

Noise Monitoring Networks as Tools for Smart City Decision-Making

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Noise Monitoring Networks (NMNs) have been implemented in many cities by town councils, allowing them to know, in real time, the environmental noise levels in the busiest streets by the continuous measurement of selected acoustic parameters throughout the year. NMNs are aimed at: 1) detecting areas of the city that breach guidelines for acoustic quality objectives; 2) obtaining noise data needed to develop and implement action plans; and 3) informing the public about the permissible acoustic pollution for different districts and times of day. The aim of this work was to analyse data from the NMN of the city of Huelva (Spain), in order to study the influence on the noise of re-asphalting the busiest streets. The street pavements improve L_{Aeq} , 24 h from 3 up to 8 dB(A), depending on the type of the route. These results could be used by council authorities in deciding when to undertake the re-asphalting of the streets of Huelva, and to select the type of asphalt that should be used.

Keywords: traffic noise; noise monitoring networks; smart city; pavement.

1. Introduction

One of the greatest problems in society is high noise levels to which the population is exposed. Many workers consider this problem as the ‘cancer’ of the twenty-first century, as it has a direct impact on quality of life (MANSOURI, 2006; COITT, 2008; GOLMOHAMMADI, 2009; PAL, 2012; GUARNACCIA, 2012; FERNÁNDEZ, 2013). After air pollution and water, the World Health Organisation (WHO, 2011) declared noise pollution as the most important environmental problem in the world. Therefore, concern over this form of pollution is gaining relevance, especially in urban areas (European Environment Agency [EEA], 2000; MÉLINE, 2013).

This problem has prompted many municipal authorities to implement different kinds of Noise Monitoring Networks (NMNs), aiming to keep real-time information of the environmental noise levels in the most significant streets, by monitoring the main acoustic parameters throughout the year (BOTTELDOORE, 2011). These NMNs give much information, for example: 1) detecting areas of the city that breach the guide-

lines for acoustic quality objectives established by legislation; 2) obtaining a dynamic noise map of the municipality through space and time; 3) obtaining noise data needed to develop and implement noise reduction plans; and 4) giving information to the public about noise pollution in the different areas and times.

In relation to the proportion of different noise sources, the majority of workers note that traffic represents the most important source of urban noise (SÁNCHEZ-SÁNCHEZ, 2015; PHAN, 2009; SUKSAARD, 1999; ALI, 2003; LI, 2002; ZANNIN, 2002). Traffic noise is generated by different sub-sources from vehicles, which can be classified into three general categories: a) power unit noise (engine, fan, exhaust and the transmission, etc.); b) aerodynamic noise, which is related to turbulent airflow around the vehicle; and c) tire/pavement noise (LAMURE, 1986; HANSON, 2004; YOUNG, 2014; BRAUN, 2013; BERNHARD, 2005; SANDBERG, 2001).

In recent years, the European Union, concerned about the problem of noise generated by the tire/pavement, has approved several regulations that seek to

influence the tire industry to reduce vehicle fuel consumption and the noise generated by this sub-source in European cities (Regulation (EC), 2009, and Regulation No 117, 2008).

The automotive industry has been developing progressively quieter engines, especially after the emergence of hybrid engines and electric motors. The same can be said for the tire industry, especially for recent decades. However, although quieter asphalt pavements are being manufactured nowadays, with the addition of rubber from recycled tires to the binder (LICITRA, 2015; SANDBER, 2013; VÁZQUEZ *et al.*, 2014; VOGIATZIS, 2014; KROOP, 2007), this novelty has not solved the increased noise coming from pavement surface deterioration.

Specifically, to study tire/pavement noise, different methods have been developed: statistical pass-by (SPB), controlled pass-by procedures (CPB), or close proximity methods (CPX) (LICITRA, 2015). Much regulation is related to these problems, such as ISO 362, ISO 11819-1, ISO 11819-2, ISO 10844, and the method of the “drum”, in the laboratory (BERNHARD, 2005). These methods measure the noise under a specific and concrete situation, and are used to standardise different types of tires, and pavements (SOHANEY, 2012; SANDBERG, 2003), but do not analyse the continuous evolution of noise produced by the degradation of the pavement.

The first objective of this work was to analyse the relationship between the noise due to traffic, and the surface state of the pavement. Secondly, we develop a method that allows continuous monitoring of the state of surface deterioration of the pavement in the main streets of a city by using the information provided by the Noise Monitoring Network (NMN).

2. Methodology and materials

The noise implemented monitoring network of Huelva is performed by 21 sonometers installed at the most significant points of the city according to the intensity of traffic. The equipment is formed of weather sound level meters, brand Ecodap, and model SRD 500, whose characteristics are:

- measurement range: 42–105 dB(A);
- type of measures: L_{Aeq} , 60min;
- precision type II according to IEC 651 (UNE-EN-60651);
- degree of protection: IP45 Microphone Wind-screen System;
- sending information: every 83 records saved;
- middle shipping: by SMS via the GSM network or GPRS.

A diagram of the NMN is shown in Fig. 1.

2.1. Study area

Four roads of the city with the highest traffic flows were selected, their codes and locations being displayed on the map of Fig. 2. The selected streets were:

- San Sebastian Street (code: SS),
- Pío XII Avenue (code: PXII),
- Galaroza Avenue (code: GA),
- Federico Molina Avenue (code: AFM).

The criteria in the selection of the streets were: 1) all the streets were paved in February 2011, with six years from the last asphaltting; 2) at least one monitoring point was located at each street; 3) they are streets with the highest flow of traffic; 4) the speed limit is

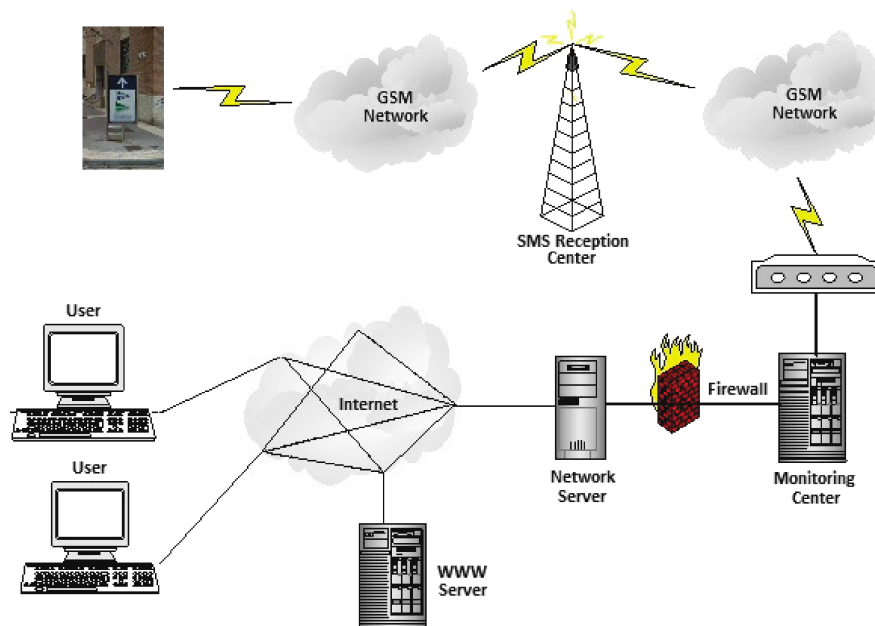


Fig. 1. Noise Monitoring Network diagram.

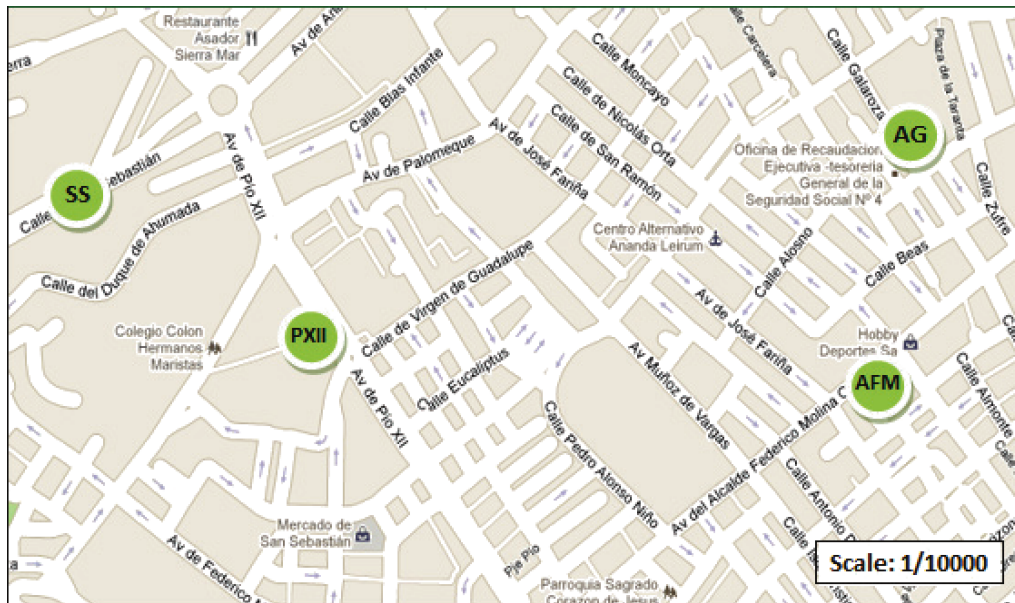


Fig. 2. Map of measurement points in the main thoroughfares of the city.

the same for all the streets; 5) the type of asphaltic mix was the same (code: AC 16 SURF 35/50 D); and 6) all have similar population density.

2.2. Methodology

The noise levels of a full month, before and after asphaltting, were used for the study, in order to analyse the effects produced by re-asphaltting on the different noise parameters ($L_{Aeq, 1h}$, the L_{A10} , L_{A50} , L_{A90} , L_{Amax} , and L_{Amin}). The time periods studied were: November 15th to December 14th 2010 for the period before re-asphaltting; and March 15th to April 14th 2011 for the period after the re-asphaltting. These dates correspond to the last re-asphaltting of the four streets, which took place in February 2011. A total of 43200×2 1-minute measurements was used, since the weekends were removed from the database because of the evolution of noise during these days being completely different to working days.

On the other hand, the traffic flows were also used (TF), given by the number of vehicles per hour running on the roads. These data were taken from the Traffic Management Centre of the City of Huelva.

3. Results and discussion

3.1. Traffic flows

The values of traffic flow (TF , v/h) throughout the 24 h period for the four studied streets, before and after asphaltting road, are reported in Fig. 3.

It is very well established that traffic flow (TF) for a specific time period follows a Poisson probability distribution, indicating that the standard uncer-

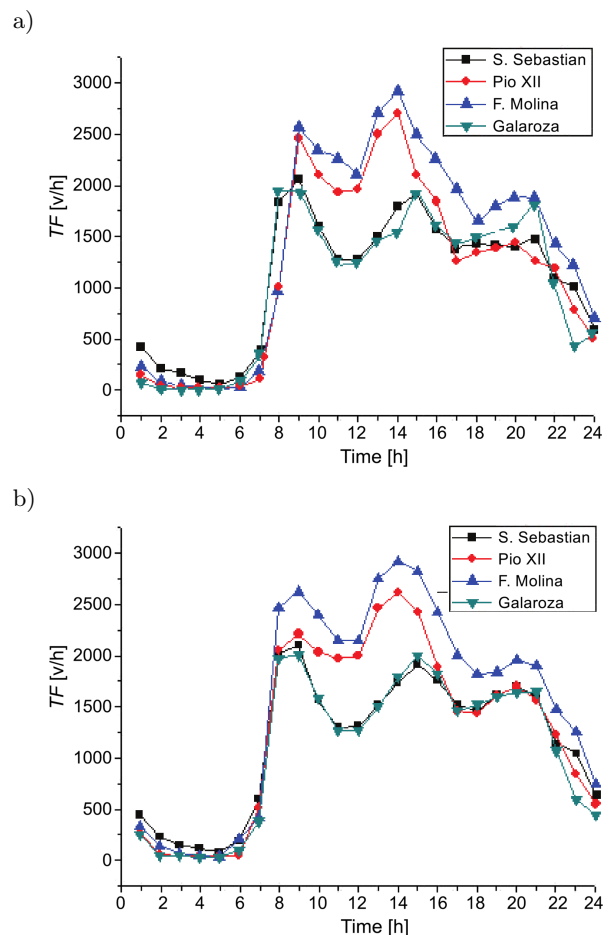


Fig. 3. Traffic flows: a) before asphaltting, b) after asphaltting.

tainty (U) of the average value (TF) can be calculated by the square root of TF ($U = \sqrt{TF}$) (TSAY,

2003). The confidence intervals for TF , before and after the roads were asphalted, and for each hour of the day, were calculated; and no significant differences (95% confidence level) were obtained. No statistical differences were also obtained by applying the t-Student test for paired samples (before and after) in each of the streets. The average paired differences of TF s and their standard uncertainties (before and after) were -50 ± 18 v/h (SS), -100 ± 50 v/h (PXII), 112 ± 62 v/h (AFM), -29 ± 19 v/h (GA), demonstrating that for each road there are no significant differences in the traffic flows before and after the asphaltting. Therefore, the TF parameter should not affect the variation of the noise levels measured before and after re-asphaltting.

Figures 3a and 3b show that the TF patterns throughout the day are very similar for GA-SS and PXII-AFM. Very low traffic flows from 01:00 to 06:00 h are observed, while from 07:00 to 08:00, a large in-

crease in traffic flow occurs, reaching a relative maximum around 09:00 h, which is the time for students to go to secondary schools. From this time until 21:00 h, two peaks related to human activity can be observed (14.00 h for lunch, and 21.00 h for shop closing time). Finally, from 22.00 to 02.00 h, the traffic flow decreases until reaching a minimum from 02.00 to 06.00 h (the nocturnal plateau).

3.2. Noise level

For every hour of the day and street, $L_{Aeq,1h}$, L_{A10} , and L_{A90} , and according to ISO standards (ISO 1996-1, 2003 and ISO 1996-2, 2007), were calculated by using the $L_{Aeq,1min}$ database with the objective of studying daily noise evolution. In addition, for every street, the reduction (before – after asphaltting) produced in the previous acoustic parameter was calculated; its hourly evolution is shown in Fig. 4. A systematic positive

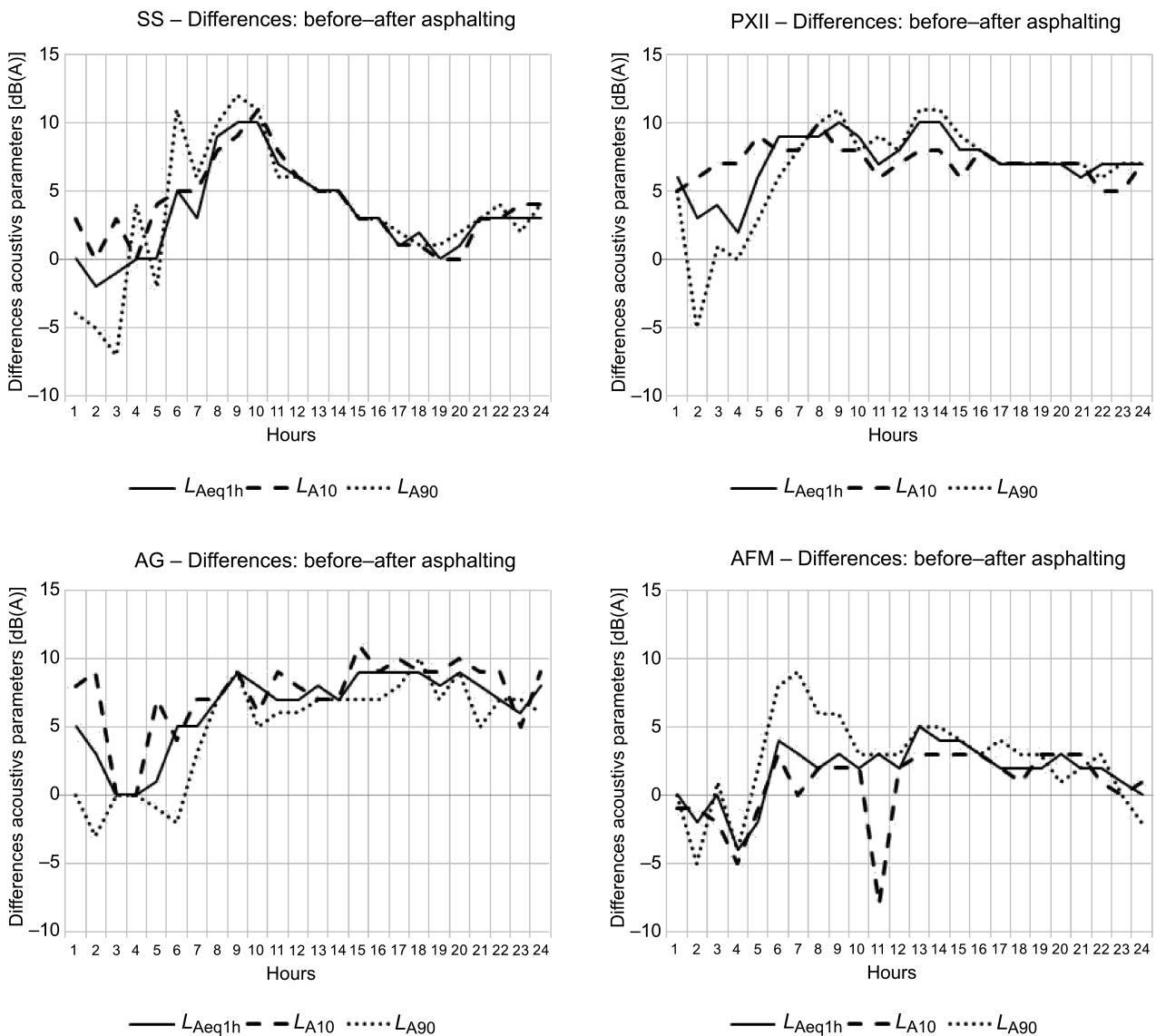


Fig. 4. Daily evolution of acoustic parameter differences before and after asphaltting.

noise level reduction is observed, depending on the values of each street. The maximum noise reduction occurs during the day (9:00–14:00 h), as observed in Fig. 4, being the peak 10 dB(A) for the SS, PXII and AD streets, and only 5 dB(A) AFM street.

The noise reduction is around 0 or even negative (SS and AFM streets) from 02:00 h to 05:00 h. This result is expected by considering that during this time interval of the night, the traffic contribution to the total level noise is expected to be negligible, since the TF is practically nil (see Fig. 3). In addition, for the L_{A10} (average of the peaks), and L_{A90} (average background), similar results are found during the day. Nevertheless, some differences are produced during the night, mainly due to the noise from the traffic being negligible and punctuated noises being produced by random noise sources coming from other human activities.

These facts show that during the day (06:00–00:00 h) the noise is mainly produced by traffic, while during dawn, the influence of the traffic on the noise is practically nil.

3.3. Relation between the traffic flow and the equivalent level

The relation between the traffic flow and the $L_{Aeq,1h}$ is shown in Figs. 5–8, e.g. before and after asphaltting, showing that there is a good linear regression between these variables. The parameters of the linear fits made by least-squares (intercept, slope), their uncertainties, and the determination coefficients (R^2) are shown below these figures.

The meaning of the intercept is obvious, representing the level noise when $\log TF = 0$; that is, when TF is very low or nil ($TF = 1$ v/h). Taking into account

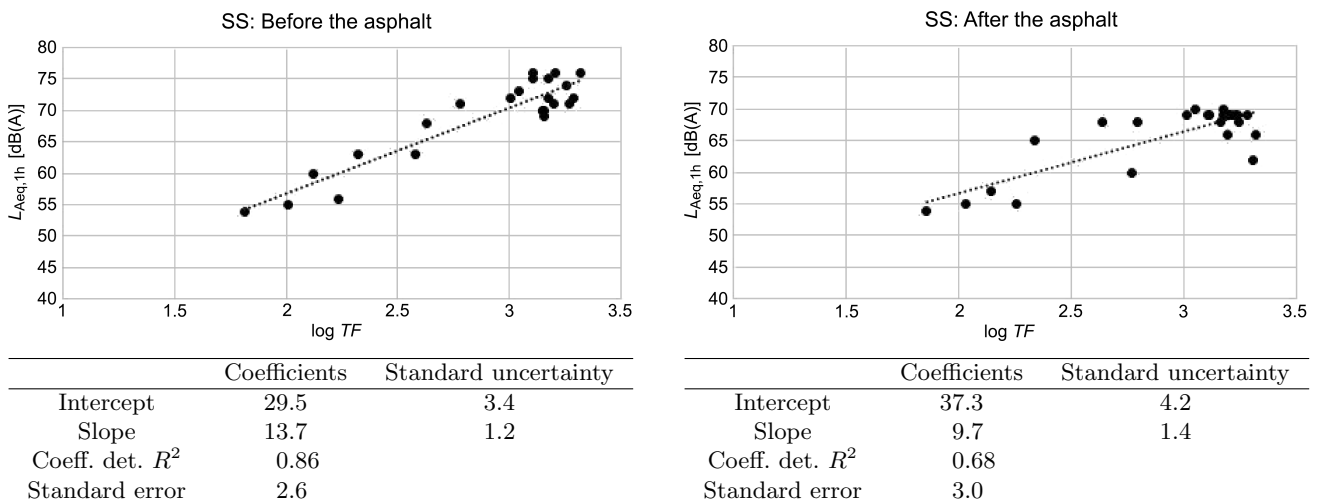


Fig. 5. Relationship between the traffic flow (log) and L_{Aeq} on the San Sebastián Street: a) before asphaltting, b) after asphaltting.

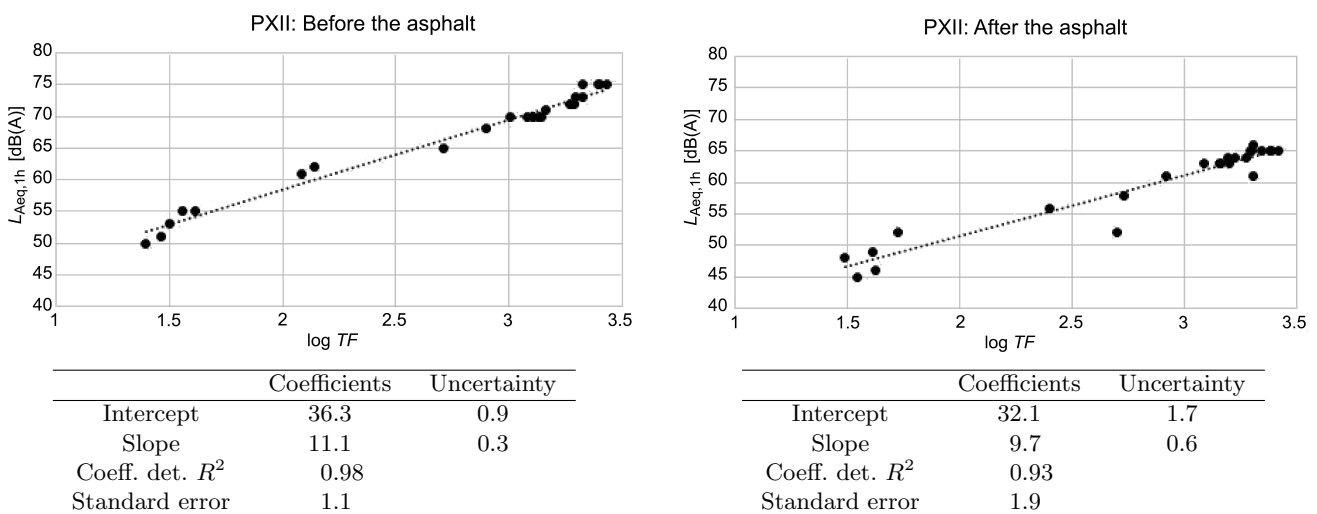


Fig. 6. Relationship between the traffic flow (log) and L_{Aeq} on the Pio XII Av.: a) before asphaltting, b) after asphaltting.

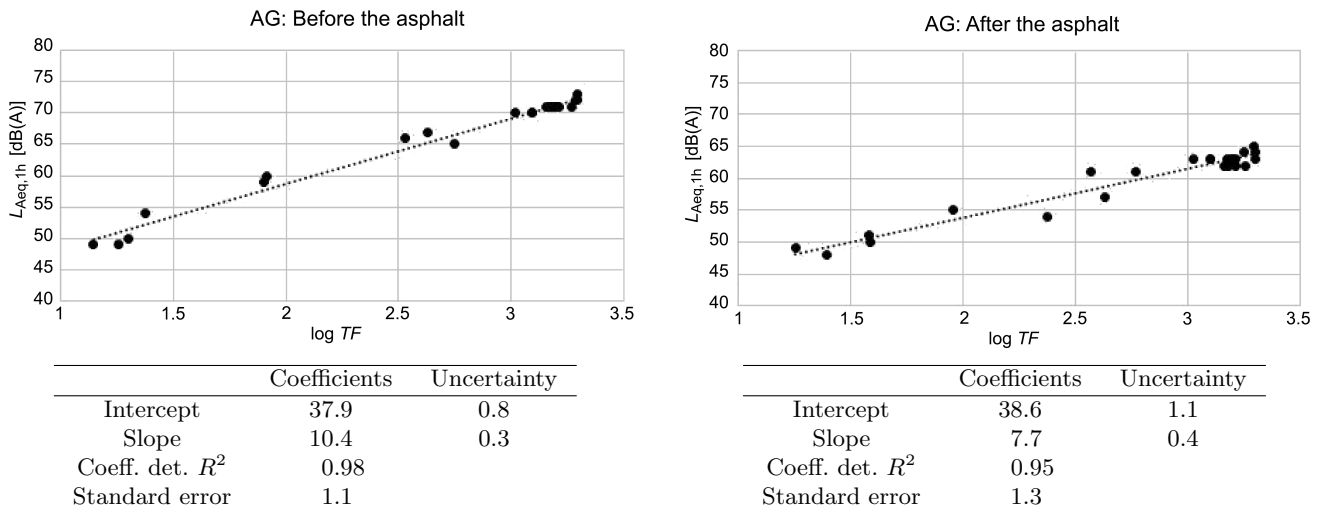


Fig. 7. Relationship between the traffic flow (log) and L_{Aeq} on the Galaroza Av.:
 a) before asphalt, b) after asphalt.

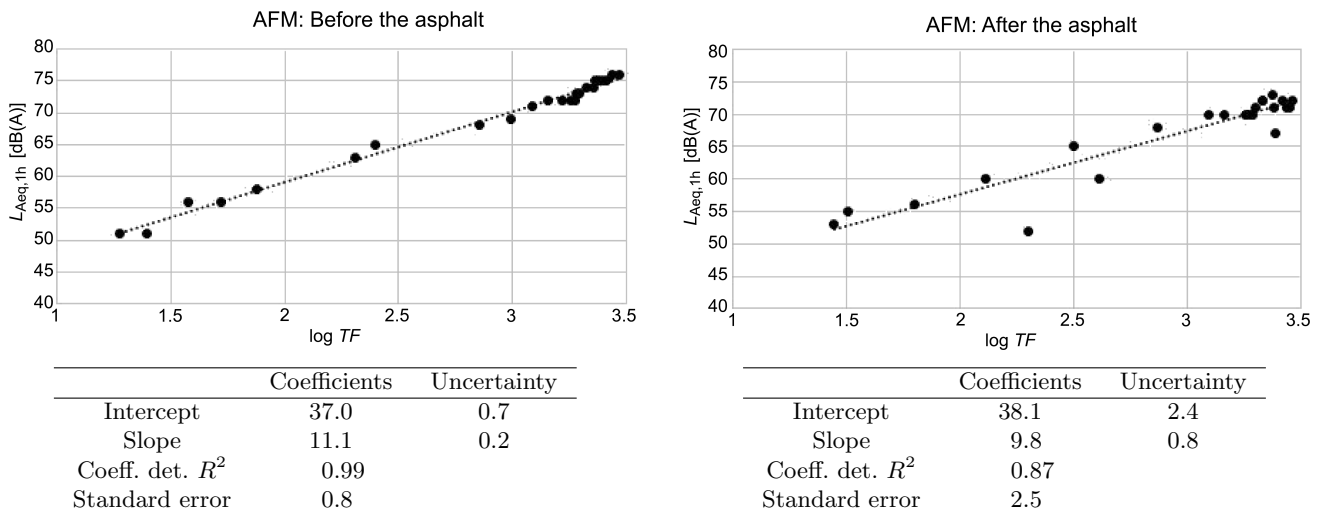


Fig. 8. Relationship between the traffic flow (log) and L_{Aeq} on the F. Molina Av.:
 a) before asphalt, b) after asphalt.

this result, the noise before and after the asphalt is practically the same, confirming that the decrease of the noise during the day is due to the new paving of the roads.

On the other hand, the slope of the straight line represents the growth rate of the level noise as the logarithm of the traffic flow increases. Therefore, taking into account that the equivalent continuous level during the measurement time of T is the logarithm of the acoustic energy received, at a specific point and road, the equivalent continuous level with a constant TF , if background is removed, is given by the following equation:

$$L_{eq,T} = 10 \cdot \log\left(\frac{E_0}{p_r^2 T}\right) + 10 \cdot \log(TF), \quad (1)$$

where E_0 is the sound exposition level for a vehicle at the considered point of the road, p_r – the reference

acoustic pressure ($p_r = 20 \mu Pa$), and TF the traffic flow, or number of vehicles (dimensionless amount), during the measurement time interval (T). The fact that the slopes of the adjustments, within the experimental uncertainties, are compatible with the value of 10, confirms that road traffic is the main source of noise in the four streets studied.

From the Eq. (1), and considering the mean constant of the fittings ($33.8 \pm 1.8 \text{ dB(A)}$), the acoustic exposition produced by a vehicle can be calculated, as $9.7 \pm 3.9 \cdot 10^{-7} \text{ Pa}^2 \cdot \text{s}$. Also one can assume that slope is exactly 10, and calculate the ordinate at the origin for each road and time interval measurement (before and after).

On the other hand, if the slope is given with a value of 10 dB(A) (not considered as a fitting parameter), and taking the previous equation as valid, the mean SEL (Sound Equivalent Level) for each road and time

(before and after asphaltting) can be calculated. The noise expositions (NE), and standard uncertainties, in $10^{-6} \text{ Pa}^2 \cdot \text{h}$, are shown in Table 1.

Table 1. Vehicle Noise Exposition (NE) (NE , $10^{-6} \text{ Pa}^2 \cdot \text{h}$) for each road and time period.

	SS	PXII	AFM	GA
Before	4.9 ± 0.6	3.5 ± 0.2	4.2 ± 0.2	3.4 ± 0.6
After	2.2 ± 0.3	0.58 ± 0.04	2.45 ± 0.18	0.17 ± 0.08
NE [%]	55 ± 8	83.4 ± 1.5	41 ± 5	95 ± 3

Many studies have shown a direct correlation between the road rugosity and the noise level due to the rolling source (CANTISANI, 2013). That is, asphalt at intermediate velocities is the main noise source considering a constant TF . The NE reduction obtained (Table 1) clearly proves that a high reduction of vehicle noise after road asphaltting is produced, showing that the degradation of the pavement is the most significant factor in the noise generated by road traffic in a city.

On the other hand, R^2 are smaller after the asphaltting, indicating that traffic has less proportion in the total noise due to the improved pavement condition.

Finally, as general comment for Figs. 5–8, the values of the obtained slopes are around 10, if the standard uncertainties are considered. This fact demonstrates that traffic is the main noise source at the studied roads.

Figure 5 shows the dependence of $L_{Aeq, 1h}$ versus the traffic flow (TF) for San Sebastián Street, showing low correlation coefficients in relation to PXII and GA. On the contrary, the slope before the paving (13.6 ± 1.2) is much higher than after (9.7 ± 1.4).

Nevertheless, the ordinates at the origin are very similar considering the experimental standard uncertainties (before: $29.4 \pm 3.4 \text{ dB(A)}$; after: $37.3 \pm 4.2 \text{ dB(A)}$). This result indicates that background noise ($TF \approx 0$), i.e. different to traffic noise, is similar for both periods of measurement.

Figure 6 shows $L_{Aeq, 1h}$ versus the traffic flow for Pío XII Avenue, showing the same and highest determination coefficients ($R^2 > 0.98$, and 0.93 , respectively), proving that for both measuring periods, the traffic is the main noise source. In fact, this street has no commercial activities, and the lowest pedestrian flow of the four studied streets. In addition, for after asphaltting, a slope of 9.7 ± 0.6 is found, in agreement with the theoretical value of 10, proving that the rest of noise sources is negligible (e.g. pedestrians, shopping, restaurants, etc.). Finally, we point out that PXII and GA have the highest level reductions of $83.4 \pm 1.5\%$, and $95 \pm 3\%$, respectively.

Similar results for GA and AFM streets were obtained. We highlight that for Federico Molina Avenue,

the lowest R^2 (0.86 and 0.68, respectively) was obtained (Fig. 8). This result should be related to the fact that AFM is the street with the highest rates of other activities such as shops, pedestrian flows, etc. In addition, the intercept does not change before and after asphaltting (from 37.0 ± 0.7 to 38.1 ± 2.4), which indicates that there is no variation in the alternative sources to the traffic before and after the asphaltting.

3.4. Comparison of the levels of L_d and L_n with the aims of acoustic quality

In order to analyse whether the noise of these four streets reached the acoustic quality objectives (AQO) established in Spanish legislation (RD: 1367, 2007), for existing urbanised areas with a predominance of residential use, we present histograms in Fig. 9, in which the values of both day equivalent level (L_d), and night equivalent level (L_n) are shown.

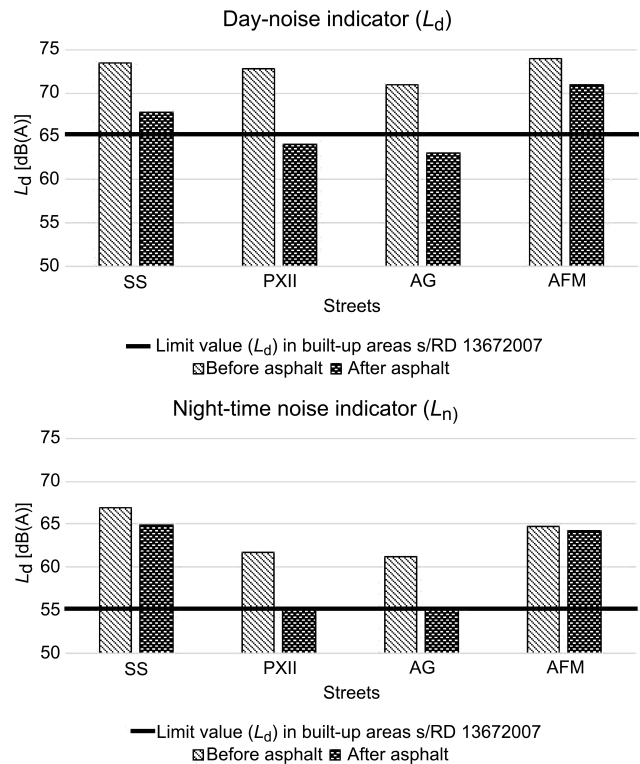


Fig. 9. Histograms comparing L_d and L_n with acoustic quality objectives.

Figure 9 shows that before the asphaltting all the streets exceed the AQOs, observing that after the asphaltting, at least in commercial streets (Pío XII Avenue and Galaroza Avenue), the AQOs are reached. Nevertheless, in the streets with more business and leisure premises (viz. San Sebastian Street, and Federico Molina Avenue), the level reduction that takes place with the asphaltting is insufficient to reach the AQOs. This result can be explained considering that in the mentioned streets, other sources such as the com-

mercial and leisure activities are non-negligible in relation to the noise traffic source.

4. Conclusions

We have attempted to determine the influence that pavement degradation produces in the noise generated by traffic in Huelva (southwest Spain). Four relevant streets were selected, and the data were taken from the Noise Monitoring Network (NMN) installed several years ago at different selected points of the city.

A very good linear correlation was determined between $L_{Aeq,1h}$ and hourly traffic flow ($R^2 = 0.7$ to 0.95), proving that traffic noise is the major source of noise in the streets.

The first conclusion was that a significant reduction in the hourly equivalent continuous level after the re-asphalting of the streets is produced, being the average decrease of $L_{Aeq,24h}$ for SS, PXII, GA and AFM streets 4.4, 8.2, 7.8, and 2.7 dB(A), respectively.

Before the re-asphalting of the four studied streets, the $L_{Aeq,T}$ for the daily and evening periods were very similar, ranging from 62.8–71.0 dB(A), while during the night period between 61.2–66.8 dB(A) was measured for the same index.

By comparing the acoustic quality objectives established by Royal Decree 1367/2007 (RD: 1367, 2007) for urbanised areas with the obtained noise levels for the different periods of day, we showed that, for all periods and roads, they were exceeded. On the other hand, after the re-asphalting only for the streets where the traffic is the only relevant noise source were the AQOs met (PXII, GA). Nevertheless, for the streets with high commercial or leisure activities (SS, AFM), the new noise levels after re-paving were not below the AQOs, proving that other community activities (shopping, recreation, etc.) have a similar weighting as road traffic source.

This study highlighted the importance of Noise Monitoring Networks (NMNs) implemented in the most innovative cities, allowing real-time recording of ambient noise levels of its main arteries. These are networks that detect areas of the city that exceed the guidelines for acoustic quality objectives established by the legislation; develop and implement action plans to combat noise; and provide information to the public, on noise pollution in their cities in different areas and times of day: see <http://www.controlruidohuelva.es/>.

In addition, it was clearly advantageous to use NMN with respect to Close-Proximity Methods (CPX) to evaluate the noise emission from a standard passenger car tire when rolling over a road surface, as described in ISO standard ISO/CD 11819-2 (ISO/FDIS 11819-2, 2016), since the improvement in the acoustic pollution is analysed under real conditions. This is because the NMN allows one to analyse the deterioration of the pavement of each of the streets dynamically,

through the continuous evolution of noise, all in real time.

Finally, we employed a methodology that could be used by the municipal authorities to decide when the repaving of every street should be carried out, taking into account the type of pavement and the established AQOs, and based on the information given by the NMNs.

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