to represent the noise levels generated by road traffic in real time to determine the population exposure to environmental noise. To this aim, a network of acoustic sensors can be deployed in representative street locations to capture and process raw acoustic data before estimating the equivalent noise levels (L_{eq}) of the maps. In the framework of the DYNAMAP project, we conducted a study of the acoustic levels of several streets to determine the most suitable places for the sensors to be deployed in the case study of Milan city. The conclusions of that analysis were that the streets under test could be described by two different time-dependent behaviors, instead of the functional classification of roads. For a proper evaluation of the equivalent value L_{eq}, several acoustic events existent in the street measurements have to be removed, since they are not generated by road traffic noise. These events, denoted as anomalous noise events, can come from sirens, horns, noisy human activities, etc. To that effect, the measured acoustic signal in the street has to be studied to classify whether the sample belongs to regular road traffic noise, or it is an anomalous noise event, assuming that the typology of these events is very diverse. In order to allow the deployment of the monitoring system, this evaluation should be conducted previously, and if possible, in the acoustic sensor sites resulting from the previous analysis. In this paper, we evaluate the different typologies of anomalous noise events observed in the city of Milan and we describe them statistically according to the identified street clusters. Moreover, we study the potential impact they may cause in the L_{eq} evaluation if not discarded.

Environmental sound recognition, dynamic noise maps, anomalous noise events, road traffic noise, L_{eq}

1. Introduction

Several studies warn about the consequences of noise pollution over the human health, disturbing the sleep [1] or affecting negatively in concentration and communication between human beings [2]. As a response to the alarming rise of environmental noise pollution, the European Union developed the European Directive 2002/49/EC related to the assessment and management of environmental noise (END) [3], which states that the noise level maps of certain city areas should be updated every five years. Thanks to the deployment of acoustic sensors networks, dynamic noise maps can address this goal by representing the equivalent noise levels generated by road traffic in real time. This way, more detailed information of the exposure of citizens to environmental noise can be obtained.

In this framework, the DYNAMAP project [4, 5] envisions the development of an automatic system able to specifically monitor the acoustic impact of traffic noise sources in real time. Two pilot areas are considered to validate the proposal in urban and suburban areas in Milan and Rome, respectively. The criteria used to identify the monitoring spots is detailed in [6], and the details about the recording campaign conducted to analyze both urban ans suburban soundscapes are described in [7]. In order to achieve the project goal, the designed system should be able to automatically acquire the acoustic data and process it to obtain the sound pressure levels generated by the road traffic. Low-cost acoustic sensors [8] are used to collect the data and a Geographic Information System (a GIS platform) [9] is employed to represent the noise map in real-time.

One of the requirements of the project is to prevent non-traffic noise sources –denoted as anomalous noise events (ANE)– from biasing the map traffic noise computation. To that effect, an Anomalous Noise Event Detection algorithm (ANED) is implemented in the low-cost sensors in order to decide whether the input sound comes from traffic or comes from ANE (see [10, 11, 12] for further details). The implemented algorithm should be capable of classifying the input sound frames into two main categories: Road Traffic Noise (RTN)/Background Noise (BCK) or ANE at the frame level. Once the label is assigned to each frame, the sound pressure level is computed after removing the frames labelled as ANE. This way, the real-time noise map can be updated with traffic noise sources avoiding certain non-traffic noisy sources as thunders, birds, trains, tramways, airplanes, music, people talking, to name a few.

As the Sound Pressure Level (SPL) varies over time, it is necessary to define the equivalent continuous sound pressure level, known as L_{eq}. In other words, the L_{eq} is a global level that would produce the same energy as the original varying SPL between two given points of time. In our case, the integration time is one second (1 s) for the analysis of ANE, and 5 min for the noise map tailoring [4]. Also, an A-weighting filter is applied to model the human-ear frequency response.

The main goal of this paper is to study the noise typology of Milan in terms of ANE, considering the two clusters described in [13] (further details can be found in [14, 15, 16]), besides analyzing the impact of the inclusion or removal of the ANE in the L_{eq} computation. For this purpose, we compare the distributions of ANEs within the two clusters in the Milan urban area in terms of occurrences, durations and Signal-to-Noise Ratio (SNR) following the methodology described in [7]. Moreover, we discuss the impact of the ANE in the L_{eq} by means of some illustrative real-life examples.

The paper is structured as follows. Section 2 describes the details of the two road clusters in the recording spots of Milan and how they differ when compared to the functional classification of roads. Next, the typology of the sound events related to the cluster classification is detailed in Section 3, including several comparisons. Finally, the paper is closed with the discussion of the impact of the ANE in the L_{eq} computation in Section 4 and the conclusions and future work in Section 5.

2. Cluster categorization

The cluster analysis applied to the 24-h continuous monitoring of the traffic noise hourly equivalent levels L_{Aeqh} of 58 [13] and 93 [17] sites in Milan showed that the database of measurements can be grouped into two mean noise profiles. These two time-dependent behaviors reflect in roads sharing the same vehicular dynamics, and show how this approach provides a more real description of the road network of a large city than the usual legislative road classification (Functional Classification). These are the reasons behind the DYNAMAP project for the reference pilot area of Milan, where a dynamic noise mapping will allow traffic noise levels to be updated by using a limited number of monitoring stations. The updating of each non-monitored road contained in the pilot area is achieved by assigning each road to one of the two clusters, therefore, according to its intrinsic traffic dynamics.

We found that a "good" and easily available "non-acoustic parameter" capable of linking efficiently each road to a specific cluster is represented by the traffic flow rate at rush hour. In Figure 1 the boxplots of the traffic flow rate at rush hour for the two cluster show that a value of about 2000 vehicles per hour represents a threshold between the two profiles [13, 17]. This result has been further confirmed by a ROC analysis [18] as reported in [17].

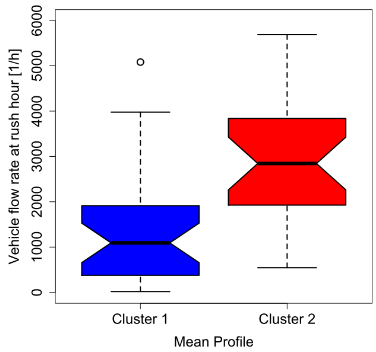

Figure 1: Box plots of the traffic flow rate at rush hour for the two cluster.

3. Anomalous noise events typology and study

In order to understand the differences in terms of ANE for the two clusters of roads, its nature is first studied. Milan scenario presents two distinct sets of recordings which must be considered. Moreover, the several recording points can be classified in clusters depending on the typology of the existing sounds and the temporal distribution along the day. In Table 1, all the Milan recording campaign details are given including the cluster and functional classification as reported in [13].

Table 1: DYNAMAP Milan Measurement Campaign.

Cluster	Street	Functional Classification	Time (UTC +01) (hh:mm)	Duration (hh:mm:ss)	ANEs found
1	Piazza Ospedale Maggiore	E	12:48	00:30:06	49
	Viale Fulvio Testi	F	17:22	00:46:36	60
	Viale Sarca	F	11:08	00:17:38	19
	Via Giovanni D'Anzi	E	14:18	00:30:20	20
			Total Cluster 1	**02:04:40**	**148**
2	Via Della Pergola	B	13:54	00:13:06	25
	Via Privata Mario Galli	A	16:33	00:17:06	62
	Via Chiese	D	11:46	00:30:45	50
	Via Gaeta	B	15:55	00:30:24	109
	Via Giuseppe Guerzoni	C	17:26	00:21:43	154
			Total Cluster 2	**01:53:03**	**400**
			All Clusters	**03:57:43**	**548**

Table 2 shows the tags used in the labelling phase together with the type of sound events that they represent. In some cases throughout this section, the ANEs are analysed in two parts for illustrative purposes, which are represented by the two set of columns in the table.

In the following subsections, several analysis of ANEs for each cluster are made in terms of several metrics. Firstly, an overview of the sound events typology for each cluster is presented, after

Table 2: Tags used in the labelling process.

airp	airplanes	*musi*	music from cars
bike	bikes	*peop*	people talking
bird	birdsong	*sire*	sirens
brak	vehicle brakes	*stru*	structure sounds and vibrations
busd	bus or tram doors	*thun*	thunders
chai	chains (e.g. from bikes)	*tram*	tramway pass-by
dog	dog barks	*tran*	train pass-by
door	house or vehicle doors	*trck*	heavy-load vehicles passing a bump
horn	vehicle horns	*wind*	noise of wind and leaf movements
mega	station PA		

that, a detailed comparison of two sound event features (duration and SNR) is given, which results reinforce the need of street clusterization.

3.1 Number of occurrences and duration of ANEs for each cluster

In this subsection, a first analysis of the ANE typology is presented. A comparison between the nature of sounds which may be heard in every cluster and the aggregated duration of each type of ANE is shown for both clusters.

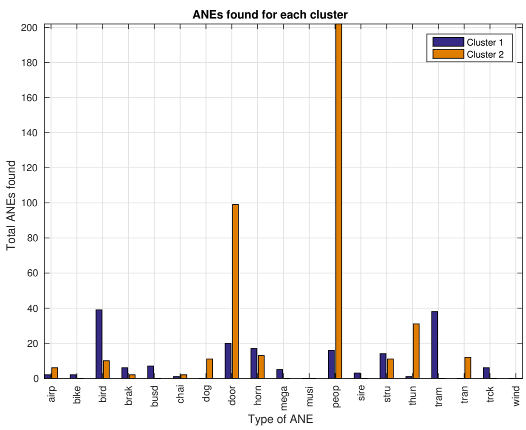

Figure 2: ANE occurrences for each cluster.

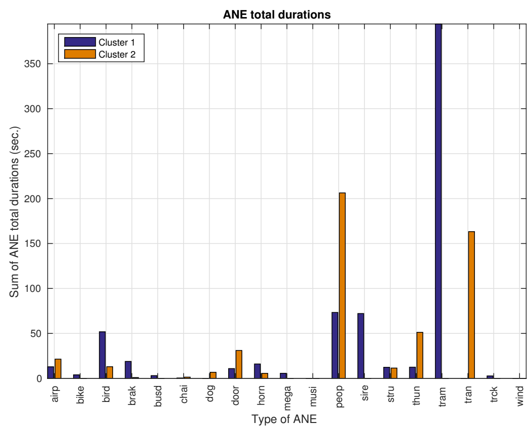

Figure 3: ANE aggregated durations per cluster.

The reader can figure out the nature of each cluster from the analysis of Figures 2 and 3. More pedestrian-related sounds are heard in *cluster 2*, i.e., door-like sounds, barks of dogs and sounds coming from people. Even though a lot of *people* sound occurrences are registered, it is worth to mention that several tags could be part of a single conversation. However, more *public transport doors*, *brakes*, *bikes* and *horns* are heard in *cluster 1*. These facts are an indication that *cluster 1* roads belong to areas with more high traffic density while *cluster 2* contains roads with higher presence of pedestrians together with lower traffic density.

3.2 Detailed analysis of the ANE duration for each cluster

In this subsection, a detailed analysis of the ANE duration is presented for each type and cluster.

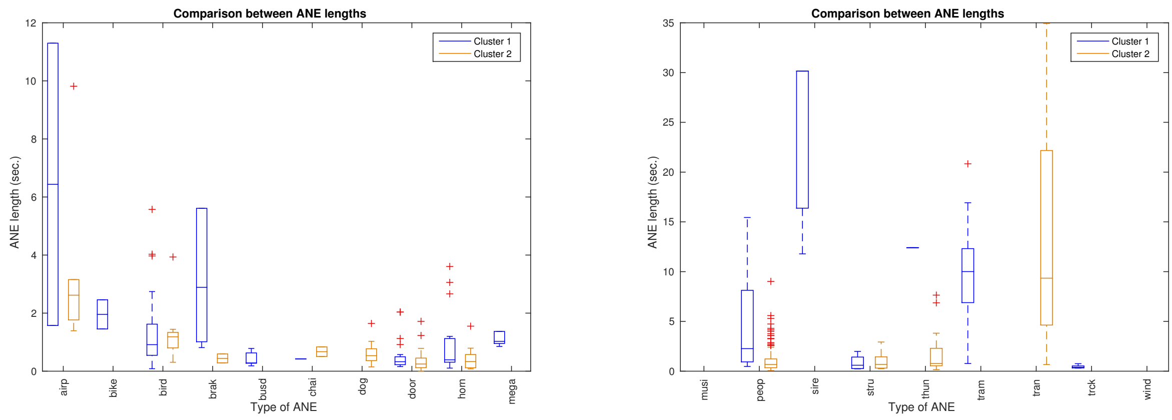

Figure 4: Duration boxplots of the ANEs in two groups (Left: first group. Right: second group.)

The reader may observe in Figure 4 the measured lengths for each ANE, which can present a great importance when considering their contribution to L_{eq} value measured during all day. Although events like *airplanes* and *brakes* are not the most frequent in any of the clusters, their presence should not be underrated. With an approximate median values of 6 and 3 seconds respectively, they stand out from other detected ANEs whose median stays between 0.5 and 1 seconds. Also *trains* and *trams*, with a median value of around 10 seconds, and sirens, with a median value of more than 15 seconds, have to be taken into account for their strong influence to the L_{eq} value calculus, especially due to ANE duration.

3.3 Detailed analysis of the ANE SNR for each cluster

In this subsection, a detailed analysis of the Signal-to-Noise Ratio for each ANE type and cluster is given. SNR can be interpreted as a measure of acoustic salience of the anomalous noise event in regard the background traffic noise. The SNR estimation is carried out comparing the median L_{eq} level of the ANE region to the median L_{eq} level of the nearest surrounding RTN region. The L_{eq} level of the surrounding RTN region is measured in both sides of the ANE if possible, right before and after the ANE occurrence. However, in some cases this is not possible and only the previous or the next region can be considered (see [12] and [7]) for further details).

Figure 5 shows the boxplots of the SNR separated by typology and cluster.

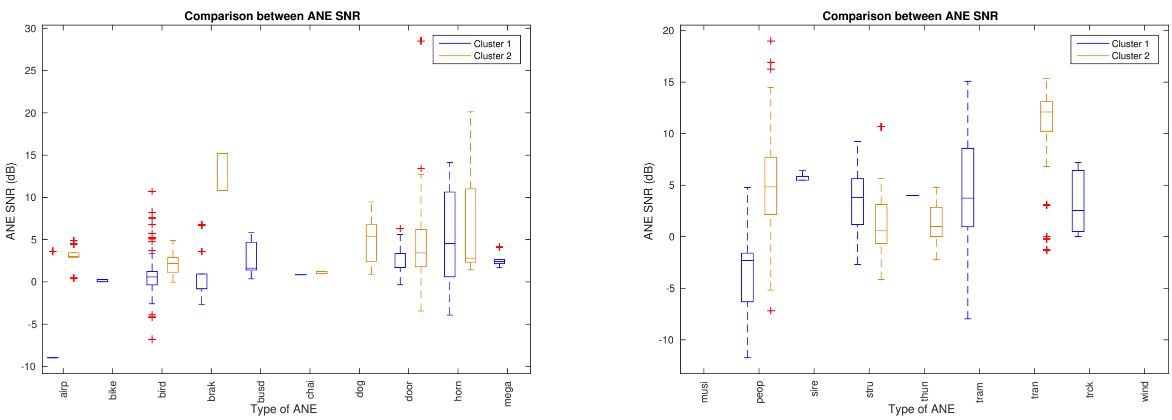

Figure 5: SNR analysis of the ANEs in two groups (Left: first group. Right: second group.)

In Figure 5 the higher SNR ANEs can be clearly identified for each cluster. The results for the evaluation of the SNR in each cluster are not equal for each ANE, despite there is a coincidence in the ANEs showing higher SNR. We can highlight that *thunders*, *doors* and *horns* are the noisiest events detected in both clusters, while *brakes*, *dogs*, *sirens tramways* and *trains* are salient but only in one.

4. Impact of the ANE SNR on the L_{eq} computation

As it has been observed in the previous analyses, the ANE present a large variability in terms of occurrences, durations and SNRs. In this section, we discuss the impact of these acoustic events in the L_{eq} computation according to their acoustic salience measured in terms of their SNR with respect to the RTN or BCK, concluding the importance of detecting properly ANE in the acoustic data measured.

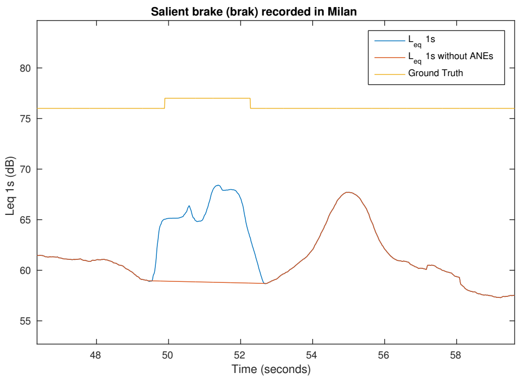

Figure 6: Example of a salient ANE.

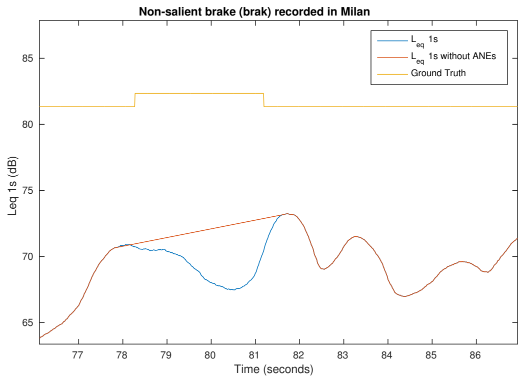

Figure 7: Example of a non-salient ANE.

In Figures 6 and 7, two examples of different ANEs recorded in Milan are shown for illustrative purposes. The first belongs to a salient ANE and the second to a non-salient ANE, both labelled as brake sounds. In both figures, the noise event activation is shown as a binary yellow function. Moreover, the L_{eq} curve with 1-s integration time is depicted when considering the whole signal (in blue), and without considering the sound level corresponding to the ANE time region by performing a simple linear interpolation of the L_{eq} values between its start and end points (in red). As it can be observed, the L_{eq} curve within the ANE time region is above the interpolated L_{eq} curve (without ANE) for the salient anomalous noise event, and its just the opposite for the non-salient ANE. For the evaluation of these two examples, the value in dB of each measured L_{eq} is not a key parameter, but the comparison amongst the L_{eq} values during the ANE and the L_{eq} values of the signal surrounding the ANE. As a next step, future work will be focused on the study of the acoustic salience of an anomalous noise event to determine whether it should be removed from the L_{eq} calculus or it should be maintained.

In Figure 8, the L_{eq} measures of two entire recordings is shown using a 5-min integration time, which is the proposal for the noise map tailoring [15]. The two examples show few samples due to the length of the measurement campaign samples (see Table 1). One can appreciate the difference between the L_{eq} curve considering the whole sound when compared to the corresponding function after excluding the ANEs. Specifically, in the leftmost example, only a difference of 1.1 dB is appreciated between the RTN-only and the whole sound, which is negligible as it lower than $\pm 2dB$ [19]. However, in the rightmost example, a difference of 7.3 dB is obtained between both values, which would have a significant impact if it is computed in the traffic noise map. These two examples show the impact that identifying the ANEs correctly can produce in the computation of L_{eq}, which leads to the need of detecting the ANEs before integrating the noise level measures in the traffic noise maps when developing acoustic sensor networks.

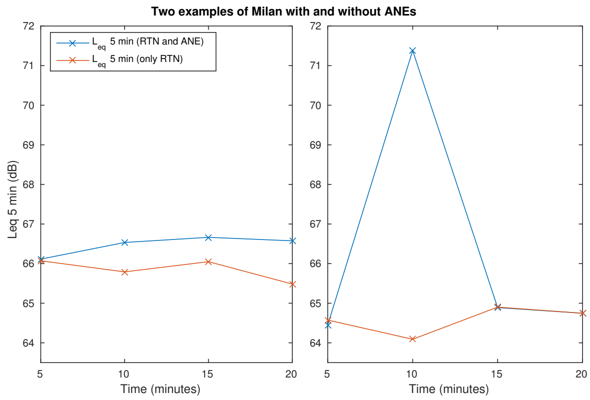

Figure 8: Left: example of the impact of a non-salient ANE in the L_{eq} computation. Right: example of the impact of a non-salient ANE in the L_{eq} computation. In both cases, an integration time of 5 minutes for the L_{eq} computation is considered.

5. Conclusions

This work has presented the analysis of a real-life anomalous noise events database collected in a urban scenario within the Milan pilot area of the DYNAMAP project. The characteristics of ANEs in terms of occurrences, durations and SNR distributions within the two previously observed road clusters in Milan and their impact in the road traffic noise level computation have been detailed through some salient and non-salient ANE selected from the databased for illustrative purposes.

The analysis of the ANE distribution within the two clusters corroborate the hypothesis of dividing the Milan streets in terms of homogeneous 24-h noise patterns instead of following their functional classification. The number of occurrences and the duration of each type of ANE category present different values per cluster; e.g. cluster 2 contains more noise samples related to pedestrians, whereas cluster 1 contains more noise samples related to public transport, which is in concordance with the typology of roads that compose each cluster. Moreover, the SNR levels for each ANE category are different for each cluster, but they share the same type of noisiest ANE categories (e.g. thunders, horns, doors, etc.).

The impact of ANEs in the L_{eq} computation has also been demonstrated through illustrative examples collected during the Milan measurement campaign. It has been shown that the inclusion or removal of both salient (high SNR) and non-salient (low SNR) do affect the computation of the L_{eq} computed with 1-s and 5-min integration times. This preliminary results encourage us to continue the study of the influence of the ANE in the calculation of the equivalent value to draw the dynamic map.

Although we have analyzed around 4 hours of real-life acoustic data, the recordings only represent between 20 and 30 minutes of audio per road at best. Therefore, more analyses need to be done to confirm the reported differences. To this aim, we plan to consider longer periods of time in the measurements to cover the whole day and night to obtain stronger conclusions. From these future analyses, we expect to obtain a more detailed analysis of the typology of ANE together with their most relevant characteristics (e.g., duration and SNR), being also necessary to extend preliminary conclusions of their impact in the L_{eq} computation for a reliable noise map update.

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