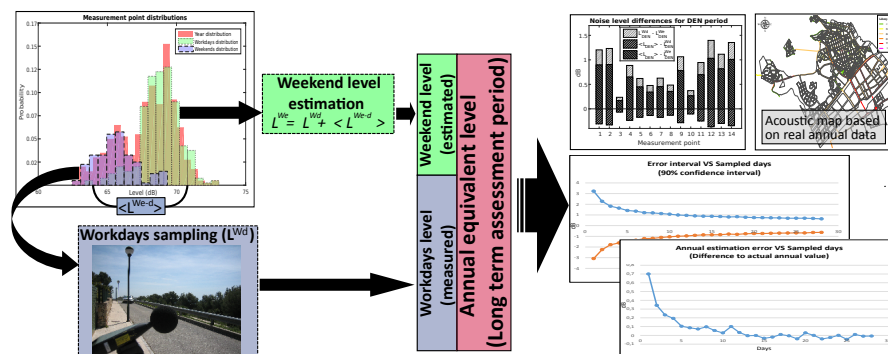


Annual traffic noise levels estimation based on temporal stratification

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Graphical abstract



Highlights

- Improvement in the estimation of long term noise levels.
- Two statistically different strata were found partitioning weekends and workdays.
- Lower variability and higher noise levels on weekdays.
- Reduction up to 38% of the required measurement days to equal random sampling accuracy.

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- Night period stratification affected by leisure activities.

Abstract

This paper proposes a temporal sampling strategy that increases the accuracy of long-term noise level estimation and allows to establish the estimation error according to the number of sampled days. Days of the week are stratified into working days and weekend days. This research shows how to use measurements of L_{eq} on working days to estimate the corresponding values for weekend days. This is possible because working days have higher noise levels and less variability than weekend days. The improvement in accuracy allows for a reduction in the number of required sampled days compared to taking samples randomly, which would help to reduce the uncertainty in environmental noise assessment. As a reference, to obtain a 90% confidence interval of $\pm 1\text{dB}$ for L_{day} , the proposed sampling strategy reduces the required measurement days by more than 38%. For L_{DEN} , the reduction is close to 18% of the total number of days. The proposed strategy could be adapted to different environments by simply changing a few parameters.

Keywords: Temporal variability, Sampling strategy, Noise assessment, Noise mapping

1. Introduction

Noise pollution is one of the main environmental issues in cities as it leads to health problems for inhabitants. The exposure to high noise levels can affect sleep, lead to cardiovascular diseases, cause cognitive problems and even cause property prices to fall [1–5]. It is therefore essential to accurately assess the noise levels to which the population is exposed in order to draw

up and evaluate the effect of environmental noise management strategies [6]. The main basic tool for this purpose are noise maps. According to European Directive 2002/49/EC [7], for strategic noise mapping, the minimum time recommended for noise assessment is one year and should be done (at least) for the indicators L_{DEN} and L_{night} . Such maps are available for many agglomerations in Europe but in most cases the information is incomplete due to the lack of data [8]. Models and standards are also applied inconsistently [9] and the accuracy of the given results is unknown.

Although numerical noise models are the preferred tool for noise mapping, [10, 11], undertaking noise measurements is an essential task for: calibrating noise map modelling tools [12, 13], evaluating the effect of local noise reduction strategies such as green zones [14–16], obtaining results in complex environments where the traffic is not the main noise source [17] or traffic data is not available [13], and obtaining more accurate results [18]. The use of experimental noise measurements is a highly demanding task that is usually simplified using sampling strategies that, as a drawback, could lead to significant differences between the estimated and the actual annual values.

A good approach to reduce variability is to take into account the spatial and temporal correlation [19, 20]. In terms of the temporal aspect of noise assessment, many studies have been carried out to estimate the day equivalent value, for which the actual noise level is approximated by one or a few short time measurements, for a duration that is much shorter than the full-day period, usually between minutes to a few hours [21–24]. An example of street categorization method shows that it is possible to estimate the day-time noise level by taking short time measurements which, depending on

the category, could be improved by restricting the measurements to certain periods of the day [23]. Regarding the minimum time needed for a sample to be representative of a specific place, it has been found that measurements
35 between 10 and 20 minutes are enough to represent the day value [23, 25]. Generally speaking, the criteria used to define the quality of the results is the time taken for the sound pressure to stabilize, e.g., that its fluctuation range be within a certain error interval, which is known as stabilization time [26].

40 In this way, the year equivalent value can be estimated with a certain level of precision using noise levels from a number of days corresponding to a time period much shorter than a whole year. For annual L_{DEN} estimation, researchers have shown that sampling random days during the year gives better precision and representativeness of year equivalent levels than
45 other techniques such as sampling consecutive days, only workdays or only weekends, or random full weeks [27]. Moreover, several authors use random sampling as a basis for comparison of optimizations or improvements proposed in sampling techniques for long-term level estimation [28–31].

The main objective of this study is to determine a sampling strategy which
50 minimizes the estimation error and, consequently, allows for the estimation of the annual value with a reduced temporal sampling. A procedure involving temporal stratification could be used to reduce variability. It is possible to identify days within a week with lower variability that can be used to estimate unsampled days and lead to a better annual estimation. This study
55 computes the average difference between weekend and workday equivalent noise levels, $L^{Wd} - L^{We}$, and uses it to estimate the weekend levels from the

measurement of randomly selected workdays.

The research is structured as follows: section 2 presents information related to sampling points and measurement analysis; section 3 presents the proposed methodology; section 4 presents the weekday analysis that led to the proposed formula and the results of its application to different day periods and parameters; section 5 presents a discussion of the results and the temporal stratification strategy application for different day periods; and finally, section 6 presents the conclusions.

2. Data

Barcelona is the capital of Catalonia, which is one of the 17 autonomous communities of Spain. It is an important hub for services and tourism, with a land area of around 102.2 km^2 and a population of about 1.6 million people according to the municipal register of inhabitants. It is the centre of a conurbation of about 3 million inhabitants. In summer, the climate is humid and hot, with temperature ranging between 23°C and 30°C , while in winter it ranges between 9°C and 12°C . Average annual rainfall is approximately 600 mm, with autumn being the most rainy season of the year.

A total of 14 Type 1 CESVA and 01dB sound level meters, equipped with an outdoor protection kit, were placed in 14 different streets in the city of Barcelona, at an equivalent height of around one storey (approximately 4m above the ground according to the European Noise Directive). Measurements of L_{Aeq} were continuously taken between 2010 and 2015. The measurement equipment was calibrated every year to ensure proper operation and accurate measurements according to regulations. Time integration for the noise level

was originally set at between 1 second and 10 minutes for different sound meters. In the end, this study only used the data of one full year for each street. The chosen year for each street was the one with the fewest missing measurements.

85 Streets were categorized according to three different categories in which urban traffic is considered to be the main source of noise [32, 33]:

- 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.
- 90 • Category 3: Ordinary streets. Mainly destination streets which are commonly used for residential, commercial or leisure purposes.

The locations of the measurements points are shown in Figure 1. According to previous experience [23, 33, 34], higher traffic flow means more stable values and the categorization is established according to traffic flow order.

95 The number of streets was also selected according this previous knowledge in order to get representative results. For category 1, less points were selected and measurement points were located in places where it is known to exist constant traffic flow. For category 2 and 3, the number of points was increased and they were located in streets with different traffic conditions and different use of the territory in order to verify that the proposed strategy was applicable in a more general way, i.e. not to be limited to certain types of streets or cities. Categories and supplementary information about each measurement point can be found in Table 1.

100

<i>Point No.</i>	Category	Street	Lanes	Parking	Year
<i>1</i>	2	Passeig de Fabra i Puig	3	1	2012
<i>2</i>	1	Carretera de Collblanc	4	-	2014
<i>3</i>	3	Carrer dels Almogàvers	4	1	2014
<i>4</i>	3	Carrer de Villarroel	4	2	2011
<i>5</i>	2	Carrer de la Marina	6	-	2011
<i>6</i>	2	Av. del Paral·lel	9	2	2012
<i>7</i>	3	Carrer de Servet	2	-	2011
<i>8</i>	2	Rambla de Prim	8	4	2013
<i>9</i>	3	Carrer de Lincoln	2	1	2014
<i>10</i>	3	Carrer de Tuset	3	2	2014
<i>11</i>	2	Carrer de Balmes	4	-	2010
<i>12</i>	3	Carrer de Joan Güell	3	1	2010
<i>13</i>	3	Carrer de Sant Quintí	4	2	2011
<i>14</i>	1	Carrer de Beethoven (Side of Diagonal)	3	1	2013

Table 1: Supplementary information regarding the measurement points. Data regarding total number of lanes and how many of them are specifically designated for parking is shown. It also shows the measurement year chosen from the total sampled years (2010-2015).

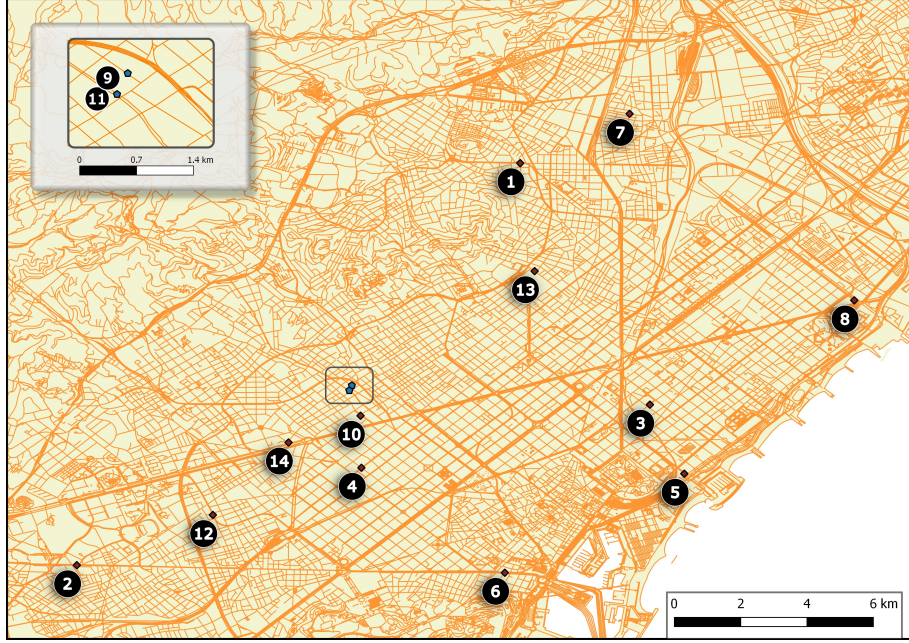


Figure 1: Location of the 14 measurement points.

105 3. Methodology

The values in dBA of L_{DEN} and L_{day} (from 7 a.m. to 7 p.m.), $L_{evening}$ (from 7 p.m. to 11 p.m.) and L_{night} (from 11 p.m. to 7 a.m.) for every single day and the actual annual level in each measurement point were calculated and stored in a local database. As described in [7], L_{DEN} is calculated using
 110 the following equation:

$$L_{DEN} = 10 \log \left\{ \frac{1}{24} \times \left(12 \times 10^{\frac{L_{day}}{10}} + 4 \times 10^{\frac{L_{evening}+5}{10}} + 8 \times 10^{\frac{L_{night}+10}{10}} \right) \right\} \quad (1)$$

For each street, noise levels were analyzed in order to find any anomaly that could alter the actual year value [35]. For all the data presented in this

paper, a total of 14 days had L_{DEN} values larger than $\langle L_{DEN} \rangle + 4\sigma$. These 14 values were considered abnormal and eliminated. Furthermore, 70% of these eliminated days had values of L_{DEN} larger than $\langle L_{DEN} \rangle + 6\sigma$. 9 of the eliminated days were especially noisy local celebrations (Sant Joan, la Mercè and a Champions League celebration). The reason for the high levels of the other 5 days eliminated could not be found.

3.1. Statistical data calculation

This paper presents a methodology for long term L_{DEN} estimation based on temporal stratification. The methodology proposed is compared to the random days sampling strategy [27, 36].

Then, for each measurement point i , 1,000 samples of N measurement days are taken according to each sampling strategy. The difference in dBA between the equivalent level of each sample and the actual value is computed as:

$$\Delta L_j^{i,N} = L_p^{i,N}(j) - \langle L_p^i \rangle \quad (2)$$

where $\langle L_p^i \rangle$ is the actual annual value computed using all the days of the year for measurement point i and period p . Where p is *day*, *evening*, *night* or *DEN*. $L_p^{i,N}(j)$ is the level for period p and measurement point i computed from the sample of N days. j is the current sample and runs from 1 to 1,000. The number of sampling days N runs from 1 to 28.

The parameter used to perform the comparison between the proposed strategy and the random sampling strategy is the number of days that have to be measured in order to have 90% of the 1,000 samples inside the interval $\langle L_p^i \rangle \pm 1dB$. In specific cases where 28 days is not enough to reach the

desired percentage, N was increased until an appropriate number of days was reached.

Therefore, to compute the percentage of samples for N days, the first step is to obtain the noise data which is stored in a local database. This connection provides a whole year of data for point i and for the required period p . $\langle L_p^i \rangle$ is then computed to be used in Equation 2. After this, $L_p^{i,N}(j)$ is computed according to each sampling strategy and $\Delta L_j^{i,N}$ is calculated for $1 \leq j \leq 1,000$ and stored in the array

$$\overrightarrow{L_p^{i,N}} = \{ \Delta L_1^{i,N}, \Delta L_2^{i,N}, \dots, \Delta L_{1000}^{i,N} \} \quad (3)$$

Then, within the array, the percentage of samples inside $\langle L_p^i \rangle \pm 1dB$ is obtained. Afterwards, the next measurement point data is selected from the data base and the whole process is repeated until all measurement points ($i=14$) and p periods are evaluated.

3.2. Temporal stratification

Apart from the physical characteristics of the street, noise depends on the types of noise sources, which could be due to traffic or other activities [34]. As this paper is focused only on traffic noise, the temporal noise evolution in each street depends mainly on the type and number of vehicles circulating through them, since physical street characteristics such as type of paving, obstacles and geometry usually never change within a street. For the purpose of this study, a temporal categoriation is proposed, differentiating working days from weekends. The temporal sampling for annual value estimation is limited to only workdays and the weekend level is calculated based on the

workday/weekend difference. The following equation is proposed to estimate the weekend equivalent level in dBA as:

$$L_p^{We} = L_p^{Wd} + \langle L_p^{We-d} \rangle \quad (4)$$

160 where $\langle L_p^{We-d} \rangle$ should be an approximation of the difference between workday and weekend noise levels of the place under study for period p and L_p^{Wd} is the workdays equivalent value for the same period computed according to:

$$L_p^{Wd} = 10 \log \left\{ \frac{1}{N} \sum_{k=1}^N 10^{\frac{L_p(k)}{10}} \right\} \quad (5)$$

165 where N is the total number of sampled days and $L_p(k)$ is the day level for period p in dBA.

Within a year $[5/7]$ of the days are weekdays, L^{Wd} , and $[2/7]$ are weekends, L^{We} . Based on Equation 1 and changing parameters to adapt it to the aforementioned two temporal strata, the following equation is proposed to estimate the annual level in dBA for period p based on N working days
170 chosen at random:

$$L_p^{i,N}(j) = 10 \log \left\{ \frac{1}{7} \left(5 \times 10^{\frac{L_p^{Wd}}{10}} + 2 \times 10^{\frac{L_p^{We}}{10}} \right) \right\} \quad (6)$$

Then, estimating L_p^{We} from measurements taken during weekdays with Equation 4, the proposed temporal stratification strategy computes $L_p^{i,N}(j)$ as:

$$L_p^{i,N}(j) = 10 \log \left\{ \frac{1}{7} \left(5 \times 10^{\frac{L_p^{Wd}}{10}} + 2 \times 10^{\frac{L_p^{Wd} + \langle L_p^{We-d} \rangle}{10}} \right) \right\} \quad (7)$$

For the case of the random sampling strategy, the following formulation
 175 is applied to calculate $L_p^{i,N}(j)$:

$$L_p^{i,N}(j) = 10 \log \left\{ \frac{1}{N} \sum_{j=1}^N 10^{\frac{L_p(j)}{10}} \right\} \quad (8)$$

4. Results

As stated in [31, 37, 38], differences between workdays and weekends can
 be found when studying the variability of days of the week. In the city under
 study, the working days are from Monday to Friday and the weekend days
 180 correspond to Saturday and Sunday.

Figure 2 shows the differences between the equivalent level computed
 only for workdays L_p^{Wd} and only for weekends L_p^{We} , with the actual level
 $\langle L_p^i \rangle$ as well as the levels L_p^{Wd} with L_p^{We} for all periods p . As one can
 see, $L_p^{Wd} > L_p^{We}$ except for some specific cases in the night period (Figure
 185 2c). It can also be seen that workday levels are higher than the annual value
 $\langle L_p^i \rangle$ with the day period being the one with the highest workday/weekend
 differences $\langle L_p^{We-d} \rangle$. This seems to indicate stratification within the week
 that would allow $\langle L_p^{We-d} \rangle$ to be calculated for the estimation of weekend
 levels.

Figure 3 shows L_p^{Wd} and L_p^{We} levels for all periods and their 68% confi-
 190 dence interval for each of the measurement points with the aim of observing
 the overlapping of the confidence intervals. Workdays always show less vari-
 ation than weekend days. Furthermore, for the day period, it is seen that
 the overlapping between workday and weekend confidence intervals is close
 195 or equal to zero in most cases. However, this trend is not clearly seen for

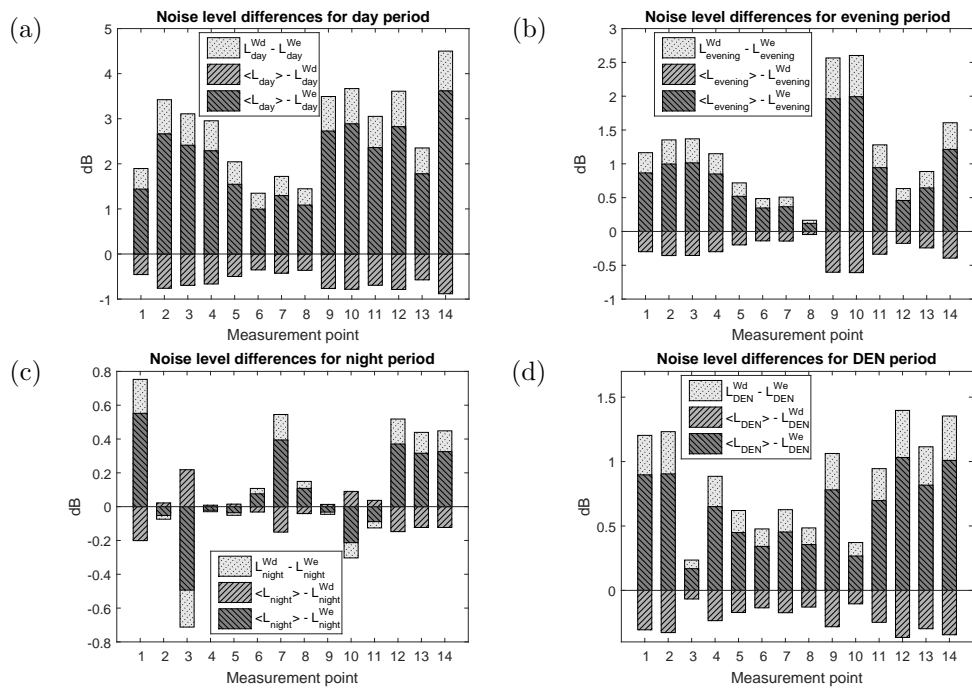


Figure 2: Difference between $\langle L_p \rangle$, L_p^{Wd} and L_p^{We} for all the periods and measurement points.

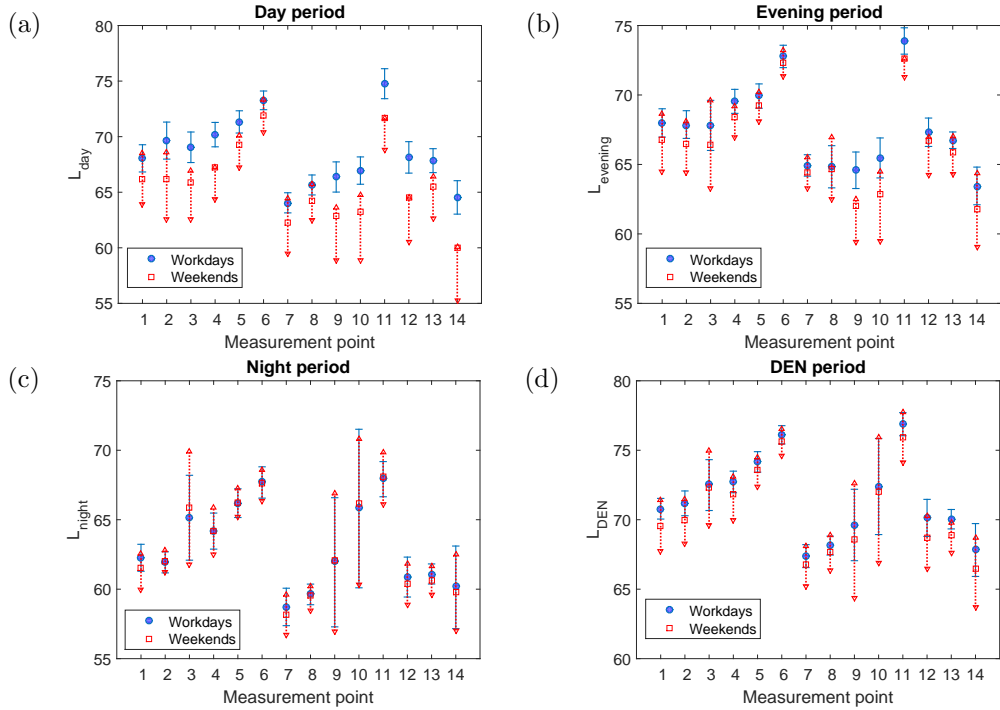


Figure 3: L_p^{Wd} and L_p^{We} mean and 68% confidence interval.

the other periods. In order to estimate L_p^{We} from L_p^{Wd} , both quantities must come from populations with different means. Since according to a Chi-square goodness-of-fit test not all the distributions can be considered as normal, a non-parametric test should be used. The Wilcoxon rank-sum test was applied to both L_p^{Wd} and L_p^{We} to test the null hypothesis that both of them come from distributions with equal means. The result of this test is shown in Table 2. It can be seen that for L_{day} , workdays and weekends belong to different distributions; for $L_{evening}$ and L_{DEN} , mean independence is not achieved in only one of the measurement points; and for L_{night} , only four of the measurement points present distributions mean independence.

Thus, given the independence between L_p^{Wd} and L_p^{We} and the smaller

Point	L_{day}	L_{eve}	L_{night}	L_{den}
1	$9E^{-18}$	$3E^{-13}$	$4E^{-11}$	$2E^{-17}$
2	$8E^{-35}$	$1E^{-17}$	0.745	$2E^{-21}$
3	$7E^{-41}$	$8E^{-13}$	0.075	0.132
4	$4E^{-39}$	$2E^{-21}$	0.141	$2E^{-10}$
5	$3E^{-35}$	$1E^{-10}$	0.864	$2E^{-10}$
6	$1E^{-10}$	$8E^{-04}$	0.977	$3E^{-03}$
7	$4E^{-25}$	$8E^{-07}$	$7E^{-03}$	$9E^{-09}$
8	$4E^{-21}$	0.079	$1E^{-03}$	$5E^{-10}$
9	$3E^{-37}$	$3E^{-31}$	0.965	$2E^{-05}$
10	$2E^{-35}$	$8E^{-25}$	0.562	$4E^{-02}$
11	$1E^{-11}$	$2E^{-06}$	0.982	$2E^{-04}$
12	$1E^{-17}$	$1E^{-07}$	0.076	$4E^{-08}$
13	$6E^{-25}$	$6E^{-16}$	$5E^{-06}$	$1E^{-20}$
14	$5E^{-20}$	$6E^{-09}$	0.559	$2E^{-04}$

Table 2: Test for distribution mean independence. Grey box indicates rejection that the data sets come from the same distribution ($p=5\%$). The p value is shown inside each cell.

variability of L_p^{Wd} , it is possible to establish a temporal stratification that separates workdays and weekends. However, this would not reduce the size of the sample unless the weekend values are estimated from workday levels [34].

210 Estimating the weekend level by setting $\langle L_p^{We-d} \rangle$ as close as possible to the actual difference for each point would bring a very accurate approximation of the actual weekend level; this should be better in cases where $\langle L_p^{We-d} \rangle$ is higher, since L_p^{We} estimation takes greater importance when its value is much smaller than L_p^{Wd} as it is related to a higher distribution mean separation.

215 Nevertheless, the noise level difference between workdays and weekends $\langle L_p^{We-d} \rangle$ should be known for each of the sampling points, which is not always possible. The calculation of $\langle L_p^{We-d} \rangle$ requires the accurate measurement of L_p^{We} and L_p^{Wd} from a large sample of days. Therefore, if one had the actual values of L_p^{We} and L_p^{Wd} it would not be necessary to estimate

220 $\langle L_p^{We-d} \rangle$.

4.1. Annual L_p estimation by using $\langle L_p^{We-d} \rangle$ as computed average

Since previous noise data for each sampling point is not always available for noise assessment of a city, the overall average for all measurement points and the average by category is used as the $\langle L_p^{We-d} \rangle$ parameter.

225 Then, $\langle L_p^{We-d} \rangle$ was first calculated for each measurement point using the following formula obtained from Equation 4:

$$\langle L_p^{We-d} \rangle = L_p^{We} - L_p^{Wd} \quad (9)$$

Table 3 shows the values of $\langle L_p^{We-d} \rangle$ for each p period computed individually for street categories and for all the streets.

230 The required number of days to have 90% of $\Delta L_p^{i,N}$ within ± 1 dB are shown in Table 4 for both strategies and for all periods.

5. Discussion

Even though there is a reduction in the required number of days in most of the cases presented in Table 4, there are some specific measurement points where the random sampling strategy is not improved or equalled.

235 For L_{day} , it is observed that, in almost all of the measurement points there is a reduction in the required number of days using Equation 7 compared to using the random sampling strategy. The total reduction in days sampled by applying the temporal stratification strategy compared to random sampling strategy is more than 38% using $\langle L_{day}^{We-d} \rangle$ from the overall
240 average and more than 39% using $\langle L_{day}^{We-d} \rangle$ from the category average.

<i>Cat</i>	<i>Point</i>	$\langle L_{day}^{We-d} \rangle$		$\langle L_{evening}^{We-d} \rangle$		$\langle L_{night}^{We-d} \rangle$		$\langle L_{DEN}^{We-d} \rangle$	
		<i>C</i>	<i>G</i>	<i>C</i>	<i>G</i>	<i>C</i>	<i>G</i>	<i>C</i>	<i>G</i>
1	2	-4.0		-1.5		-0.3		-1.3	
	14								
2	1	-2.0		-0.8		-0.2		-0.7	
	5								
	6								
	8								
	11								
3	3	-3.0		-1.4		-0.4		-0.8	
	4								
	7								
	9								
	10								
	12								
	13								

Table 3: $\langle L_p^{We-d} \rangle$ computed for each category (*C*) and overall for all the streets (*G*) for all periods.

Point	Cat	L_{day}			$L_{evening}$			L_{night}			L_{DEN}		
		D_R	D_G	D_C	D_R	D_G	D_C	D_R	D_G	D_C	D_R	D_G	D_C
1	2	7	6	5	7	6	6	10	8	9	4	3	3
2	1	10	5	5	5	4	4	2	2	2	4	3	3
3	3	9	6	6	19	16	15	23	30	30	12	12	11
4	3	6	3	3	4	3	3	6	5	5	4	3	3
5	2	4	3	3	3	3	3	4	4	4	3	3	2
6	2	3	3	2	2	3	2	5	4	4	3	2	2
7	3	8	5	5	4	4	4	7	7	8	5	4	4
8	2	6	5	4	13	18	14	5	4	4	4	3	3
9	3	12	7	7	9	6	7	48	51	48	25	21	23
10	3	16	10	11	11	9	10	39	42	44	27	28	24
11	2	7	3	4	4	3	3	7	6	5	4	3	2
12	3	11	6	6	17	10	10	10	9	8	8	6	7
13	3	7	4	5	4	3	3	3	2	2	3	2	2
14	1	13	7	6	10	6	6	23	24	22	13	11	12
Total		119	73	72	112	94	90	192	198	195	119	104	101

Table 4: Number of days required to make the 90% confidence interval of $\langle L_p^i \rangle \pm 1dB$ for the random sampling strategy (D_R) and temporal stratification strategy, computing $\langle L_p^{We-d} \rangle$ as the measurement point average (D_G) and category average (D_C) for all periods. Measurement points are shown in bold italics where there is an increase in the required number of days with respect to the random sampling strategy.

For measurement point 6, as shown in Figures 2 and 3, the combination of the low variability, which requires fewer days to reach the desired confidence interval, and the fact that $\langle L_{day}^{We-d} \rangle$ by category is closer to the actual value, leads to a reduction in the required days when using the value per category and not with the overall average.

For $L_{evening}$, in all but two streets, the random sampling estimation is equalled or improved with an average reduction in the required days by more than 16% and 19% by computing $\langle L_{evening}^{We-d} \rangle$ as the overall or category average, respectively. The low variability of measurement point 6 is reflected in the low number of required measured days. Furthermore, the fact that $\langle L_{evening}^{We-d} \rangle$ as the overall average is more than double the value compared to the individual one, makes the overall average less suitable for this measurement point than the category one. For measurement point 8, there are several reasons that could lead to the increase in the number of required days. As seen in Table 2, this measurement point is the only one for this period that does not meet the distribution mean independence which, combined with its high variability, causes the estimation of L_p^{We} using the temporal stratification strategy to be inaccurate.

For the *night* period, in all but four measurement points, the random sampling estimation is equalled or improved. As seen in the total number of days for this period, there is no overall reduction; however, if we look at the measurement points individually, the increase in the number of days is concentrated in only four of the whole set of measurement points: 3, 9, 10 and 14. For the particular case of measurement point 3, 28 days are not enough using both, overall or category average as $\langle L_{night}^{We-d} \rangle$. This lack

of improvement may be associated with the combination of high variability, the fact that L_{night}^{Wd} and L_{night}^{We} come from the same distribution and that the condition $L_{night}^{Wd} > L_{night}^{We}$ is not fulfilled. This is also observed in points 9, 10 and 14. It can be seen that, for the *night* period, some specific measurement
270 points do not give as good results as for other periods. In order to establish the reason for this, a revision of the surrounding area was performed.

For measurement point 14, which is one of the main ring roads of Barcelona and also a commercial hub of the city, it was found that the possible reason for L_{night} to be higher at weekends could be due to its extensive link with
275 commercial areas, as the road is full of large shopping centres, high-fashion clothing and jewellery stores, and some night clubs which could increase traffic flow on non-working days.

For measurement points 3 and 9, it was observed that their location is in the same street as well-known nightclubs. This means that their proximity to
280 the clubs could increase the traffic flow during early and late *night* periods, as well as noise due to human interactions.

Measurement point 7 is located in front of a park on a narrow street with vehicle circulation mainly from the people living in the neighbourhood. Something to emphasize for this point is that, even though the test for dis-
285 tribution mean independence indicated means separation and that it meets the condition $L_{night}^{Wd} > L_{night}^{We}$, a reduction in the number of required days was not achieved. The possible reason for obtaining this result could be that $\langle L_{night}^{We-d} \rangle \approx 0.6 \text{ dB}$, which for the overall and category average is even lower ($< 0.5 \text{ dB}$). This small value is a negligible difference and makes the
290 temporal stratification strategy unsuitable for this point.

Measurement point 10 is located in a narrow street in which there is a high concentration of commercial areas and restaurants. At approximately 150 metres from the measurement point there are two small-sized night clubs which could greatly affect the traffic flow, as there is only one lane for circulation.

It is observed that almost all of the aforementioned measurement points are affected by leisure activity. This activity implies that the variability of the L_p^{We} levels is very high (as seen in Figure 3) which, combined with the fact that L_p^{We} and L_p^{Wd} come from the same distributions, means that the estimation based on L^{Wd} is not a suitable strategy for these measurement points.

Finally, for L_{DEN} , a similar result as the *day* period is obtained. It is seen that, by using $\langle L_{DEN}^{We-d} \rangle$ as the category average, the required number of days is reduced for every measurement point. When using the overall average there is a reduction in the required days in all but one measurement point.

If the proposed strategy were to be used in different cities, the parameters to be adapted to each place under assessment are $\langle L_p^{We-d} \rangle$ and the number of working days and weekend days, which for Barcelona are 5 (from Monday to Friday) and 2 (Saturday and Sunday), respectively. The selection of an accurate $\langle L_p^{We-d} \rangle$ value is essential to obtain significant improvements. In terms of noise data, if there is enough previous information available, $\langle L_p^{We-d} \rangle$ could be computed as the category average and, in cases where there is little information available, an overall average could be used. As shown in Table 4, for the temporal stratification strategy, results are better when using $\langle L_p^{We-d} \rangle$ for each street category, as the required number of

days is reduced even further compared to $\langle L_p^{We-d} \rangle$ obtained as an over-
 all average for all streets. As shown in this research, a combination of the
 proposed methodology together with the street categorization method is a
 very good option; this would help to save resources and increase the esti-
 320 mation accuracy as it would only require as many $\langle L_p^{We-d} \rangle$ values as
 street categories under study. As noise pollution is becoming a priority is-
 sue in cities, the number of fixed networks is growing [39–44]. This means
 that the $\langle L_p^{We-d} \rangle$ could easily be obtained for a larger number of measure-
 ment points, which would increase the accuracy of the temporal stratification
 325 strategy.

6. Conclusion

It has been shown that, in the city of Barcelona, there is a temporal
 stratification for days of the week as their values follow different distributions,
 with the workday noise level being higher and the variability being lower
 330 than for weekends. Based on this temporal stratification, a new sampling
 strategy was introduced. It was shown that measuring only on workdays and
 estimating weekend noise level from the $\langle L_p^{We-d} \rangle$ value, brings a significant
 improvement in accuracy compared to the random sampling strategy for the
 estimation of the annual $\langle L_p^i \rangle$. For the case of the annual $\langle L_{DEN}^i \rangle$
 335 estimation, using $\langle L_{DEN}^{We-d} \rangle$ by category led to an improvement for each of
 the sampling points studied, for which the average reduction is 1.29 days per
 measurement point compared to the random sampling strategy.

The temporal stratification strategy works well for streets with normal
 traffic, but in those with significant leisure activity, a high variability is de-

340 tected for night period values, which leads to poorer results than the random
sampling strategy, for the aforementioned reasons. The proposed method
assumes that $\langle L_p^{Wd} \rangle \neq \langle L_p^{We} \rangle$; if this is not true, as it is in most of
the cases for the night period, the temporal stratification strategy does not
bring a significant improvement as $\langle L_p^{We-d} \rangle \approx 0$. This means that, at this
345 time, it is advisable to apply the temporal stratification strategy to streets
where traffic is due to regular people displacement, and for the streets with
a strong presence of leisure activities, further research is required as the per-
formance is not so good because of the local effect of these activities on the
surrounding traffic. All this suggests that it is necessary to carry out double
350 categorization: one by type of street and the other by use of the area.

For the entity in charge of the noise assessment of a city, using the cate-
gorization method together with the proposed strategy, makes the sampling
process less demanding as the measurements only have to be done on work-
ing days and in a reduced number of sampling points. Furthermore, the
355 improvements in accuracy lead to a reduction in the number of sampling
days required to equal or improve the population coverage with respect to
using the random sampling strategy. The proposed methodology, allows the
authorities in charge of environmental management to get traffic noise data
faster and saving resources without compromising the precision and repre-
360 sentativeness of the noise levels.

Acknowledgements

The authors would like to thank Barcelona City Council for providing
the noise data used in this study. This work is part of the doctoral thesis

by Guillermo Quintero that is under way at the Polytechnic University of
365 Catalonia (UPC) with grant support provided by CONACyT.

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