Applied Acoustics 204 (2023) 109241

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical note

Different types of criteria for dealing with anomalous noise events in urban environments under stable road traffic flow conditions

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ARTICLE INFO

Article history:
Received 16 November 2022
Received in revised form 2 January 2023
Accepted 23 January 2023
Available online 30 January 2023

Keywords:
Road traffic noise
Elimination criteria
Measurements
Temperature
Strategic noise maps
Uncertainty

ABSTRACT

The management of anomalous noise events in the assessment of environmental noise of specific sources is an important issue for determining the actual exposure of the population to noise pollution. Of all the sources currently considered in the European Noise Directive, road traffic is the most important in cities, both in terms of its temporal and spatial presence, as it is generally maintained 24 h a day and affects almost all streets in urban environments. This paper proposes two types of criteria for dealing with these events in urban environments under stable vehicle flow conditions. The results show the convenience of using each type of the suggested criteria for the elimination of anomalous noise events depending on the objective of the research. Those exclusion criteria based on applying a threshold to the average sound level, may be considered the best among the proposed options to study the variation of the annual average $L_{Aeq,1h}$. However, to study the relation between road traffic noise and temperature, a novel proposal for anomalous event elimination criteria based on dividing the full temperature range into small intervals may be a relevant approach. Overall increases of 8 %, respectively, 14 %, in the explanation of variability were found for the criteria C6 (successive application of the thresholds ±10 dB, ±6 dB and ±3 dB at each temperature interval of 3 °C) with respect to the cases where anomalous sound events were not excluded, respectively, using criteria C1 from the scientific literature. The application of this type of criteria for the management of anomalous noise events could also be useful for the study of the relation between road traffic noise and other objective and subjective variables in cities, especially in those areas with a greater daily thermal oscillation.

1. Introduction

In situ measurements are widely used in urban areas to assess the acoustic situation in a given location or to determine the exposure of the population to environmental noise [23,15,13]. However, cities are complex environments not only in terms of the variety of noise sources [14,12,22,11,20], but also in terms of the urban characteristics of the streets [18,10,16]. The emergence of unforeseen event-based sources or non-target sources is a common cause of an increased variability of measured noise levels in cities [2,9,1] and discrepancies between measured values of noise indicators and those calculated by the software in strategic noise maps [8,5,17]. Therefore, the management of anomalous noise events can be a key issue in the assessment of environmental noise in urban environments. Van Renterghem et al [21] used the notes taken during short short-term measurements to discriminate between measurements where road traffic was the main source of noise in order to discard invalid measurements from their specific research. Alsina-Pagès et al. [3] tested a procedure for the automatic elimination of anomalous noise events from audio recordings where road traffic noise was the sound source under study and concluded that, although the idea is feasible, further research is needed. Barrigón Morillas et al. [6] studied the hour-to-hour variability of road traffic flow in a large urban area with many traffic gauging stations and found a time interval in which more than 95 % of the hourly average values deviated less than 26 % from the average flow. This average flow variability was equivalent to an average variability in noise levels of 1 dBA, thus the exclusion criteria for anomalous noise events of ±10 dB from the average noise level that was used in their investigation can be considered to be not very restrictive when the main source of noise is road traffic noise.

The present paper proposes two types of criteria for dealing with anomalous noise events in urban environments where road traffic noise is the main sound source. The key novelty of the study

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https://doi.org/10.1016/j.apacoust.2023.109241
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is to carry out an event elimination analysis based on the fact that the sound power generated by road traffic is temperature-dependent [7,4], even at the speeds of vehicles in cities [6].

2. Methodology

Continuous in situ measurements of the equivalent sound level with an integration interval of one hour ($L_{Aeq,1h}$) were carried out over the whole of 2019 at several points distributed throughout the city of Madrid (Spain), together with road traffic flow and temperature monitoring, as described in detail in the paper by Barrigón Morillas et al. [6]. Given that road traffic flow was sufficiently stable over the time interval considered that its hourly variability was such that more than 95 % of the $L_{Aeq,1h}$ values were in a range of ±1 dBA, first, a non-restrictive criterion to discard those anomalous noise events that exceeded the annual average noise level at each measurement station by ±10 dB was considered. Furthermore, taking into account the stability of the flow, it is also of interest to apply more restrictive criteria such as ±6 dB and ±3 dB to analyse their effect on the management and discarding of anomalous noise events.

In addition, since the level of road traffic noise decreases with temperature [6,4,19,7], it may be of interest to take this into account in analyses where there is a large thermal oscillation. If a coefficient of variation of road traffic noise level with temperature of 0.1 dB/°C [4] is considered and taking into account that the temperature in Madrid ranged in 2019 between a minimum of −1.5 °C to a maximum of 43.5 °C, a variability of the road traffic noise level of 4.5 dB can be expected to occur only due to temperature variation. Therefore, it may be of interest to apply an anomalous event elimination criterion by considering short temperature ranges where this variability is small. A proposal of criteria is made in this study where the average sound level is calculated in each 3 °C interval over which the thresholds of ±10 dB, ±6 dB and ±3 dB are applied for the elimination of anomalous noise events.

In this study, six different criteria, grouped into two types, were used to exclude anomalous noise events:

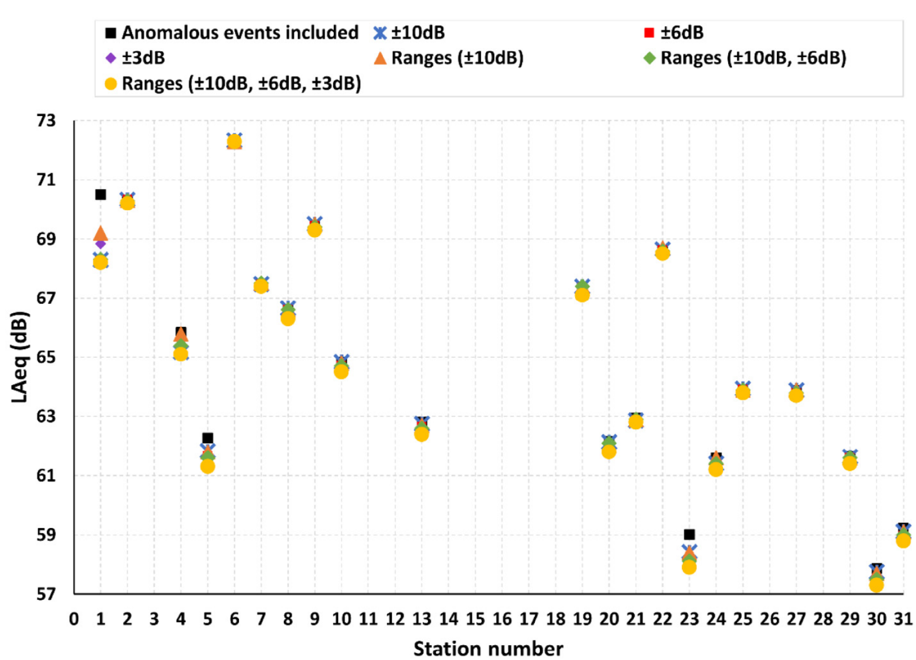
a) Group A: criteria based on a threshold for the full temperature range:

- Criterion 1 (C1): the annual average value of $L_{Aeq,1h}$ is calculated for the full temperature range (−1.5 °C to 43.5 °C) and all values exceeding it by a threshold of ±10 dB are excluded.
- Criterion 2 (C2): the annual average value of $L_{Aeq,1h}$ is calculated for the full temperature range (−1.5 °C to 43.5 °C) and all values exceeding it by a threshold of ±6 dB are excluded.
- Criterion 3 (C3): the annual average value of $L_{Aeq,1h}$ is calculated for the full temperature range (−1.5 °C to 43.5 °C) and all values exceeding it by a threshold of ±3 dB are excluded.

b) Group B: criteria based on a threshold for each temperature interval:

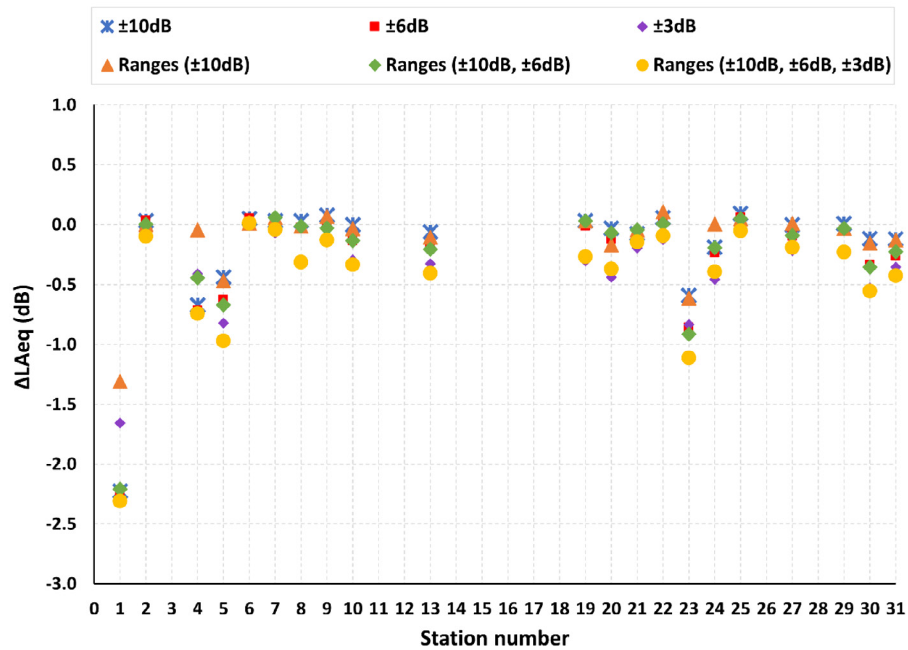
- Criterion 4 (C4): the annual average values of $L_{Aeq,1h}$ in each temperature range of 3 °C (from −1.5 °C to 43.5 °C) are calculated and all values exceeding them by a threshold of ±10 dB are excluded.
- Criterion 5 (C5): the annual average values of $L_{Aeq,1h}$ in each temperature range of 3 °C (from −1.5 °C to 43.5 °C) are first calculated and all values exceeding them by a threshold of ±10 dB are excluded. Then, considering the values not eliminated, the

a)



b)

Fig. 1. A) annual average values of $L_{Aeq,1h}$ for the case where anomalous noise events are not excluded and those where exclusion criteria C1–C6 are applied; b) difference between the annual average $L_{Aeq,1h}$ between the case where anomalous events are included and those where exclusion criteria are applied; c) variation of the percentage of the number of data (n) eliminated when applying the different criteria with respect to the case in which they are included.



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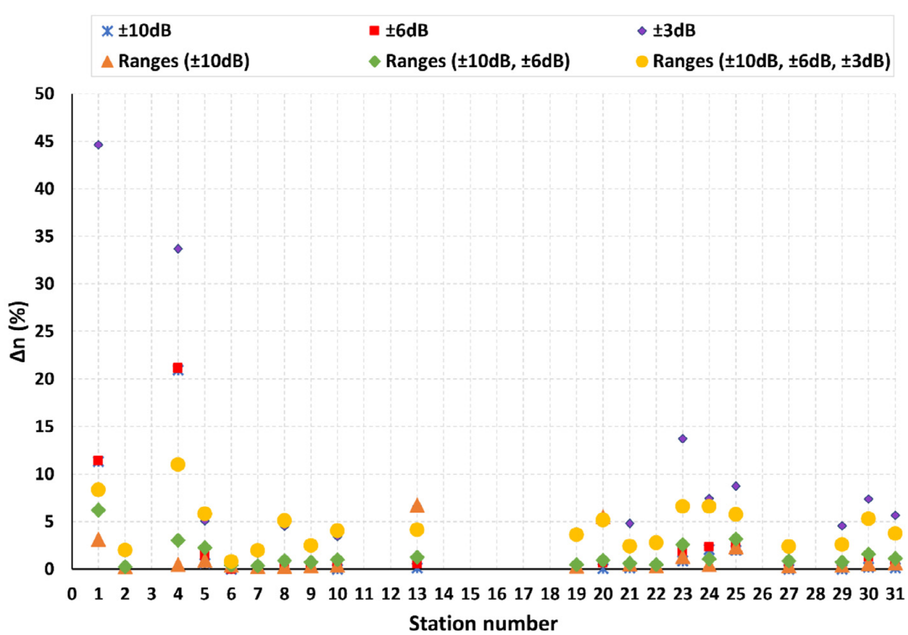

Fig. 1 (*continued*)

average value of $L_{Aeq,1h}$ in each temperature range is calculated again and all values exceeding them by a threshold of ±6 dB are eliminated.

- Criterion 6 (C6): the annual average values of $L_{Aeq,1h}$ in each temperature range of 3 °C (from −1.5 °C to 43.5 °C) are first calculated and all values exceeding them by a threshold of ±10 dB are excluded. Then, with the values not eliminated, the average value of $L_{Aeq,1h}$ in each temperature range is calculated again and all values exceeding them by a threshold of ±6 dB are eliminated. Finally, with the values not removed, the average value of $L_{Aeq,1h}$ in each temperature range is recalculated and all values exceeding them by a threshold of ±3 dB are deleted.

3. Results and discussion

3.1. Study of the annual average equivalent sound level

A relevant aspect for estimating the effects of urban noise on citizens is to know the values of average noise levels over long periods of time, in many cases a year. For this reason, the effect that the different criteria for the elimination of anomalous noise levels have on the annual average of L_{Aeq} is analysed. Fig. 1a shows the annual average values of $L_{Aeq,1h}$ in the time period from 8 a.m. to 8p.m. from Tuesday to Thursday, when the traffic flow is stable at each of the 21 measurement stations in Madrid [6], both the case where anomalous noise events are not excluded and those where criteria C1 to C6 are applied for their elimination. If the average of the differences of $L_{Aeq,1h}$ are calculated for all measurement stations between the cases in which the different exclusion criteria are applied and that where the anomalous events are included, the values of the differences of the annual average $L_{Aeq,1h}$ for criteria C1 to C6 are respectively −0.20 dB (C1), −0.28 dB (C2), −0.37 dB (C3), −0.13 dB (C4), −0.26 dB (C5) and −0.44 dB (C6). These results show that the application of any of the anomalous event elimination criteria does not generally result in a substantial variation of the annual average $L_{Aeq,1h}$. It is also observed that by applying a criterion with an increasingly restrictive threshold within each of the criteria groups A and B, the average $L_{Aeq,1h}$ value decreases slightly compared to the previous criteria.

When a station-by-station analysis is performed from Fig. 1b, it is noted that the general trend previously reported is maintained for most of the measurement points. The exceptions are stations 1, 4, 5 and 23, where larger variations of the annual average value of $L_{Aeq,1h}$ are observed with respect to the case where anomalous events are included. As can be seen in Fig. 1c, which shows the percentage of data eliminated when applying the different exclusion criteria, this may be related to the fact that a greater number of anomalous sound events occur at these stations regarding road traffic noise. The case of station 1 is that in which a higher percentage of data (n) related to anomalous events is eliminated when applying criteria 3, reaching a value of 44.6%.

The general trend of the results obtained for the differences of the average value of $L_{Aeq,1h}$ in the monitoring stations of Madrid in that period of the day in which the flow of road traffic is stable does not show large differences between the two groups of criteria A and B for the elimination of anomalous events. If the higher complexity of data processing in group B is taken into account, as well as its higher cost due to the need for a network of temperature monitoring stations, it seems that the exclusion criteria of group A may be the optimal option to study the variation of the annual average of L_{Aeq} of the measurement stations in a city due to the presence of anomalous events.

3.2. Study of the relation between sound level and temperature

Another aspect of interest in estimating the exposure of population to noise pollution is the evaluation of the effect that temperature variations may have on the measured noise levels. Specifically, in the urban environment, this aspect may be of particular interest, given that speeds are at the limit at which rolling noise begins to be significant compared to engine noise. Table 1 shows the values obtained for the slope of the linear regression analysis between road traffic noise levels and temperature in the different measurement stations in Madrid for both the case where anomalous noise events are not discarded and for those cases corresponding to the six criteria described in section 2 for their exclusion. As reported in detail in the work of Barrigón Morillas et al. [6], these values are obtained for $L_{Aeq,1h}$ considering the days from Tuesday to Thursday and during the period from 8 a.m. to 8p.m., in which the vehicle flow is stable. If the average of the differences of slope are calculated for all measurement stations between the cases in which the different exclusion criteria are applied and that where the anomalous events are included, the average values for criteria C1 to C6 are respectively −0.008 (C1), −0.007 (C2), 0.004 (C3), −0.006 (C4), −0.007 (C5) and −0.007 (C6). It can first be observed that increases in the negative slope generally occur between the case where the anomalous events are not discarded and those where an elimination criteria is used. Some more significant increments are observed for example at monitoring stations 1 and 4, which may be associated with the presence of several types of sound sources other than road traffic noise (see Fig. 1c). However, an exception occurs in the case of criterion C3, where an average decrease of 0.004 in the slope is observed. This finding may be

Table 1
Variation of the slope of the linear regression analysis between road traffic noise levels and temperature in the different monitoring stations in Madrid for the six criteria used for the exclusion of anomalous noise events.

Station number	Station name	SLOPE						
		Anomalous events included	±10 dB	±6dB	±3dB	Ranges (±10 dB)	Ranges (±10 dB, ±6dB)	Ranges (±10 dB, ±6dB, ±3dB)
1	Paseo de Recoletos	−0.028	−0.069	−0.068	−0.042	−0.053	−0.066	−0.067
2	Carlos V	−0.053	−0.059	−0.059	−0.056	−0.059	−0.059	−0.060
4	Plaza de España	−0.034	−0.104	−0.104	−0.067	−0.055	−0.067	−0.097
5	Barrio del Pilar	−0.050	−0.055	−0.049	−0.043	−0.055	−0.050	−0.048
6	Gregorio Marañón	−0.073	−0.080	−0.080	−0.078	−0.080	−0.080	−0.080
7	Escuelas Aguirres	−0.069	−0.073	−0.074	−0.072	−0.075	−0.075	−0.078
8	Cuatro Caminos	−0.077	−0.092	−0.091	−0.090	−0.092	−0.093	−0.096
9	Ramón y Cajal	−0.087	−0.098	−0.097	−0.090	−0.099	−0.098	−0.096
10	Manuel Becerra	−0.028	−0.036	−0.037	−0.035	−0.038	−0.038	−0.039
13	Arturo Soria	−0.119	−0.125	−0.125	−0.116	−0.126	−0.126	−0.128
19	Santa Eugenia	−0.078	−0.084	−0.082	−0.065	−0.085	−0.084	−0.070
20	Embajada	−0.105	−0.107	−0.105	−0.086	−0.108	−0.107	−0.098
21	Barajas Pueblo	−0.128	−0.120	−0.120	−0.107	−0.121	−0.122	−0.121
22	Cuatro vientos	−0.119	−0.113	−0.113	−0.105	−0.114	−0.114	−0.114
23	El Pardo	−0.075	−0.063	−0.064	−0.047	−0.069	−0.067	−0.067
24	Campo de las Naciones	−0.101	−0.091	−0.090	−0.076	−0.099	−0.095	−0.092
25	Sanchinarro	−0.094	−0.116	−0.117	−0.102	−0.117	−0.121	−0.118
27	Castellana	−0.089	−0.096	−0.097	−0.094	−0.097	−0.097	−0.097
29	Ensanche de Vallecas	−0.122	−0.123	−0.122	−0.111	−0.125	−0.125	−0.123
30	Urb. Emabajada II	−0.110	−0.102	−0.100	−0.082	−0.103	−0.102	−0.098
31	Tres Olivos	−0.078	−0.080	−0.077	−0.068	−0.082	−0.079	−0.078

related to the rather restrictive threshold of ±3 dB in criterion C3 with respect to the annual average $L_{Aeq,1h}$ not taking into account the demonstrated dependence of road traffic noise level on temperature [4,7]. The stability in the slopes between the results of groups A and B seems to indicate that if a factor of efficiency in data processing and cost is taken into consideration, it would not be necessary to use the criteria with temperature ranges (C4, C5 and C6) even in this type of study. However, in the case of group A criteria, care must be taken when using very restrictive criteria such as criterion C3, because the threshold applied may be very close to the variability of road traffic noise level associated with temperature (4.5 dB in this case where the thermal oscillation ranges from −1.5 °C to 43.5 °C).

Another important aspect of this study is the variation of the explanation of the variability of the noise level of urban road traffic based on the temperature. In this regard, Fig. 2 shows the value of the coefficient of determination R^2 of the linear regression analysis between road traffic noise levels and temperature in the different monitoring stations in Madrid for the case where anomalous noise events are not discarded and for the six criteria used for their exclusion. The average of the differences of R^2 for all measurement stations between the case in which the anomalous events are included and the different exclusion criteria were respectively 0.06 (C1), 0.08 (*C*2), 0.09 (C3), 0.04 (C4), 0.07 (C5) and 0.14 (C6). Therefore, it can be first noted that all these elimination criteria provide an average increase of the explanation of road traffic noise variability from temperature with respect to the case where all anomalous noise events are included in the study, reaching a maximum average value of 14 % using criterion C6. The results also show that the application of criteria C4 and C5 using temperature ranges of 3 °C and thresholds of ±10 dB and ±10 dB, ± 6 dB respectively does not provide an improvement in general terms in explaining the variability of urban road traffic noise from temperature compared to criterion C1 used in previous research [6]. However, adding the ±3 dB threshold in criterion C6 leads to an average increase in the explanation of variability of 8 % compared to criterion C1. Even this increase in explanation over that of criterion C1 reaches significant values, up to 19 %, at monitoring stations 8 and 13. From these findings it can be concluded that the application of group B of exclusion criteria for anomalous sound events based on temperature ranges may be a good approach for the study of the explanation of variability in the relation between road traffic noise and temperature in urban environments, especially criterion C6 and in cities with a large thermal oscillation.

4. Conclusions

Different types of criteria were proposed to manage anomalous noise events when assessing road traffic noise in an urban environment under stable vehicle flow conditions. Based on the findings from the monitoring of noise levels for one year in Madrid (Spain), it can be concluded that the criteria for the elimination of anomalous noise events in each study or investigation must be in accordance with the objective pursued.

When the aim of the study was to determine the annual average sound level in an urban environment associated with a stable road traffic noise flow, the results revealed that the use of the exclusion criteria of group A, based on applying a threshold to the average sound level, could be a good approach if factors such as cost and complexity of data processing are taken into account. The use of thresholds of ±10 dB (C1), ±6 dB (C2) and ± 3 dB (C3) for the full range of temperature with respect to the average sound level showed respectively differences in the annual average $L_{Aeq,1h}$ of −0.20 dB, −0.28 dB and −0.37 dB compared to the case where anomalous noise events are not excluded.

When the objective was to study of the relation between road traffic noise level from a stable vehicle flow and temperature in the city, the application of the criteria of groups A and B represent an improvement compared to the case where the anomalous events are not eliminated. If the variation of the slope of the linear regression is analysed, the results generally show a stability of the slope between the groups A and B. Therefore, an efficiency factor both in terms of data processing and cost may lead to the choice of group A criteria for this specific purpose. However, it is neces-

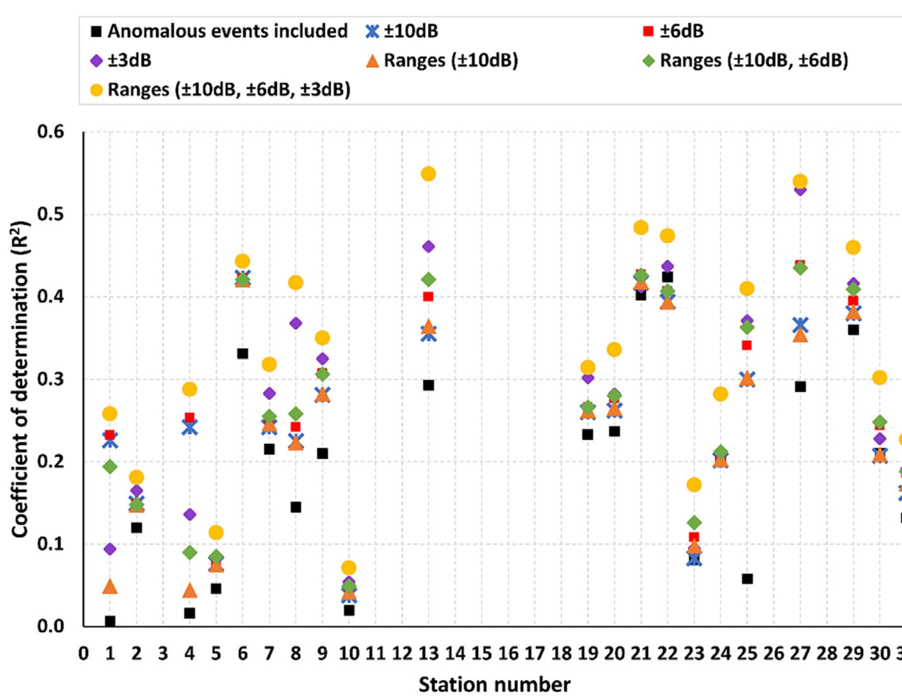

Fig. 2. Variation of the coefficient of determination (R^2) of the linear regression analysis between road traffic noise levels and temperature in the different monitoring stations in Madrid for the four criteria used for the exclusion of anomalous noise events.

sary to note in this respect that a criterion of this group with a very restrictive threshold, such as criterion C3, could lead to results that do not take into consideration the variability of the road traffic noise level with temperature. When studying the improvement in the explanation of traffic noise variability from temperature using elimination criteria, criterion C6 (based on the partitioning of the total temperature range into 3 °C intervals and the successive use of the thresholds ±10 dB, ±6 dB and ±3 dB above the average sound level) leads to increases of 14 %, respectively, 8 %, with respect to the cases where anomalous sound events are not discarded and the application of criterion C1 previously used in the scientific literature.

Funding

This project was co-financed by *European Regional Development Fund* (ERDF) and *Junta de Extremadura* (IB18050 and GR21061). This work was also supported by *Consejería de Economía, Ciencia y Agenda Digital* of *Junta de Extremadura* through grants for attracting and returning research talent to R&D&I centres belonging to the Extremadura Science, Technology and Innovation System (TA18019), where *University of Extremadura* was the beneficiary entity.

CRediT authorship contribution statement

David Montes González: Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Juan Miguel Barrigón Morillas:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Guillermo Rey-Gozalo:** Methodology, Software, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the Madrid City Council for their collaboration and Alicia Bachiller León for her help in data processing.

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