Temporal and spatial stratification for the estimation of nocturnal long-term noise levels

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Abstract

Noise pollution in cities is mainly caused by the vehicular traffic but, depending on the place under assessment, it could be affected by the land use. For noise assessment and strategic noise mapping, the night period equivalent level (L_{night}), which evaluates sleep disturbance, is one of the requirements of the European Directive 2002/49/EC to be presented for the equivalent time of one year. This research aims to find the influence of the land use in the weekdays stratification to improve the accuracy of the long-term noise level estimation for the night period. It is found that depending on the land use of the place under assessment, the weekdays temporal and spatial stratification could be affected by leisure activities. From a statistical analysis based on a clustering procedure of L_{night} samples in 19 points, it is observed that both, temporal and spatial stratification depend on the intensity of the surrounding leisure activity, and not on traffic. Following these stratification criteria, a sampling method is presented that reduces by 47% the number of days needed to estimate the annual levels with respect

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to random sampling.

Keywords: Noise assessment, Land use, Night period, Leisure noise, Cluster analysis

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Main finding

The intensity of night leisure activities affects the temporal (modifying weekdays/weekends) and spatial (forming new streets categories) stratifications.

Abbreviations and acronyms

The acronyms and abbreviation used in the present paper are listed as follows:

T.C.	Traffic Categorization
DOW	Day Of the Week
PCA	Principal Component Analysis
L_j	Nocturnal noise level of the j^{th} strata
D_j	Number of days of each the j^{th} strata
S_L	Stratas with lower variability
N_j	Number of days sampled in the j^{th} strata
$< L_{j,min-j} >$	Noise level difference between the strata with the lowest and the j^{th} strata with high variability

1. Introduction

Exposure to noise pollution can generate both auditory and non-auditory negative health effects as it is related to annoyance, stress and cognitive problems (WHO, 2011). Some recent researches state that, according to epidemiological studies, noise could also bring different cardiovascular diseases as well as psychological problems (Stansfeld and Matheson, 2003, Basner et al., 2014, WHO, 2016, Münzel et al., 2018). Specifically, night noise exposure propitiates a reduction in the quality of sleep (Basner and McGuire, 2018, Rudzik et al., 2018) and hypertension (Foraster et al., 2014). However, in order to properly carry on epidemiological studies of noise exposure for long periods, long-term noise information is required which is not usually available (King and Rice, 2009, Foraster et al., 2014, Morley and Gulliver, 2016).

Several studies have been conducted in order to improve the estimation of annual values by using temporal sampling strategies which tend to reduce the required measurement time when the noise source is traffic. Random sampling is taken in most cases as a benchmark strategy (Gaja et al., 2003, Makarewicz and Galuszka, 2011, Can et al., 2011, Barrigón and Prieto, 2014, Prieto et al., 2016, Hueso et al., 2017). Some procedures related to extrapolate short time measurements to long-term values are shown in (Safeer et al., 1972, Gaja et al., 2003, Ng and Tang, 2008, Romeu et al., 2011, Brocolini et al., 2013, Prieto and Barrigón, 2015) and some works suggest that a spatial stratification based on street traffic (Prieto et al., 2016, Quintero et al., 2018) or the role of the streets within the city regarding traffic distrubution (Barrigón et al., 2005b, Romeu et al., 2006, 2011) led to a reduction of sampling points.

There are many other studies also indicating that land use can affect urban noise level, such as (Doygun and Kuşat Gurun, 2008, Tsai et al., 2009, Wang et al., 2016, Han et al., 2018), specially in case of leisure activities for the night period (Barrigón et al., 2005b,a, Romeu et al., 2010, Ballesteros et al., 2015, 2016, Ottoz et al., 2018). Concretely, a spatial stratification of streets based on traffic characteristics fails to improve the estimation of night levels (Quintero et al., 2018) as it does for day and evening periods, probably due to the presence of leisure activities nearby the streets.

The proposed research aims to find the influence of land use, and in particular leisure activity, for the nocturnal noise assessment in order to improve the long-term noise level estimation. The objective is to optimize the estimation of the annual value of L_{night} (European Comission, 2002), through a temporal and spatial stratification that does not come from the street classification based only on traffic, but done by clustering procedures to determine the influence of leisure noise in the categorization.

2. Material and methods

2.1. Material under study

This research was carried out in the city of Barcelona which is located in the north-east of Spain. Barcelona has 1.6 million of inhabitants within a land area of about 102.2 km^2. It is the administrative center of a region of more than 7 millions of inhabitants, a commercial center of about 3 million customers and an important tourism destination with more than 4 million people received during 2016 according to official information of the city hall (Ajuntament Barcelona, 2017).

Continuous noise measurements were performed between 2010 and 2015 in 19 sampling points, close to different recreational and leisure activities in the city of Barcelona, using Type 1 sound level meters (CESVA and 01dB brands). Their placement can be observed in Figure 1. The sound meters were calibrated every year to ensure their proper operation according to regulations. They were also equipped with outdoor protection kit and placed according to the European Noise Directive, approximately at 4 m above the ground, mostly on light poles. These points belong to places affected by some leisure or recreational activities in order to study the differences between the real land uses. The noise source of leisure is not the recreational activity itself but the concentration of traffic caused by these activities which may alter the temporal traffic pattern distribution. The measurement point is placed to be representative of the street segment between intersections, to guarantee that the whole nocturnal sound environment was assessed and all noise sources are considered (differences above 10 dB between sources would result in source omission). Table 1 extends the information about the sampling points.

All the considered streets have a mix of different activities and residential buildings, as a result, most of them are considered ”residential” by the land use classification of the city (Figure 1). Moreover, the definition of leisure activity is rather complex as many activities can be tagged as leisure. The hypothesis is that leisure activities influence the night noise patterns, which could depend on the type of leisure activity. For this study, a classification of leisure activities is defined as:

- Commercial (Com): Mostly focused in shopping centers. Mainly day-time activities.
- Food and services (Fs): Restaurants, pubs, with some retail shops nearby. Mainly day or early night activities.

- Leisure (Lei): Streets with taverns, discotheques, mostly focused in nighttime leisure. Mainly night activities.
- Tourism (Tou): Tourism spots or places with high tourism activity. Mainly day and night activities.

The mentioned zone characteristics were selected based on the nearby activities that the place under assessment has (maximum around 3 blocks of radius).

The traffic categorization of streets (T.C.) is the same as used in previous studies, but adding pedestrian streets (Barrigón et al., 2005b, Romeu et al., 2006, Jiménez et al., 2008, Quintero et al., 2018):

- Category 1 : Urban ring roads or access roads. Roads that surround the city or that allow access to the city.
- Category 2 : Main streets. Roads within the city which mainly distribute traffic throughout the urban area.
- Category 3 : Ordinary streets. Mainly destination streets.
- Category 4 : Pedestrian streets. Streets whose traffic is very limited or they are only pedestrian.

According to (European Comission, 2002), the night period corresponds to the time between 23:00 hours of the current day until 7:00 hours of the next day. Then, from the original data, the daily equivalent L_{night} was computed (ISO, 2004) together with its corresponding measurement date/time and was stored in a local database for all the sampling points. Only one year of data from the total measurement period (2010-2015) of each sampling point was used for this research, the year with more measured days excluding the days removed after an analysis of days with abnormal noise levels that affected the annual average (Quintero et al., 2018).

2.2. Procedure

In order to increase the long-term estimation accuracy of L_{night} and to shorten the temporal sampling, an estimation based on the temporal and spatial stratification methodology proposed in (Quintero et al., 2018) are followed. To face the uncertainties to establish the categories due to the different leisure activities included in this work, the categorization is performed through a statistical analysis of clusters according to following procedure:

1) A **temporal stratification** is performed to find how the weekdays are grouped within the week.
2) A **spatial classification** to group streets with similar weekly noise patterns is done.
3) A **long-term estimation** is performed by employing the found time-space stratas. Results are compared to random sampling.

2.2.1. Temporal stratification

The steps to follow are:

(a) Determine the optimal number of clusters for each of the sampling points, obtained through the *silhouette* method (Rousseeuw, 1987). The input data is the L_{night} of all the sampled days within each street.

(b) A cluster analysis for an automatic classification of weekdays in each measurement points is performed. The selected clustering algorithm is *k-means* (Jain, 2010) and the input data is the same as for *silhouette* method (L_{night}).

(c) To proof that the found stratas are actually independent subsets, the Wilcoxon rank-sum test is used to reject the null hypothesis that the found stratas come from continuous distributions with equal means. This non-parametric test was selected because not all the data is normally distributed and due to the small number of samples. A statistical analysis is then performed to find the stratas with less variability, which would be the selected to perform the measurements.

2.2.2. Spatial classification

The procedure is:

(a) Similar to what was found in (Zambon et al., 2016), a cluster analysis to group sampling points by the weekly noise pattern is performed using again the $k - means$ clustering algorithm. The input data, in order to classify streets by the variations of the noise levels during the week, is the night equivalent noise level for each day of the week (DOW), $< L_{i,DOW} >$. It is centered to the long-term equivalent level ($< L^i_{night} >$) to perform the classification by the noise pattern of the week, rather than the actual noise levels, and it is computed according to:

$$< L_{i,DOW} >= 10log\left\{\frac{1}{M}\sum_{j=1}^{M}10^{\frac{L^i_{night}(j)}{10}}\right\} - < L^i_{night} > \qquad (1)$$

where i represents the sampling point and j runs from 1 to the M total days of each DOW within each sampled set. The cluster analysis is performed using the data of the whole set of streets.

(b) A Principal Component Analysis (PCA) is done to extend the information about how the noise level of each DOW influences the spatial classification. A PCA gives information about how each variable affects the clustering process and allows to observe the composition of each cluster itself. It also helps to reduce the input variables (usually correlated) into uncorrelated variables called principal components retaining most of the information. The input parameter is the same used for the cluster analysis (Equation 1).

2.2.3. Long-term estimation

For the long-term L_{night} estimation and the accuracy comparison to random sampling, the procedure is as follows:

(a) L_{night} estimation. To estimate the long-term reference period with fewer samples, it is proposed to take samples during the days of the strata with less variability (S_L), and estimate the noise level of the strata with the highest variability, based on an approximation of the noise level difference between their equivalent noise levels (Can et al., 2011). Then, for the annual estimation of L_{night}, for k clusters of D_j weekdays, the following equation is proposed:

$$< L_{night} >= 10log\left\{\frac{1}{7} \times \left[\sum_{j=1}^{k}\left(D_j \times 10^{\frac{L_j}{10}}\right)\right]\right\} \quad (2)$$

where D_j is the number of days of each strata and $D_1 + D_{(...)} + D_K$ must be equal to 7 and L_j is the night equivalent noise level of each strata computed by:

$$L_j = 10log\left\{\frac{1}{N_j}\sum_{m=1}^{N_j}10^{\frac{L_j}{10}}\right\} \quad (3)$$

where N_j is the number of sampled days, used only fot the stratas with lesser variability. For the strata with highest variability, L_j is estimated by:

$$L_j = L_{j,min} - < L_{j,min-j} > \quad (4)$$

where $L_{j,min}$ is the noise level of the strata with the lowest variability, and $< L_{j-j,min} >$ is the difference between the noise level of the strata with low and the one with highest variability.

(b) Statistical data computation. The data used to compare the accuracy of the long-term estimation is the N sampling days required to have 90% of the estimated values inside the interval $< L^i_{night} > \pm 1$ dB, where $< L^i_{night} >$ is the year average (ISO, 2004) for each i street. Then, for computing the percentage of samples inside $< L^i_{night} > \pm 1$ dB, 1000 samples are taken from the data stored in the database for each i and for $1 \leq N \leq 50$ sampling days. The long-term estimation is then computed using Equation 2 and its difference to the actual long-term level $< L^i_{night} >$ is calculated as (Quintero et al., 2018):

$$\overline{\Delta L^{i,N}_j} = < L^{i,N}_{night} > - < L^i_{night} > \quad (5)$$

where $< L^{i,N}_{night} >$ is the $1 \leq j \leq 1000$ equivalent night level for the N sampled days in measurement point i, computed according to Equation 2 for the proposed stratas and according to:

$$< L_{night}^{i,N} >= 10log\left\{\frac{1}{N}\sum_{j=1}^{N}10^{\frac{L_{night}^{i}(j)}{10}}\right\} \qquad (6)$$

for the random sampling strategy. Finally, from the vector of data $\overline{\Delta L_j^{i,N}}$, the N number of days required to have 90% of the 1000 estimation values inside ±1 dB is obtained.

3. Results

3.1. Cluster analysis for temporal stratification

The optimal number of cluster is 2 in all but 3 streets (Table 2). For the objective of the present research, the value is fixed at $k = 2$ since computing the silhouette value with $k = 2$ for those points, the difference to the optimal is very low (0.01, 0.01 and 0.03 for points 4, 8 and 18 respectively).

Figure 2 shows the DOW density of all streets within each cluster. As it can be seen, the highest concentration of days is Friday/Saturday in one of the clusters and the remaining days in the other cluster, which could be interpreted as a stratification. The *Wilcoxon rank-sum* test showed that the weekends and working-days subsets in all but one point (Table 2), come from different distributions ($p = 0.05$). The only exception is the sampling point 9 which, as seen in Figure 2, is a clear outlier for several days in both clusters.

The variability analysis is then performed. The working-days equivalent level L_{night}^{Wd}, the weekends equivalent level L_{night}^{We} and the corresponding 95% confidence interval of the new stratas were computed. The results are presented in Figure 3. As it can be observed, in most of the streets, the 95% confidence interval of the new weekend strata is lower than the working-days interval, thus, L_{night}^{We} would correspond to the strata with low variability. Then, it is proposed to take samples during weekends and estimate the working-days equivalent level for the night period.

3.2. Street categorization by land use

Table 3 shows the corresponding cluster category of each sampling point as well as the $< L_{j,min-j} >$ parameter, computed for each point and for the cluster average. As it can be seen, $< L_{j,min-j} >$ increases as the cluster does (Cluster A with the lowest value to Cluster D with the highest).

To observe the week noise level dynamics for each cluster, the streets were grouped by the obtained classification and the mean $< L_{i,DOW} >$ and the standard deviation for all streets within each cluster was computed. The results are shown in Figure 4. It can be appreciated that each cluster has different $< L_{i,DOW} >$ patterns during the week. It is seen that the classification of streets is related to the noise level difference between working-days and weekends, $< L_{j,min-j} >$.

To get more information of the spatial classification of streets, a PCA analysis was performed. More than 90% of the variability is explained by the first 2 principal components. Figure 5 shows the scatter plot of each sampling point by using the new coordinates defined by the principal components. The influence that Friday and Saturday have in the streets defines half of the clusters, with a negative influence in Clusters C and D, which means that the noisy days are weekends. The rest of the working-days (except Thursday) have a direct influence in Cluster A and B since the streets of these clusters are in the positive side of Component 1, which means that the important days for this type of clusters are working-days. Component 2 has direct influence in the Cluster C, since it is totally on its negative side. The streets that belong to this cluster are the pedestrian ones. As seen in Figure 4, for the pedestrian streets all the working-days have similar $< L_{i,DOW} >$, including Thursday, but, for the rest of the clusters, Thursday is observed to have a $< L_{i,DOW} >$ level between working-days and weekends. The absence of traffic in pedestrian streets, could increase the stratification for the night period (with constant values for working-days and for weekends, but with a marked difference between them) as the noise would be mostly due to leisure and human interactions, which tends to be higher during weekends.

3.3. Long-term estimation

In order to set the $< L_{j,min-j} >$ for the estimation of $< L_{night}^{Wd} >$, since previous noise data will not always be available for all the places under assessment, the average value of all the streets within each one of the proposed cluster categories is used for the long-term estimation.

The N required number of days to have 90% of samples within the interval $< L_{night} > \pm 1$ dB was computed for each street (Table 3). It is also computed for the random sampling strategy to be used as a reference (Gaja et al., 2003, Barrigón and Prieto, 2014, Quintero et al., 2017). The results are shown in Table 3. The global reduction using spatiotemporal stratification compared to random sampling is about 47%.

4. Discussion

Four different street categories are found according to the night noise levels behaviour for the whole week. Relating these categories to the nearby activities of each street (Table 3), some trends can be found depending, basically, of the activity period (day/night). Moreover, as traffic noise is also considered, there is some influence of the traffic category (T.C.) of each street (also in Table 3). Considering these variables, the land use categories found can be generally described from the cluster letter as:

- Category A: Streets with daytime activities, with almost no night life, and supporting considerable traffic (T.C. 1 and 2), so that there is little influence of land use on the categorization. The influence is observed since two T.C. are put together in a same category. These streets could be targeted as Commercial Streets.
- Category B: This category is rather similar to category A, but these streets have a greater density of commercial and food related services, basically daytime activities but with some presence of leisure activities. Mainly composed by T.C. 2 and 3, so the weight of ordinary traffic in the weekly acoustic pattern is not so high as in the category A. These streets could be targeted as a High Density Commercial Streets.
- Category C: Clearly composed by pedestrian streets with great influence of tourism activity. Noise is caused basically by street crowds. These streets could be targeted as Pedestrian Recreational Streets.
- Category D: Streets mainly intended for nighttime leisure activities, with many bars and nightclubs in the surroundings, but with streets opened to traffic. In this case, noise comes from street crowds and traffic as well, but probably the weekly acoustic pattern of traffic is influenced by the traffic flow attending to those activities. These streets could be targeted as Recreational Streets.

This is clearly a tentative classification as, for example, there are only two streets in Category D, so further research is required in order to give a quantitative value to the nearby activities that would make the classification more objective.

There are some measurement points that seem not to fit within the new categorizations due to their lack of improvement, but most of them are in Cluster A, which is the one with less influence of leisure noise during night-time. Within this category, measurement point 9 is a special case, as it fails the independence test and it is considered an outlier as seen in Figure 2. It is a street with very few activity (some small businesses) and very few traffic as well. However, its $< L_{night} >$ is above 57 dB. This value is caused by the traffic noise of the Meridiana Avenue, a main access to Barcelona with a traffic flow over 100,000 vehicles per day, which is only 2 blocks away and point 9 is directly connected to it. Points 2 and 10 from the same category, a reduction in the required days is also not achieved. Both streets have high traffic flow as they are main avenues, although both have influence of commerce activity, probably it is not enough to have an effect into the land use, which is also reflected in a low $< L_{j,min-j} >$ and should be classified according to T.C.

For sampling point 17, from Cluster B, also no improvements are obtained. Computing $< L_{DOW} >$, it was observed that $< L_{Thu} >$ is as high as the weekend (Friday and Saturday) which brings an estimation error, then, Thursday should be separated from working-days for this particular point. The temporal cluster of Street 17 should include Thursday in the weekend cluster which perhaps could define one more category, although it has not been considered in this work as only this case has been found.

As seen in Table 3, for the estimation of long-term values, the cluster categorization brings good improvements as it reduces the global required days in about 47%. It is also observed that the obtained reduction is higher when the $< L_{j,min-j} >$ is high.

Based on a scheme of spatial categorization by temporal evolution, similar as presented in (Zambon et al., 2016), the classification proposed in Section 3.2, extends the temporal evolution to be a whole week pattern in order to take into account the noise level variations due to the nearby activities, which was first observed in (Quintero et al., 2018) to be reflected during the night-time in the weekly noise evolution. The present research also complements the traffic categorization, whose methodology was proved to be applicable at nighttime (Rey et al., 2014) based only on traffic noise (Barrigón et al., 2005b), since now the influence of leisure noise is taken into account as well.

The actual and estimated long-term night noise levels, as shown in Table 3, are consistent with previous studies carried out in other cities around the world (Jakovljevic et al., 2009, Nug, 2014, Frei et al., 2014, Drew et al., 2017, Drudge et al., 2018), but all in all, they are above the WHO recommended limits (WHO, 2009),

The proposed methodology is a tool that, by addressing the spatiotemporal influence of recreational noise, would help authorities to perform the noise assessment for these types of noise scenarios in a more efficient manner and draw action plans accordingly. The parameter $< L_{j,min-j} >$, for the case of practical application of the methodology, should be computed based on previous noise levels (where available) or extrapolated from other urban zones with similar characteristics.

5. Conclusion

The effect of the land use in the street categorization for the night period is found. Based on a cluster analysis, 4 street categories are proposed: Category A (Commercial Streets), comprises streets almost without night life activities and high traffic flow; Category B (High Density Commercial Streets) is formed by streets that include a wide range of businesses such as schools, health care, financial institutions, which are mostly open only during commercial hours; Category C (Pedestrian Recreational Streets), is mainly formed by pedestrian streets that could have recreational places focused on people passing by or tourism activity; finally, Category D (Recreational Streets), comprises streets whose main land use is for leisure, they could have many nightclubs and pubs nearby. For sampling points affected by leisure activities at night, the weekends are found to be Friday and Saturday, and not Saturday and Sunday as for the day period. Also contrary to what happens during the day period, the variability for the night period is lower during the weekends.

The long-term estimation was performed using the spatiotemporal categorization procedure and $< L_{j,min-j} >$ as the category average. For the annual L_{night} estimation, the reduction in the required number of days to have 90% of the samples inside $< L_{night} > \pm 1$ dB was higher than 47%. As observed in Figure 4, the clusters are separated by the difference of noise level between working-days and weekends, being Category A the one with the lowest difference, which means that its land use is more residential with a few or without leisure places, and is suggested to be used the categorization based on traffic, and Category D the one with the highest difference which means it is the one with more influence of leisure noise.

Acknowledgments

Special thanks to the Barcelona City Council for providing the noise data used in this research and to CONACyT for the support with the grant (260828/409838).

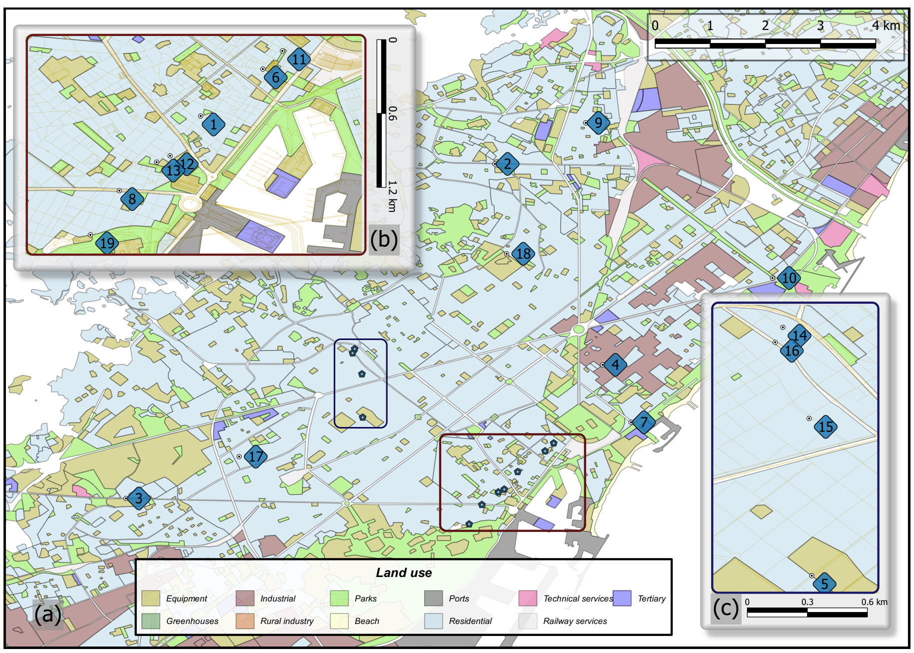

Figure 1: Location of the 19 sound meters in the city of Barcelona and its corresponding land use (Metropolitan Area of Barcelona (AMB)). Figure 1(b), corresponds to the downtown, which has high tourism and shopping/restoration activity. Figure 1(c), has mostly local recreational activity. Figure 1(a) has points distributed all over the city of Barcelona, also in zones with nighttime noise problems.

Point No.	**T.C.**	**Nearby act.**	**Address**	**T. lanes**	**P. lanes**	**Year**	**Land use**
1	4	Tou	Carrer dels Escudellers, 53	-	-	2012	Residential
2	2	Com	Passeig de Fabra i Puig, 274	3	1	2012	Residential
3	1		Carretera de Collblanc , 126	4	-	2014	Equipment
4	2		Carrer dels Almogàvers, 120	4	1	2014	Industrial
5	2	Fs	Carrer de Villarroel, 170	4	2	2011	Equipment
6	4	Tou, Com	Carrer de l'Argenteria, 69	-	-	2013	Residential
7	2	Tou	Carrer de la Marina, 33	6	-	2011	Residential
8	2		Av. del Paral·lel, 55	9	2	2012	Residential
9	3		Servet, 37	2	-	2011	Residential
10	2	Com, Fs	Rambla de Prim, 19	4	-	2013	Residential
11	4	Fs, Lei, Tou	Passeig del Born, 19	4	2	2014	Residential
12	4	Tou	Carrer de Montserrat, 4	-	-	2014	Residential
13	4	Tou	Carrer de l'Arc del Teatre, 5	1	-	2014	Residential
14	3	Lei, Com	Carrer de Lincoln, 8	2	1	2014	Residential
15	3	Fs, Lei	Carrer de Tuset, 17	3	2	2014	Residential
16	2	Com	Carrer de Balmes, 246	4	-	2010	Residential
17	3	Fs, Lei	Carrer de Joan Güell, 153	3	1	2010	Residential
18	3	Fs	Carrer de Sant Quintí, 112	4	2	2011	Equipment
19	3	Lei	Carrer de Beethoven, 2	3	1	2013	Residential

Table 1: Supplementary information of the measurement points. The address, traffic categorization (T.C.), nearby activities, total number and parking exclusive lanes are shown. The column year shows the selected measurement year from the whole set of measurement (2010-2015). The land use is also shown as obtained from (Metropolitan Area of Barcelona (AMB)).

Point	**Silhouette**	**Optimal K**	***p*-value**
1	0.75	2	4.04E-24
2	0.91	2	4.47E-07
3	0.73	2	3.16E-10
4	0.74	**3**	3.49E-27
5	0.76	2	3.77E-31
6	0.76	2	2.45E-34
7	0.75	2	2.83E-22
8	0.76	**6**	5.98E-13
9	0.75	2	***0.51***
10	0.89	2	3.21E-02
11	0.80	2	5.07E-42
12	0.84	2	4.32E-25
13	0.75	2	1.08E-22
14	0.81	2	1.38E-39
15	0.85	2	1.84E-34
16	0.77	2	7.49E-11
17	0.74	2	7.43E-10
18	0.72	**7**	7.79E-06
19	0.75	2	1.38E-12

Table 2: Silhouette average, optimal number of clusters and p-value of the test for distribution mean independence for each measurement point. Values of optimal $k < 2$ are in bold italics. Values of $p > 0.05$ are also in bold italics and mean that the hypothesis that the datasets belongs to distributions with the same mean could not be rejected (p=5%).

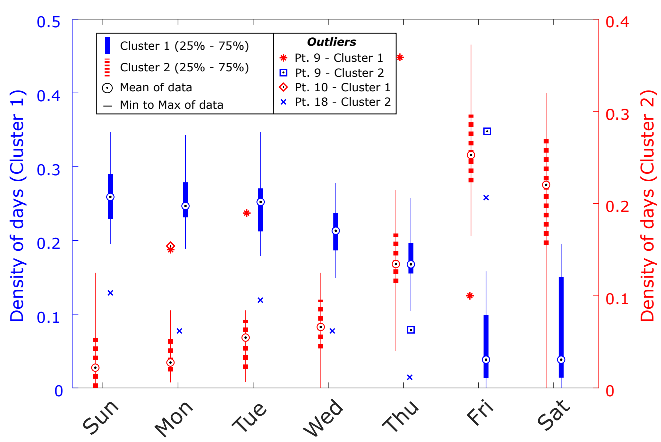

Figure 2: Box-plot of each day of the week density for all of the measurement point within each of the two clusters.

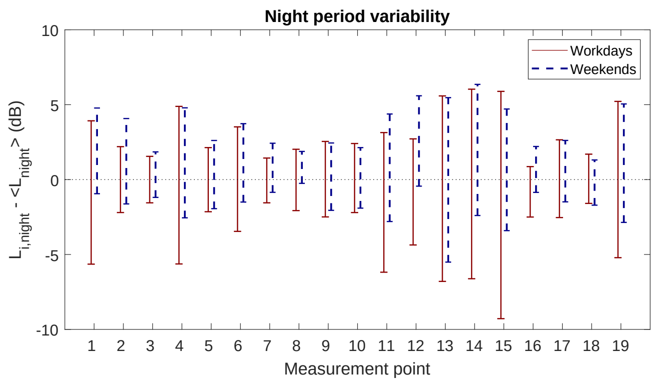

Figure 3: Variability of the night period. L^{Wd}_{night} and L^{We}_{night} centered to the $< L_{night} >$ and its 95% confidence interval in dB.

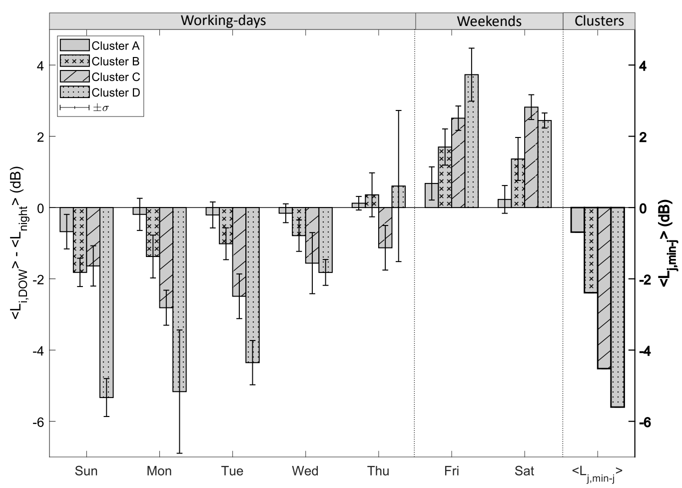

Figure 4: Mean value for each day of the week (Equation 1) of the streets within each cluster category and its corresponding standard deviation. The noise level difference ($< L_{j,min-j} >$) is also shown.

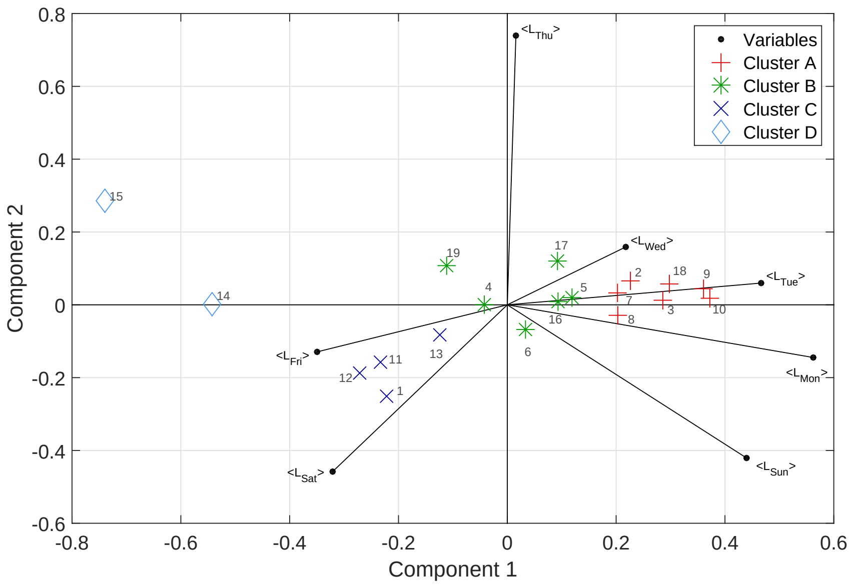

Figure 5: Scatter plot of P.C. 1 vs P.C. 2 for each street. Every point in the scatter plot shows the street number and a symbol corresponding to its cluster. Black dots represent the coefficients of P.C. 1 and P.C. 2 for each DOW and the length and direction of each vector of the input variables, represent the contribution of each of the variables into the first two principal components.

	Categories		$< L_{j,min-j} >$		N Days		Estimations		
Point	**T.C.**	**Cl.**	**Ind.**	**Cl.**	**Ran**	L_{night}	$< L_{night} >$	$< L^N_{night} >$	**Nearby Act.**
2	2		1.02		10	***11***	62.0	63.6	Com
3	1		0.58		2	2	61.9	61.1	
7	2		1.13		4	4	66.2	66.4	Tou
8	2	A	1.50	0.69	5	5	67.6	68.2	
9	3		0.07		7	***12***	58.5	58.1	
10	2		0.07		5	***19***	59.7	59.7	Com, Fs
18	3		0.45		3	3	60.9	60.1	Fs
4	2		2.95		23	14	65.3	64.8	Lei
5	2		1.86		6	5	64.1	63.9	Fs
6	4	B	2.75		11	5	59.4	59.0	Tou, Com
16	2		2.07	2.39	7	3	67.9	66.5	Com
17	3		1.69		10	***12***	60.7	61.2	Fs, Lei
19	3		3.02		23	13	60.1	60.9	Lei
1	4		3.20		30	7	64.4	64.6	Tou
11	4		4.57		42	6	64.4	63.6	Fs, Lei, Tou
12	4	C	5.10	4.52	31	9	61.5	62.0	Tou
13	4		3.46		24	20	70.3	70.1	Tou
14	3		6.15		48	15	62.0	61.5	Lei, Com
15	3	D	5.04	5.60	39	9	65.9	65.2	Fs, Lei
	Total				**330**	**174**			

Table 3: Traffic categories (T.C.), cluster categorization of sampling points (Cl.) and $< L_{j,min-j} >$ computed individually for each sampling point and as the cluster category average is shown. The required number of days to have 90% of samples within $< L_{night} >$ ± 1 dB for random sampling strategy (Ran) and for the proposed stratas, setting the $< L_{j,min-j} >$ as the cluster category (Cl.) average for night period, is also shown. N is bold italic when the required days is higher for cluster category than for random sampling. Finally, the actual annual level $< L_{night} >$ and estimated noise level using N sampled days $< L^N_{night} >$ for each sampling point is presented as well.

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