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Long term monitoring of noise pollution in social gatherings places: time analysis and acoustic capacity as support of management strategies

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ABSTRACT

City of Torino (Italy), as many European cities, is facing noise pollution related to recreational noise of nightlife in open urban areas, such as streets, squares and terraces, where thousands of people meet spending all evening and night time. Noise from people speaking in these spaces can be very loud, due to crowd levels (since communication is possible only with a raised voice level) and people behavior.
This study shows the analysis of long term noise data collected in two years by a low-cost IoT network in San Salvario area. It highlighted regularities on night levels, mainly on a weekly basis with a seasonality.
Preliminary investigations on time series have been developed, in order to correlate noise levels and number of people involved, coupling environmental noise data and crowd sensors. Moreover, the concept of 'Acoustic Capacity' related to the noise levels has been investigated.
This approach based on a deeper quantitative knowledge is explored as an help to local administration and stakeholders in planning and implementing mitigation actions.

Keywords: urban open space, recreational noise, Lombard effect, contextual factors, acoustic capacity

1. INTRODUCTION

Nightlife in open-air creates increasing challenges for cities, in terms of annoyance and noise pollution affecting citizen living in the neighborhoods of open air social gatherings places (e.g. in front of bars and in pedestrian areas). In these locations the crowd gradually increases during the evening period, thus causing huge side effects not only due to noise (chatting, shouting, quarrels), but also due to traffic jam, irregular parking, obstruction of driveways, rubbish thrown carelessly on the ground, etc. Noise due to people chatting and shouting outdoor can easily overwhelm what is coming from the inner activities of pubs, bars or clubs and can be particularly intrusive in summer time, when the windows of the dwelling are left open to increase the thermal comfort (1,2).

There are several studies that have investigated the outdoor noise generated by social gatherings conditions (1, 4, 5, 6), however there are only a few studies that have performed long term monitoring (7, 8, 9, 10). A stronger quantitative assessment could support City administrations and stakeholders in defining policies and action: even if in the last years, an increasing number of studies have been focused on the prediction of crowd noise in pedestrian areas or in restaurants, there is a lack of investigations on long term-monitoring of noise data and number of people in highly crowded social gatherings places.

A few algorithms have been proposed to predict noise from small to medium sized crowds in restaurant terraces (up to 20 people) (12) or public space (from 10 to 100) (11) correlating the number of people with level of noise and considering the individual voice effort and whether the noise from individuals is synchronized or randomly distributed in time.

In those studies, crowd noise has be shown to be comprised of two components, i.e. a babble due to individuals in a group of people communicating with each other and transient peaks due to events such as

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people laughing, yelling and cheering. Previous research has suggested that the babble component of crowd noise can be considered as quasi-steady in long-term monitoring due to changes in the emission level as the number of people talking varies (11,13).

Under this condition, crowd noise is usually quite intermittent, having a nearly instantaneous increase and decrease in size i.e. number of people. Previous studies have thus suggested that more than one noise indicator is necessary to adequately describe crowd noise: L_{Aeq} or L_{A10} would represent the quasi-steady babble noise, as well as L_{A1} or L_{Amax} would be good descriptors for peaks due to events (11).

Other researches focused on noise in pedestrian areas, showing a clear relationship between the number of talkers and the crowd density (from 0 to 0.4 persons/m^2) and the sound pressure levels L_{Aeq}. The influences of contextual factors on soundscape and acoustic comfort, as the shop openness, season and commercial function were also investigated (14). The relationship between the number of talkers and the crowd density was found to be not significant at crowd densities below 0.05 persons/m^2, as in this case the sound level appears to be primarily influenced by other sound sources such as traffic noise (15).

Noise in social gatherings places due to a larger number of people has been investigated in indoor venues, taking the Lombard effect into account, and confirming a strong dependence on the number of people present in the room; in this case L_{Aeq} is the noise indicator assumed to describe crowd noise (16).

Both in outdoor and indoor, other secondary factors that influence crowd noise can be considered, as whether or not alcohol has been consumed, the size of the smaller groups of which the crowd is composed; the average age and gender make-up of the crowd; the acoustic characteristics of the venue, and the situational context in which the crowd is placed (11,16).

In order to perform a better quantitative assessment of noise pollution in social gathering places a preliminary quantitative analysis is presented, based on data collected in San Salvario district, Torino.
Moreover, the concept of 'Acoustic Capacity', i.e. to which extent the number of persons should be accepted in the room in order to obtain sufficient quality of verbal communication related to the noise levels (17) has been applied to public space, considering the relationship between crowd density, venue capacity and noise thresholds, in order to evaluate the strategies that would allow for planning and implementing effective mitigation actions.

2. CROWD NOISE MONITORING IN LARGO SALUZZO

2.1 Description of the Venue

One of the most know gathering places in Torino is Largo Saluzzo, located in the historic district of San Salvario. where the large number of restaurants, bars, pubs, and clubs attract each week (especially from Thursday to Saturday) hundreds of people spending all evening and night on terraces and streets (Figure 1).

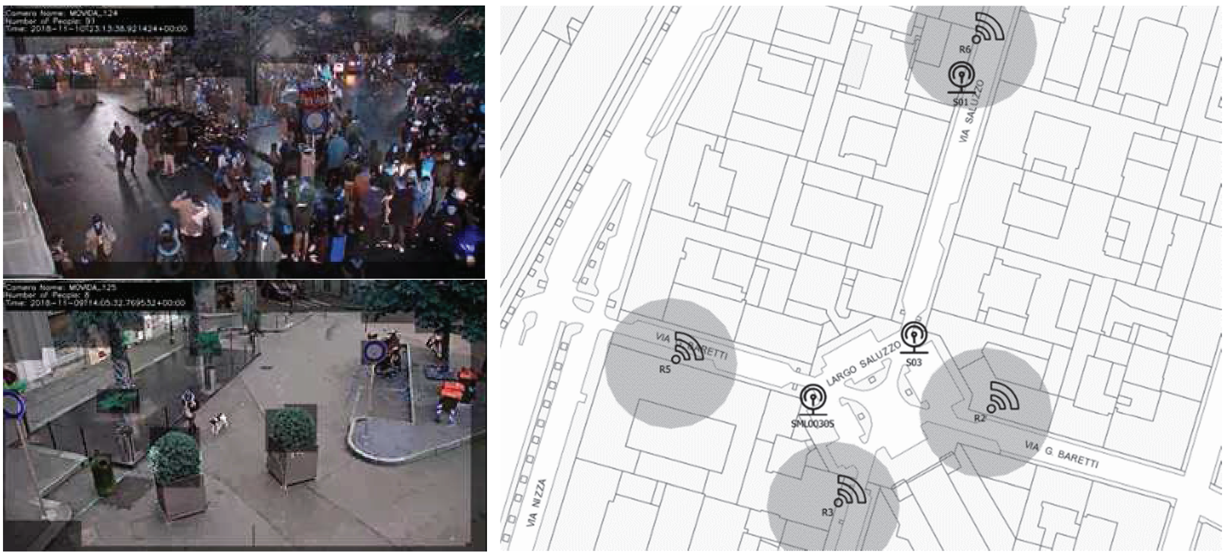

Figure 1: Largo Saluzzo in late night and early morning (left); installed SLMs and WiFI scanner (right)

This small square (2000 m^2 including pedestrian and road area with a volume of approximately 3000 m^3) is one the hot spots of night recreation noise pollution in the urban area. The acoustic measurements reported in (17) show a reverberation time at 500-1000Hz of 1.86s. In the following steps the area of Largo Saluzzo has been approximated to a large courtyard with totally absorptive ceiling and streets exits; thereby an equivalent absorption area has been estimated (A_{tot}= 2582,52 m^2) considering these areas with an absorption coefficient equal to 1 and the other surfaces with the properties introduced in (17).

City of Torino decided to start facing problems of this venue by a data-driven approach based on long-term monitoring and in 2016 has been put in place in Largo Saluzzo a video-surveillance system and a low-cost IoT noise monitoring network. These facilities have been integrated in the last years within the MONICA (19) and ROCK Projects in the framework of European Union's Horizon 2020 research and innovation programme.

2.2 Environmental Noise Monitoring

Considering the high spatial variability of noise in gathering places, a sound level meter monitoring network based on five low-cost IoT sensors has been deployed in San Salvario district by City of Torino, thus integrating previous shorter monitoring campaigns with Class 1 Sound Level Meters (SLMs), thus achieving a better noise knowledge across the area.

This network has been temporary integrated with Class 1 IoT SMLs in the framework of MONICA project since November 2018 (20); In particular, class 1 SLM 00305 (largo Saluzzo) was added to S01 (via Saluzzo) and S03 (largo Saluzzo) – see Figure 1.

Data collected with a sampling time of 1 second are continuously sent via 4G to IoT Open Data Platform to be aggregate on L_{Aeq} on hour and night basis. Monthly calendar plots as shown in Figure 2 are elaborated for each noise sensor, providing an overview of hourly noise levels distribution.

All collected data shows that the overall noise levels in the most impacted area have high variability, with $LA_{eq\ night}$ levels between 60 dB and 72 dB and picks on Friday and Saturday nights between 11 PM and 3 AM levels between 62 dB and 75 dB $L_{A1\ hour}$ (10).

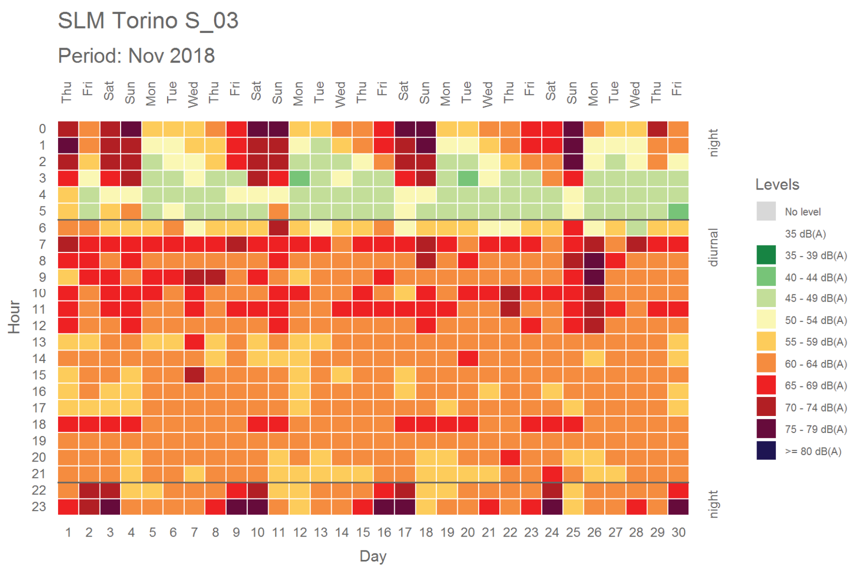

Figure 2: calendar plot of noise levels in Largo Saluzzo, November 2018

The chart shows a certain regularity of the noise levels on weekend nights, from 23 PM to 3 AM, as well as in case of midweek feast days (e.g. Hallowing before All Saints' day on the 1st November) reflecting the presence of people in the venue.

For the monitoring period between 25th October-31st December 2018 some extra analysis has been carried on, in order to compare data collected by the low-cost IoT network and by the Class 1 SLM.

Results of the Spearman correlation indicated that there was a very strong correlation between low-cost IoT and Class 1 SLM noise $L_{Aeq\ 1hour}$ levels, (rs[605] = .95, $p < .001$).

While the scatter plot and a comparison between the two distributions confirm a good coherence between 60 and 80 dB $L_{A1\ hour}$, at lower levels the two sensors show differences (Figure 3): the sensor responses and dynamic should be investigated, as well as local variations of background noise.

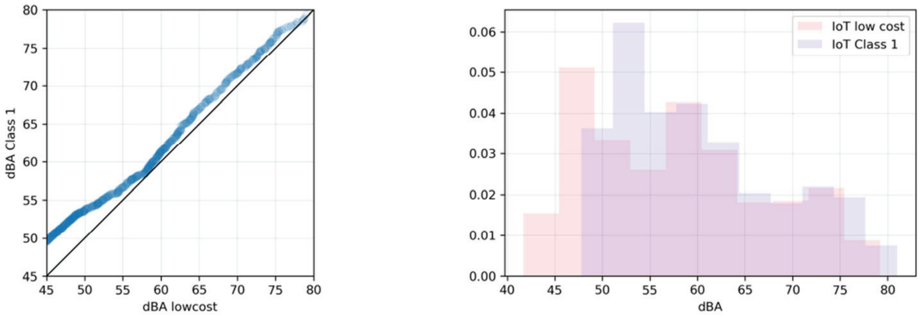

Figure 3: scatter plot (left) and distribution (right) of hour noise levels in Largo Saluzzo, low-cost vs class 1

Statistical values L_{max}, L_{A1}, L_{A5}, L_{A10}, L_{A50}, L_{A90}, L_{A95}, L_{A99} and L_{min} are estimated for each hour on the basis of $L_{Aeq\ 1sec}$ measured by Class 1 SLM.

From a qualitative point of view, the analysis of the noise sources of the area of San Salvario led by Local Police and the Regional Environmental Protection Agency, as well as from psychoacoustic researches (21) reported that the most relevant and annoying noises in the area are due to people behaviors. The most considerable contribution in the wider venues like squares comes from people gathering in front of bars and pubs and in public space, chatting and yelling and consuming alcoholic beverages.

2.3 Crowd Analytics

Gatherings places are often crowded, but due to their spontaneous nature the number of people staying in these area is usually roughly estimated assuming an average density from 0.5 – 0.7 persons/m^2 up to 2 persons/m^2.

A better estimation of the crowd density is considered significant for all issues related to safety and security, but could also help to predict noise pollution. In particular it has been of great interest the investigation of the correlations between measured noise levels and crowd density (15).

In order to close this gap, City of Torino is coupling video algorithms provided by MONICA Horizon 2020 with sensors counting digital signals generated by mobile phones (or other wearable Iot devices) and transmitted over WiFi, provided by ROCK Horizon 2020.

Since October 2018 four WiFi scanner have been installed nearby Largo Saluzzo, three scanners have been placed near Largo Saluzzo (R2, R3, R5) and a fourth in Via Saluzzo (R6).

WiFi scanner of MAC address, providing information about number of unique WiFi devices, allows an anonymous estimation of the number of people present in an area, evaluating also the duration of their stay; aggregated figures are elaborated statistically to get crowd analytics.

In order to estimate people gathering in the public space or in front of pubs and bars, visits shorter than 5 minutes in the entire site are excluded as due to people crossing the area on foot or by bicycle or car; devices detected longer than 6 hours are omitted by default as WiFi hotspot, workers or residents in their dwellings.

The assessment of the number of people on a hourly basis has been computed by cumulating all durations from 5 to 180 minutes (weighted if sub-hourly); this value is set as the minimum of a range in which the maximum is estimated considering also visitors detected for a duration between 180 and 360 minutes.

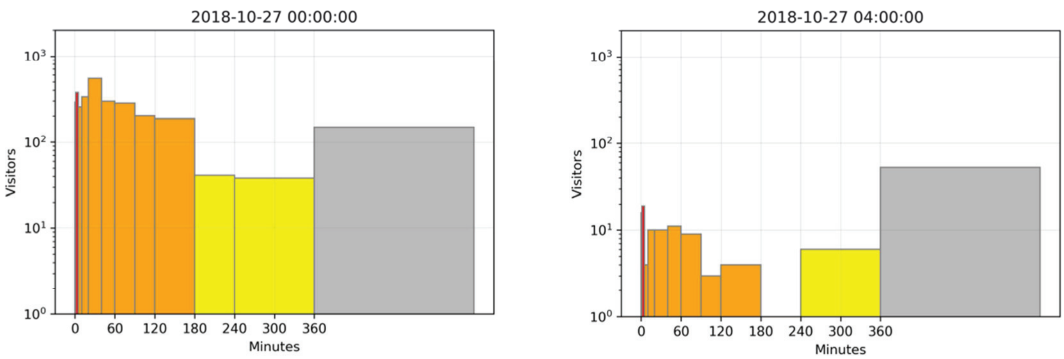

Figure 4: Number and durations of visits in Largo Saluzzo venue: Saturday 27.10.2019 0 AM / 4 AM

Charts of a Friday evening (Figure 4) show a great variability in the number of gathering visitors up to 180 minutes (orange), while the long term presences (yellow) are stable until midnight (customers of restaurants) and decrease during the night, till a little value. Visitors crossing the area (red, less than 5 minutes) seem proportional to values of gathering visitors, while stable devices (grey, more than 360 minutes) shows a strong regularity of presence along the night.

The total number of visitors in Largo Saluzzo is estimated by reducing the total number by 15%, thus excluding visitors counted in R6 region only. In this study, the monitoring period between 25th October-31st December 2018 has been considered and correlated to sound levels.

3. ANALYSIS OF LONG TERM NOISE DATA

3.1 Long Term Crowd Noise Data

The observation of data collected since June 2016 show a certain regularity on hourly noise levels distribution. As shown in Figure 5, levels are distributed in three clusters considering LAeq 1 hour at evenings-night (22:00-06:00): cluster 1 includes Sunday, Monday and Tuesday; cluster 2 groups Wednesday and Thursday; cluster 3 groups Friday and Saturday. Further corrections have been made considering the feast days as Sundays and the pre-feast days as Saturdays A seasonal trend is noticeable, with higher levels in spring and autumn, and lower in winter and in summer, in particular in August.

An ANOVA (Analyses of Variance) has been performed on the L_{Aeq} values over the entire monitoring period using the SPSS Statistics software. The independent variables that have been considered are the number of people, the day of the week, the hour (22:00-06:00), and the weather conditions (quantity of rain). The data have been first analyzed with a normality test (Kolmogorov-Smirnov test), which showed a skewness and kurtosis within the range of -2 to +2 (22).

It was found that the effect of the quantity of rain is not statistically significant $F(20, 593) = 0.890$ and $p = 0.601$. Conversely, the effect of the number of people, the day of the week, and the hour resulted statistically significant with $F(379, 234) = 6.239$ and $p = 0.000$, $F(6, 607) = 31.411$ and $p = 0.000$, and $F(8, 605) = 66.517$ and $p = 0.000$, respectively.

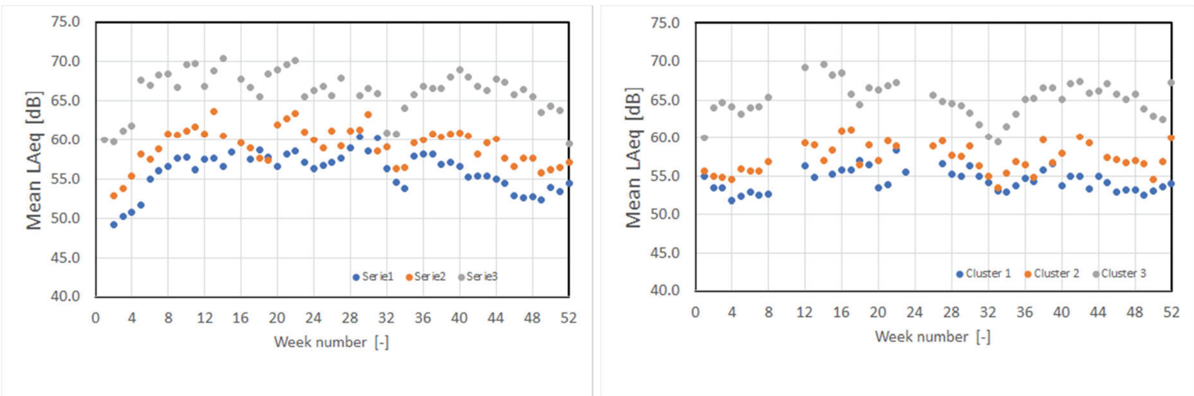

Figure 5: Crowd noise levels during (01/06/2016-31/12/2017) and (01/01/2018-03/03/2019) averaged over a period 21:00-06:00 and grouped in three clusters (cluster 1=Sunday, Monday and Tuesday; cluster 2=Wednesday and Thursday; cluster 3= Friday and Saturday).

3.2 Prediction Model and Acoustic capacity

Rindel (17) has introduced a prediction model for the background noise estimation in places for social gatherings (see Eq. 1), where the phenomenon of the Lombard effect is well-known. This phenomenon describes the effect of the raise in voice levels due to a background noise level (LAeq, dB) higher than 45dB. It has been validated considering the diffuse sound field in large food courts, while for environments with low ceiling and high absorption the prediction model overestimates the background sound pressure levels. This last condition is more similar to the sound field generated within Largo Saluzzo. As can be observed form Eq. 1, the parameters that need to be defined by the user are c (the Lombard slope), g (the group size g=N/Ns) and Ap (the equivalent absorption area of 1 person). The Lombard slope varies in the range 0.5-0.7 dB/dB (16). It can assume also lower values (0.2-0.4 dB/dB) for different sources of background noise (23). Ap can vary in the range of 0.2-1 m2 depending on the clothing and standing conditions of the single person (16).

The model considers the background noise level in terms of A-weighted equivalent sound pressure level

(L_{Aeq}, dB). However, the A-weighted statistical level that is exceeded for 90% of the measuring time (L_{A90}, dB) has been found (24) to be more appropriate for the background noise estimation mainly due to babble noise (≈crowd noise) and thus has been used instead of L_{Aeq}.

$$L_{N,A} = \frac{1}{1-c}\left(69 - c \cdot 45 - 10log\left(g\left(\frac{0.16V}{T \cdot N} + Ap\right)\right)\right)(dB) \quad (1)$$

Figure 6 shows L_{A90} as function of the number of people in the square recorded during the period between 25th October-31st December 2018. The analysis has been performed separately for each cluster shown in sec. 3.1.

The equations of the linear regression lines have been added to describe the measured data (red and green dots) and compare to the predicted equation (blue dots). The background sound pressure levels below logN=1.8 (≈63 people corresponding to a crowd density of 0.03 people/m^2) are around 46 dB (red dots), which indicates that there is a Lombard effect change-point at this level. Therefore, the prediction model, i.e. Eq. 1 has been applied only from this point on. Eq.1 has been applied using g=3.5, c=0.25/0.45/0.55, and Ap=0.7m^2. A value of g=3.5 indicates that 29% of the people is speaking, which remains the same for the different clusters. It can be noticed that the main difference between the clusters is due to the Lombard slope, i.e. the value of c. This value increases for cluster 3 reaching a value of 0.55, which is in the typical range of this parameter for social gatherings (0.5-0.7). It can be noticed that for the same number of people the values of the background noise result different (e.g. for logN=2.5, L_{A90} is around 57dB for cluster 1, 63dB for cluster 2 and 65dB for cluster 3). This suggest that there might be also other behavioural factors that influence the highest values of the background level (e.g. related to the age of the active people within each cluster). Ap values have been set at 0.7 m^2, which was considered adequate for a person in winter cloths.

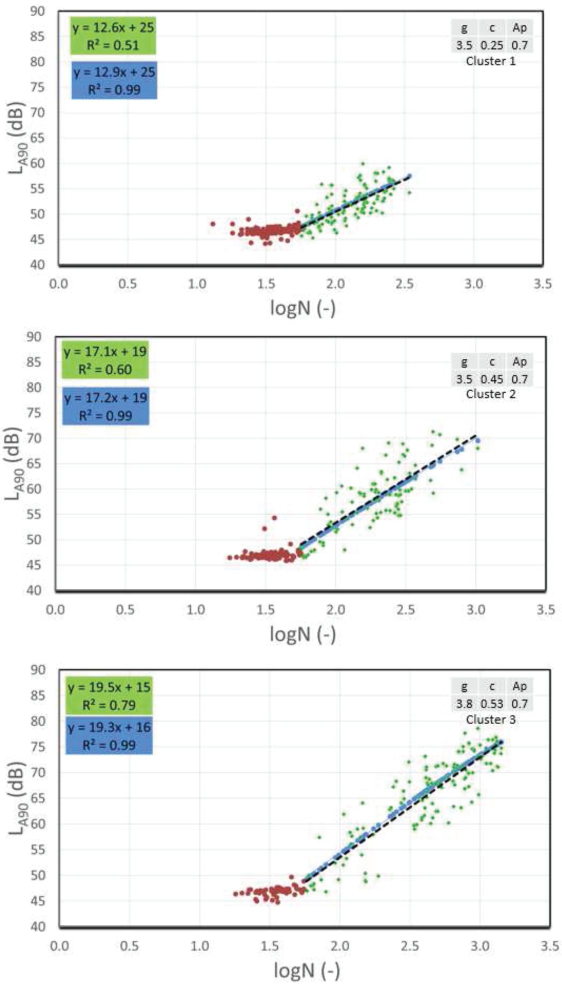

Figure 6: L_{A90} as function of the number of people in the square. Red and green dots indicate the

measured background noise levels. The blue dots indicate the predicted values with Eq.1.

A further analysis has been made regarding the acoustic capacity of this square. This parameter has been introduced by Rindel (17) in order to indicate a design criteria that could be controlled to maintain a sufficient quality of the verbal communication. This is achieved when the background noise is lower than the threshold of 71dB and it limits the maximum number of people allowed to be present simultaneously in the same environment. It can be useful to calculate the maximum number of people (N_{max}) allowed also within Largo Saluzzo square once that the background noise levels threshold are set. Usually these levels are given as L_{Aeq}, however here we refer to as L_{A90}. The parameters that have been tuned above for each cluster based on the prediction model are used in Eq. 1 where the unknown factor becomes the number of people ($N=N_{max}$); a limit of density of 2 persons/m^2 has been set.

Table 1 shows these estimations for the three clusters. It shows that considering the parameters (g, c, Ap) for cluster 3, the N_{max} is lower than for the other clusters. Consequently, the number of people needs to be either limited or their behavior needs to be addressed towards cluster 1 or 2;

Table 1: Number of people compared to the background sound pressure level at thresholds indicated with $L_{N,A}$ values. The values of g, c and Ap have been obtained in the previous paragraph.

$L_{N,A}$ (dB)	**Cluster 1**		**Cluster 2**		**Cluster 3**	
	N_{max}	**Crowd density (people/m^2)**	**N_{max}**	**Crowd density (people/m^2)**	**N_{max}**	**Crowd density (people/m^2)**
50	87	0.04	69	0.03	**62**	0.03
55	213	0.11	132	0.07	**109**	0.05
60	551	0.28	257	0.13	**191**	0.10
65	1644	0.82	516	0.26	**342**	0.17
70	-	-	1109	0.55	**629**	0.31

4. CONCLUSIONS

After a few years of data collection, a good knowledge of outdoor noise level, including a yearly spectrum of hourly noise levels, is available in some gathering place in Torino, Italy.

Regularities on overall noise levels in relation with the seven nights of the week allow to cluster data into three groups, with medium, high and very high crowd noise levels. A certain degree of seasonality can be enlightened, with maximum levels in spring and autumn.

A deeper investigation of the relationship between number of people and background noise has been performed, coupling noise and crowd IoT sensors.

The assumption that in social open air gathering places communication interaction are similar to those in restaurants or reception halls has been applied using Rindel model. This shows a strong correlation of number of people and L_{A90} as background noise indicator, well described by group size and Lombard effect, given the acoustic absorption of the venue and people. As each cluster of nights shows some differences on the Lombard slope only, it is supposed that it is due to some influences of contextual and behavioral factors. However, this will need a more systematic questionnaire-based study, which has not been performed in the period considered here.

The same model allows the assessment of the noise level of the crowd is related to given noise thresholds, and suggests that communication actions increasing awareness of attendees could led to a noise reduction.

Both these elements could help the implementation of reduction initiatives of noise pollution in social gathering places, that remains an open challenge.

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REFERENCES

1. Federazione Italiana Pubblici Esercizi. Le Opportunità della Movida. Andare oltre la deriva circense di

centri e luoghi storici delle città italiane. Rapporto Finale. Indagine Fipe-Censis (in Italian); 2013.
2. Ottoz, E., Rizzi, L., Nastasi, F.). Recreational noise: Impact and costs for annoyed residents in Milan and Turin. Applied Acoustics, 2018, 133. p. 173-181.
3. Pittaluga I., Schenone C., Mangili G. Analysis and control of recreational noise in the historical center of Genoa. Italy 19nd Proc. International Congress on Sound and Vibration, July 2012.
4. Fimiani, F., Luzzi, S. Monitoring and reducing noise related to movida: real cases and smart solutions. Proc 22nd International Congress on Sound and Vibration; July 2015.
5. Cerniglia, A., Zambon, G. Advanced monitoring and analysis on recreational noise in urban area. Proc. INTER-NOISE and NOISE-CON Congress and Conference Proceedings,Vol. 253, No. 2, Institute of Noise Control Engineering; August 2016. pp. 6358-6365.
6. Ballesteros, M.J., Fernández, M.D., Flindell, I., Torija, A.J., Ballesteros, J.A. Estimating leisure noise in Spanish cities. Applied Acoustics 2018, 86. p. 17-24
7. Da Vilva, R., Mietlicki, F., Sineau, M. Noise generated by late-night establishments: a new monitoring and management tool. Proc INTER-NOISE and NOISE-CON Congress and Conference (Vol. 247, No. 4, Institute of Noise Control Engineering, September 2013. p. 4193-4202.
8. Farrés, J. C. Barcelona noise monitoring network. Proc. EuroNoise 2015. p. 218-220.
9. Vinci, A. Tonacci, C. Caudai, P. De Rosa, L. Nencini, L. Pratali: The SENSEable Pisa Project: Citizen-Participation in Monitoring Acoustic Climate of Mediterranean City Centers. Clean Soil Air Water, 45, 2017.
10. Gallo, E., Ciarlo, E., Santa, M., Sposato, E., Fogola, J., Grasso, D., ... & Halbwachs, Y. Analysis of leisure noise levels and assessment of policies impact in San Salvario district, Torino (Italy), by low-cost IoT noise monitoring network. Proc. Euronoise, May 2018; p. 27-31.
11. Hayne, M. J., Taylor, J. C., Rumble, R. H., Mee, D. J. Prediction of noise from small to medium sized crowds. Proceedings of Acoustics 2011.
12. Curcuruto, S., Marsico, G., Betti, R., Mazzocchi, E., Atzori, D., Silvaggio, R., Characterization of sound power level of speech from restaurants in outdoor, Proc. 23rd International Conference on Sound and Vibration, ICSV23; July 2016.
13. Hayne, M. J., Rumble, R. H., Mee, D. J. Prediction of crowd noise. Proc. 1st Australasian Acoustical Societies Conference, December 2006.
14. Zhao, X., Zhang, S., Meng, Q., Kang, J. Influence of Contextual Factors on Soundscape in Urban Open Spaces. Applied Sciences, 8(12) 2018, 2524.
15. Meng, Q., Kang, J. The influence of crowd density on the sound environment of commercial pedestrian streets. Science of the Total Environment, 511, 2015. p 249-258.
16. Rindel, J. H. Verbal communication and noise in eating establishments. Applied Acoustics, 71(12), (2010). p. 1156-1161.
17. Rindel J.H. The acoustics of places for social gatherings. Euronoise 2015, 31 May-3 June 2015, Maastricht, Netherlands, 2015.
18. Calleri C., Shtrepi L, Armando A., Astolfi A., Investigations on the Influence of Auditory Perception on Urban Space Design Through Virtual Acoustics, in Aletta F. and Xiao J. Handbook of Research on Perception-Driven Approaches to Urban Assessment and Design, IGI Global, USA, 2018, p. 343-367.
19. Guillén, S. G., Sala, P., Fico, G., Arredondo, M. T., Cano, A., Posada, J., ... & Wolfert, S. IoT European large-scale pilots–integration, experimentation and testing. Cognitive Hyperconnected Digital Transformation: Internet of Things Intelligence Evolution, 2017.
20. Vincent, B., Haddad, K., Gallo, E., Doucet, C., Nozal, D. C., Jahn, M., ... & Song, W.. MONICA, a European project focused on the Internet of Things for the acoustic quality and safety of outdoor large scale events. Proc. INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 258, No. 7). Institute of Noise Control Engineering; December 2018. pp. 810-820.
21. Calleri C., Shtrepi L., Armando A., Astolfi A. Evaluation of the influence of building façade design on the acoustic characteristics and auditory perception of urban spaces, Building Acoustics 2018, Vol. 25(1) 77–95.
22. George, D., Mallery, P. SPSS for Windows Step by Step: A Simple Guide and Reference 17.0 Update. 10th Edition, Pearson, Boston, 2010.
23. Giguère C, Laroche C, Brault C, Ste-Marie J-C, Brosseau-Villeneuve M, Philippon B, Vaillancourt V, Quantifying the Lombard effect in different background noises. J. Acoust. Soc. Am. 2006120, 3378,
24. Bottalico P. and Astolfi A. Investigations into vocal doses and parameters pertaining to primary school teachers in classrooms. J. Acoust. Soc. Am. 131 (4), 2012. P. 2817–2827.