Applied Acoustics

Uncertainty evaluation of road traffic noise models in two Ibero-American cities

--Manuscript Draft--

Manuscript Number:	APAC-D-20-00411R3
Article Type:	Technical Note
Section/Category:	Europe and Rest of the World
Keywords:	Noise Mapping; uncertainty; road traffic
Corresponding Author:	Guillermo Rey Gozalo Universidad de Extremadura Cáceres, Spain
First Author:	Guillermo Rey Gozalo
Order of Authors:	Guillermo Rey Gozalo
	Valentín Gómez Escobar, PhD
Abstract:	In this study, the differences between calculated and measured noise values were evaluated in situ through more than 550 measurements in two Ibero-American cities. These categorisation method-based noise measurements were performed at 216 sampling points located on five different types of urban roads. Two different calculation methods were used for noise modelling—XPS 31-133 and CNOSSOS-EU. In addition to the magnitude and average of the uncertainties, their biases were evaluated independently in the calculation. These uncertainties were analysed overall for each city and considering the type of urban road. The relationship between road traffic characteristics (flow and percentage for each vehicle class) and the type of uncertainty was also studied. A high percentage of the uncertainties of both methods are lower than 3 dB in both cities. However, the calculation methods are different from each other in terms of the distribution of errors for the various types of urban roads and the bias of the estimates. The XPS 31-133 method provides the worst estimates for sound measurements performed on residential streets, whereas the CNOSSOS method presents the largest estimation errors on main streets. In terms of the bias, the XPS 31-133 method overestimates the noise values, primarily in residential streets; this overestimation is explained by the increase in the flow and percentage of medium heavy vehicles. On the other hand, the CNOSSOS-EU method underestimates the noise values in a high percentage of measurements performed on the various types of urban roads. This underestimation is significantly related to the increase in light vehicles flow.
Suggested Reviewers:	Paulo Henrique Trombetta Zannin Federal University of Curitiba paulo.zannin@gmail.com Researcher involved in environmental acoustics and population noise exposure
	Gianluca Memoli National Physical Laboratory gianluca.memoli@npl.co.uk Researcher involved in environmental acoustics and population noise exposure
	Giovanni Zambon University of Milan-Bicocca giovanni.zambon@unimib.it Researcher involved in environmental acoustics and population noise exposure
Opposed Reviewers:	
Response to Reviewers:	Reviewer #2 I appreciate the work done by the authors to improve the quality of the paper. I strongly believe that the decision of converting it to a technical note is very sensible. There are some issues that needs further consideration (below). The authors would like to thank the reviewer for his/her comments and suggestions

Uncertainty evaluation of road traffic noise models in two Ibero-American cities

Guillermo Rey Gozalo[a,b,*], Valentín Gómez Escobar[a]

[a]Departamento de Física Aplicada, Institute for Sustainable Regional Development (INTERRA), Escuela Politécnica, Universidad de Extremadura, Avda. de la Universidad s/n, 10003 Cáceres, Spain; e-mail: valentin@unex.es

[b]Facultad de Ciencias de la Salud, Universidad Autónoma de Chile, 5 Poniente 1670, 3460000 Talca, Región del Maule, Chile.

[*]Corresponding author. *E-mail address*: guille@unex.es (G. Rey Gozalo)

Abstract

In this study, the differences between calculated and measured noise values were evaluated *in situ* through more than 550 measurements in two Ibero-American cities. These categorisation method-based noise measurements were performed at 216 sampling points located on five different types of urban roads. Two different calculation methods were used for noise modelling—XPS 31-133 and CNOSSOS-EU. In addition to the magnitude and average of the uncertainties, their biases were evaluated independently in the calculation. These uncertainties were analysed overall for each city and considering the type of urban road. The relationship between road traffic characteristics (flow and percentage for each vehicle class) and the type of uncertainty was also studied. A high percentage of the uncertainties of both methods are lower than 3 dB in both cities. However, the calculation methods are different from each other in terms of the distribution of errors for the various types of urban roads and the bias of the estimates. The XPS 31-133 method provides the worst estimates for sound measurements performed on residential streets, whereas the CNOSSOS method presents the largest estimation errors on main streets. In terms of the bias, the XPS 31-133 method overestimates the noise values, primarily in residential streets; this overestimation is explained by the increase in the flow and percentage of medium heavy vehicles. On the other hand, the CNOSSOS-EU method underestimates the noise values in a high percentage of measurements performed on the various types of urban roads. This underestimation is significantly related to the increase in light vehicles flow.

Keywords: Noise mapping; uncertainty; road traffic.

1. Introduction

The strategic noise maps are the main tool for noise assessment and management according the Environmental Noise Directive (END) [1]. There are different methodologies for noise mapping but calculation methods are the most commonly used. Some European Union Member States (EU MS) developed their own calculation methods. For EU MS that have no national calculation methods or wish to change it, the French national calculation method (NMPB-Routes-96/XPS 31-133) was recommended for road traffic noise [1]. These methods have also been used and tested in non-European countries [2–4] and in comparative studies between European and non-European cities [5]. Noise exposure levels in non-European cities are relevant to the World Health Organisation (WHO), as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world [6]. Noise maps are available for agglomerations with more than 100,000 inhabitants in Europe. Noise pollution problems are also found in towns [7,8].

A wide range of calculation methods has been used cross-nationally, which has prevented to evaluate noise exposure levels comparatively across all countries. Consequently, the European Commission (EC) established that EU MS should use common noise assessment methods (CNOSSOS-EU) in 2019 [9]. Implementing this method in non-European countries would also contribute to the development of globally common actions.

CNOSSOS-EU propagation models for road sources were developed from the NMPB French model [10]. However, source models developed new emission values for road vehicles. The CNOSSOS-EU method groups vehicles into five separate categories, whereas only three are established in the NMPB/XPS 31-133 method. Some authors have found inaccuracies in the sound power coefficients for road vehicles in the CNOSSOS-EU method [11]. This methodology is to be applied for the next round of noise mapping in 2022. It is therefore important to analyse their estimates in different urban environments.

Calculation methods follow a rigorous validation process. However, road characteristics sampled for validation may differ from urban roads [12]. The "Good Practice Guidance for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure" (WG-AEN) [13] recommends *in situ* measurements to validate the noise levels modelled by calculation methods. This validation is also considered as the calibration of the computation models. There are current studies where the CNOSSOS-EU method is validated in urban environments. However, the number of *in situ* sampling points is very low and most of them are located on major urban roads [14,15]. Other current studies compare the predictions of the CNOSSOS-EU method with other noise models but no *in situ* measurements are performed [16,17].

The calibration of the calculation methods is essential because it is extremely difficult to include all the elements and characteristics of the real environment that is being modelled. Thus, some suppositions about building absorption, building height, vehicle speed, ground region absorption, and other factors are commonly used in noise mapping.

These suppositions, commonly based on expert recommendations [13,18] or national regulations, can introduce an uncertainty in the calculated noise values.

The first question that can arise when a change in the calculation method is established is whether the results obtained using the two methods are similar; thus, a comparison between the different methods is necessary. Comparing these two noise mapping methods (CNOSSOS-EU and XPS 31-133) from the data reported in previous studies is complicated because the input data required for both the methods is different.

Extensive measurements were conducted in this study, and data from more than 550 noise measurements were used to compare the uncertainties associated with the two calculation methods. The magnitude and bias of the difference between the calculated and measured noise levels were analysed. A total of 216 points were sampled in two cities located in different Ibero-American countries (Spain and Chile). The sampling points were located on different types of urban roads. Previous studies report less variability in the sound levels and the characteristics of road traffic within each type of urban road [3,19]. These variables were also related to the urban features of the streets [20].

The main objective of this study is to evaluate the difference between the measured and calculated noise levels for two different calculation methods (XPS 31-133 and CNOSSOS-EU) and to analyse some possible factors that cause this difference, such as the type of street where the sampling point was located or the characteristics of the traffic flow (number of vehicles, type of vehicles, and so on). The uncertainty bias (positive or negative difference) was analysed independently because it could be related to different sources. Application of the CNOSSOS-EU method in non-European countries and town will also be analysed in this study.

2. Methods

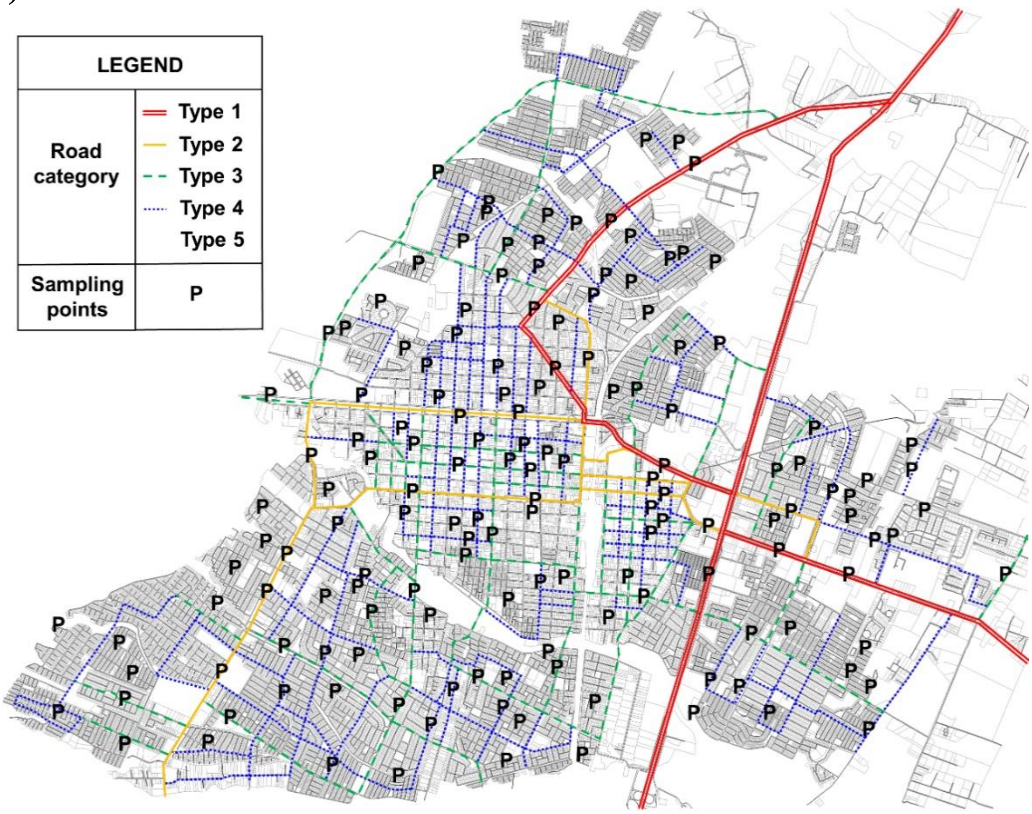
2.1. Cities studied

The city of Talca is located in central Chile and has approximately 220,000 inhabitants but its population increases during the university's academic year. The active population works mainly in the service and industrial sectors (approximately 55% and 36%, respectively). The mean annual temperature is 13 °C, whereas the mean annual rainfall is 750 mm. Moraleja town is located in the region of Extremadura (Southwest of Spain). It has a population of approximately 6,750 inhabitants. Most buildings have one or two floors as in Talca. The mean annual temperature is 16 °C, whereas the mean annual rainfall is 694 mm. Commerce and industry associated with the agricultural sector is predominant in this town.

2.2. Noise measurement procedure

Urban roads were classified into different types according to the categorisation method (see Fig. 1). Noise levels are expected to be significantly stratified in these road types as shown in previous studies [7,21]. Sampling points were randomly located within each urban road type.

a)



b)

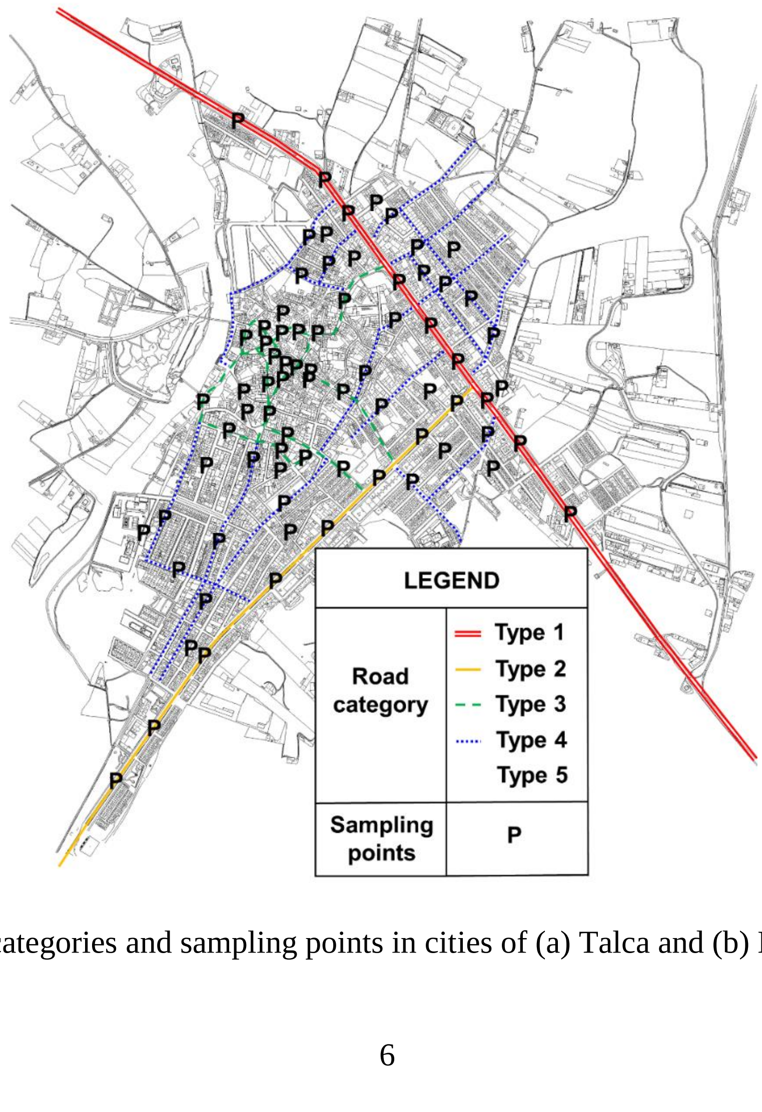


Fig. 1. Road categories and sampling points in cities of (a) Talca and (b) Moraleja

Noise measurements were performed during daytime on working days in 2016 and 2018 in both the cities. Two or three 15-min measurements were performed at each sampling point, at different daytime intervals and on different working days. The ISO 1996-2 guidelines were considered in the measurements [22]. A duration of 15 minutes was established in the measurements because some urban roads registered a low flow of vehicles [22]. This measurement duration has also been used in previous studies [23,24]. Class 1 sound-level meters were used (2250 and 2238 Brüel & Kjaer) and calibrated before and after each measurement. The sound-level meter was located 1 m from the curb and away from any reflective surface. The urban and road traffic characteristics were also recorded. Thus, vehicle flows corresponding to the five categories defined by CNOSSOS-EU method [9] were registered during the measurements.

In addition, other relevant information such as meteorological conditions, street dimensions, road surface types, and conservation of the road surface was also registered. Road traffic was the noise source considered for this study. Therefore, the measurement was restarted when another noise source impacted the sound values.

2.3. Noise modelling

The Predictor v.11.20 software was used for noise mapping. The three-dimensional models of the two cities are shown in Fig. S1.

The following configuration options was used for noise modelling:

- Number of reflections: 1
- Meteorological conditions: Default values of Toolkit 17 of the WG-AEN [13] were considered. Probst [25] proved that it is not necessary to take into account meteorological influences in the recommended calculation methods.
- Building height: Ground floor—4.5 m; each additional floor—3 m [26]

- Absorption of buildings and barriers: Reflective
- Flow type: Constant flow
- Vehicles speed: Maximum speed allowed for each street.

The receiver points were located in noise model at the same position where *in situ* measurement was carried out. For this purpose, photographs were captured during the sampling. A total of 555 sound measurements were estimated with calculation methods.

Road traffic flow and category was registered on the urban roads during the sound measurements. The mean value of the flow of each vehicle type was assigned for the non-sampled nearby streets considering the type of road category.

2.4. Statistical analysis

A descriptive and inferential analysis was performed on the differences between the sound levels calculated by the noise method ($L_{eq\text{-}method}$) and those measured *in situ* ($L_{eq\text{-}measurement}$). The statistical parameters of centralisation, dispersion, and shape were obtained from these differences or uncertainties to obtain as much information as possible about the accuracy of the noise methods. These parameters were calculated for all the measurements performed in the city and for each road category.

The distribution of the uncertainties did not differ significantly from a normal distribution ($p > 0.05$ according to the Kolmogorov–Smirnov test); therefore, parametric tests were conducted for the inferential analysis. Average values of the uncertainties in both the methods were compared using the *t*-test. In addition, the paired *t*-test was used to determine the significance of the uncertainty bias. Finally, the relationships between the uncertainties and road traffic characteristics were analysed (Pearson's *r*). In this analysis, uncertainties were differentiated according to their bias.

– Positive error: $L_{eq\text{-}method}$ (dBA) > $L_{eq\text{-}measurement}$ (dBA)

– Negative error: $L_{eq\text{-}measurement}$ (dBA) > $L_{eq\text{-}method}$ (dBA)

The variables associated with the source of the noise from the road traffic analysed were: log(Q_L), log(Q_H), log(Q_{mh}), log(Q_{hd}), log(Q_M), log(Q_{ma}), log(Qmb), %Q_L, %Q_H, %Q_{mh}, %Q_{hd}, %Q_M, %Q_{ma}, and %Q_{mb}, where log Q is the decimal logarithm of the vehicle flow, % represents the percentage of vehicles, L denotes light motor vehicles (Category 1 in END [9]), H denotes heavy vehicles (Categories 2 and 3 in [9]), mh represents medium heavy vehicles (Category 2 in [9]), *hd* represents heavy duty vehicles (Category 3 in [9]), *M* indicates powered two-wheelers (Category 4 in [9]), *ma* indicates mopeds (Category 4a in [9]), and *mb* indicates motorcycles (Category 4b in [9]).

The correct interpretation of the results obtained for the relationship between the sign of the uncertainty and the correlation coefficient is the following:

- Positive error and positive correlation coefficient: The overestimation error increases with increasing flow or percentage of road traffic and percentage.
- Positive error and negative correlation coefficient: The overestimation error decreases with increasing flow or percentage of road traffic.
- Negative error and positive correlation coefficient: The underestimation error decreases with increasing flow or percentage of road traffic.
- Negative error and negative correlation coefficient: The underestimation error increases with increasing flow or percentage of road traffic.

3. Results and discussion

3.1. Analysis of the noise modelling mapping uncertainty

The difference between the sound level estimated by the calculation method (XPS 31-133 or CNOSSOS-EU) and the sound level measured *in situ* was analysed. This difference, $L_{\text{eq-method}} - L_{\text{eq-measure}}$ (dBA), was referred to as noise modelling uncertainty. Average values of $L_{\text{eq-method}} - L_{\text{eq-measured}}$ (dBA) are shown in Table 1 and 2.

Table 1

Average values and percentages of differences between calculated and measured sound levels in Talca city.

		Overall	Urban road category				
			1	2	3	4	5
XPS 31-133	Average value ± standard deviation	0.78 ± 2.22	–0.92 ± 1.51	0.05 ± 2.12	–0.06 ± 1.48	0.89 ± 2.37	1.56 ± 2.21
	Average value ± standard deviation (absolute values)	1.86 ± 1.44	1.49 ± 0.92	1.77 ± 1.13	1.19 ± 0.87	2.06 ± 1.46	2.11 ± 1.69
	Percentage between 0 and 3 dB	80.05	91.67	89.74	94.67	74.77	72.37
CNOSSOS-EU	Average value ± standard deviation	–1.68 ± 2.16	–3.65 ± 1.62	–3.03 ± 1.82	–2.72 ± 1.34	–1.89 ± 1.77	–0.36 ± 2.13
	Average value ± standard deviation (absolute values)	2.28 ± 1.51	3.65 ± 1.62	3.03 ± 1.82	2.73 ± 1.32	2.13 ± 1.47	1.76 ± 1.25
	Percentage between 0 and 3 dB	69.33	29.17	51.28	56.00	72.07	84.87

Table 2

Average values and percentages of differences between calculated and measured sound levels in Moraleja town.

		Overall	Urban road category				
			1	2	3	4	5
XPS 31-133	Average value ± standard deviation	0.97 ± 2.54	1.88 ± 1.30	0.69 ± 1.21	0.94 ± 2.46	1.29 ± 2.88	0.38 ± 2.96
	Average value ± standard deviation (absolute values)	2.04 ± 1.78	1.94 ± 1.21	1.18 ± 0.70	1.85 ± 1.87	2.38 ± 2.05	2.30 ± 1.86
	Percentage between 0 and 3 dB	74.03	77.78	100	75.00	65.00	70.00
CNOSSOS-EU	Average value ± standard deviation	–2.43 ± 1.89	–3.21 ± 1.62	–3.54 ± 1.41	–2.04 ± 1.85	–2.07 ± 1.90	–2.41± 2.01

	Average value ± standard deviation (absolute values)	2.67 ± 1.53	3.21 ± 1.62	3.54 ± 1.41	2.21 ± 1.63	2.38 ± 1.48	2.84 ± 1.31
	Percentage between 0 and 3 dB	62.34	38.89	37.50	80.00	75.00	57.50

Considering overall sound measurements (see Tables 1 and 2), average absolute value of the uncertainty in both methods is close to 2 dB, which is considered as high accuracy by the WG-AEN [13]. This guide recommends that the noise modelling uncertainties should not exceed 5 dB. The average values obtained for the overall measurements are corroborated by the high percentage of differences of less than 3 dB between the two cities. These percentages are higher than those obtained in previous studies [3,4,27]. Therefore, both methods are suitable for noise mapping in non-European countries and in small cities.

Considering the average absolute values obtained in urban road categories (see Tables 1 and 2), there are differences in the trend between the two calculation methods. The uncertainties increase their average value and standard deviation from the noisiest urban roads to the quietest ones for the XPS method. The opposite phenomenon occurs for the CNOSSOS-EU method. Suárez et al. [28] and Bertellino et al. [14] also observed a decrease in the uncertainties in the noise models on urban roads that registered a higher flow of road traffic. Bertellino et al. [14] and Guarnaccia et al. [29] found that the uncertainties obtained using the CNOSSOS-EU method were similar to other calculation methods for urban roads with sound levels of approximately 55 dBA.

The urban roads that registered the highest flow of vehicles (Categories 1 and 2) present uncertainties, with the absolute average values exceeding 3 dB in the CNOSSOS-EU method. However, the uncertainties in the XPS method do not exceed 2 dB for these road categories. These results lead to significant differences between the two methods in their estimates on these urban roads (see Table 3). Both calculation methods generate similar average errors (1.8 to 2.8 dB) for urban roads in residential use (Categories 4 and 5). Category 3, urban service road, indicates differences between the two cities. The measured noise levels are high for Category 3 in Talca, whereas they are closer to those recorded for residential urban roads in Moraleja. The average errors obtained using both methods present significant differences for Category 3 in Talca, but these differences are not significant in Moraleja.

Table 3

Comparison of absolute average errors between XPS 31-133 and CNOSSOS-EU (*t*-test).

Talca		**Moraleja**	
Category	***p*-value**	**Category**	***p*-value**
1	<0.001	1	<0.05
2	<0.001	2	<0.001
3	<0.001	3	>0.05
4	>0.05	4	>0.05
5	>0.05	5	>0.05

The uncertainties in both the calculation methods differ depending on the type of urban road. Although the estimates obtained from both the methods are accurate, these errors can exceed 3 dB on urban roads with high road traffic flow for the case of the CNOSSOS method. This result implies that the errors of the main urban roads only should not be analysed, as the highest percentage of the population lives on residential roads [30]. Although both methods present low average uncertainties for residential roads, the variability in these values is high for these road categories (see Tables 1 and 2).

Considering the bias of the noise estimates, it can be seen that the average differences obtained using the XPS 31-133 model are mostly positive, which indicates that the calculated values are greater than the measured values, whereas the average differences obtained using the CNOSSOS-EU model are negative, which indicates the contrary case. The average values for the overall measurements in both cities are significantly different with respect to zero according to the paired *t*-test ($p < 0.01$). These results are corroborated by the shape of the uncertainly distributions shown in Fig. S2. Although the distributions of the differences present a similar shape for both cities and models, the differences obtained using the CNOSSOS model clearly tend toward negative values and those obtained using the XPS 31-133 model tend slightly toward positive values.

The trend of average uncertainties in the different urban road categories is similar to that obtained for the overall measurements (Tables 2 and 3). However, the positive bias of the XPS 31-133 method is less pronounced. Thus, the averages of the differences obtained between Categories 2 and 3 in Talca and between Categories 2 and 5 in Moraleja are close to zero. These average values do not even present significant differences with respect to zero according to the paired *t*-test. The average uncertainties obtained using the CNOSSOS-EU method and its absolute values are similar, indicating that almost all the uncertainties are negative.

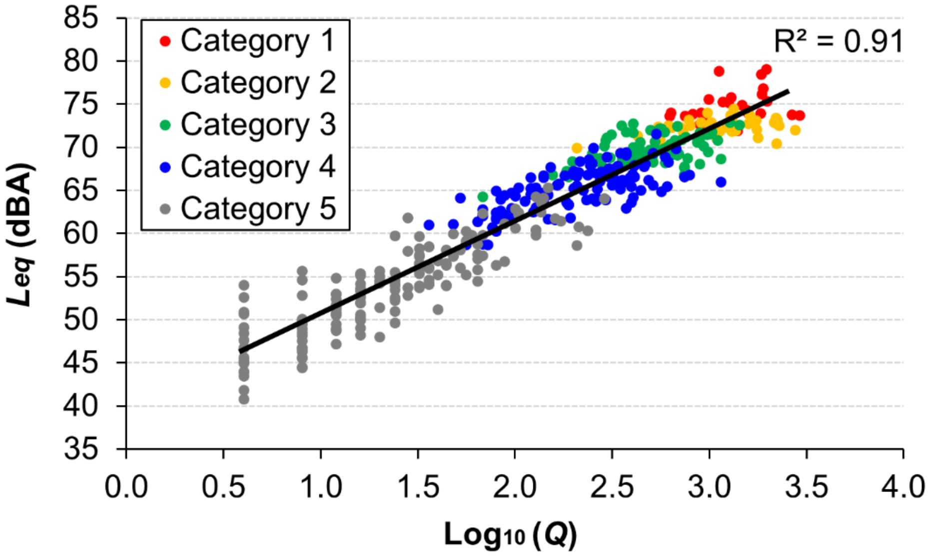
The percentages of negative differences obtained for overall measurements using the XPS 31-133 model were 35.41% and 34.42% in the cities of Talca and Moraleja, respectively. These percentages were 79.55% and 91.56% for the CNOSSOS-EU model. Considering these results, it can be concluded that the XPS 31-133 model tends to overestimate the noise levels and the CNOSSOS-EU model underestimates them. Morley et al. [31], Khan et al. [16], Bertellino et al. [14], and Guarnaccia et al. [29] also indicated the underestimation of the sound levels in the CNOSSOS-EU method. However, the other previous calculation methods—RLS-90 [3,4], CRTN [31,32], RTN-96 [16], ISO 9613-1/2 [33,34], and XPS 31-133 [14,35]—tend to overestimate the sound levels. These results may generate discrepancies in the selection of the calculation method. In previous studies, some authors have pointed out that, from a preventive point of view [3,36], an overestimation of sound levels is preferable. The uncertainties associated with the calculation models also impact the estimates of the effects of noise on health [37].

The estimates from both noise methods exhibit a similar trend for both cities despite their different location and size. This is an interesting result for the worldwide application of these calculation methods. The average error and percentage of error between 0 and 3 dB are slightly higher in Moraleja than in Talca. The lower flow of road traffic recorded in the road categories of Moraleja are impacted by this higher uncertainty in the calculation models. Similar results have been obtained in other cities of different population sizes [3,28].

3.2. Relationship between noise modelling uncertainty and road traffic characteristics

Road traffic is the main source of noise in urban environments. Fig. 2 shows the relationship between the equivalent sound level and the logarithm of the road traffic flow recorded in the measurements performed in this study. Only road traffic flow explains 91% and 83% of the equivalent variability in sound level. Therefore, the variables associated with the sound source explain the sound levels present in urban roads to a significant extent. For this reason, the relationships between the uncertainties in the calculation models and the variables associated with road traffic were analysed. The urban road categories are also differentiated in Figure 2. The average sound levels of these categories were significantly stratified (except between Category 1 and 2 in Moraleja). Therefore, the analysis of the relationship between noise modelling uncertainty and road traffic characteristics was carried out for each road category.

a)



b)

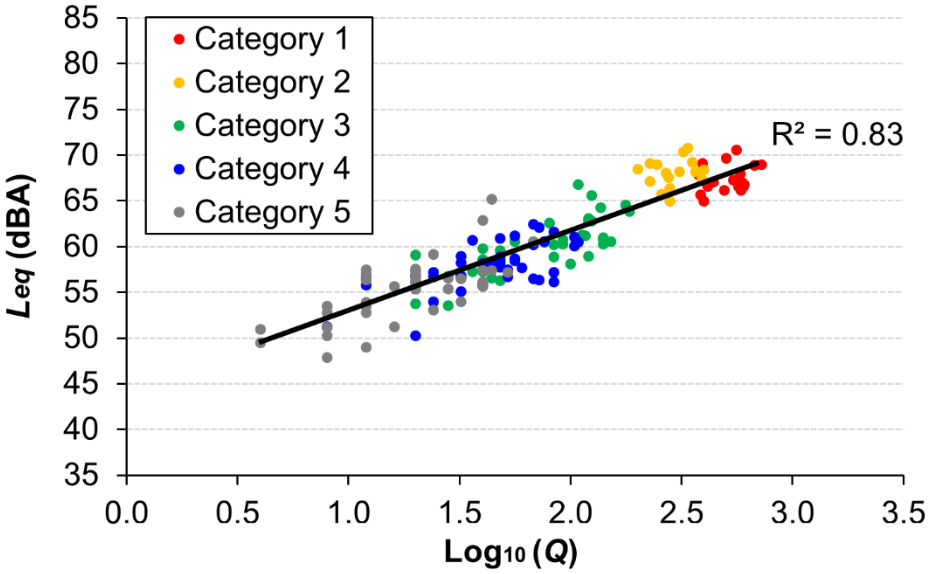


Fig. 2. Relationship between equivalent sound level and road traffic flow in (a) Talca and (b) Moraleja

The negative errors (the calculated values are lower than the measured values, and, thus, there is an underestimation in the calculation model) and positive errors (the calculated values are higher than the measured values, and, thus, there is an overestimation in the calculation model) were analysed independently. Differentiating in terms of the sign of uncertainty provides more information on the source of errors [38]. With respect to the variables associated with road traffic, the flow and percentages of the categories of vehicles proposed by the END were considered [1,9]—light motor vehicles, heavy vehicles, medium heavy vehicles, heavy duty vehicles, powered two-wheelers, i.e., mopeds and motorcycles.

As mentioned earlier, the sign of the error and the correlation coefficient (Pearson's *r*) must be considered to correctly interpret the results. The results obtained using the XPS 31-133 and CNOSSOS-EU methods are presented in Tables 4 and 5 and Table 6, respectively.

As illustrated, the XPS method tends to overestimate the sound levels. However, this bias is slight and not even significant in certain categories. Table 4 presents the relationships among the positive errors obtained using the XPS 31-133 method (overestimation) and the road traffic variables. This was an overall analysis that was performed for all the estimated sound values in the cities, by differentiating based on the road category.

Table 4

Relationships among positive uncertainties in XPS 31-133 method and flow of various vehicle types recorded under each type of road category

Pearson's *r*	**Variable 1: Positive Error**											
Variable 2	**Road categories in Talca**						**Road categories in Moraleja**					
	1	**2**	**3**	**4**	**5**	**Overall**	**1**	**2**	**3**	**4**	**5**	**Overall**
$\log(Q_L)$	-	-	-	-0.33^{**}	-	-0.30^{***}	-	-	-	-	-	-0.20^{*}
$\log(Q_H)$	-	0.66^{***}	-	0.54^{***}	-	-	0.49^{*}	-	-	-	-	-0.52^{***}
$\log(Q_{mh})$	-	0.74^{***}	-	0.46^{***}	-	-	0.56^{*}	0.65^{*}	-	-	-	-0.43^{**}
$\log(Q_{hd})$	-	-	-	0.51^{**}	-	-	-	-	-	-	-	-
$\log(Q_M)$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{ma})$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{mb})$	-	-	-	-	-	-	-	-	-	-	-	-
$\%Q_L$	-	-0.54^{**}	-0.52^{**}	-0.66^{***}	-	-0.26^{***}	-	-	-0.63^{***}	-0.68^{***}	-0.59^{*}	-0.56^{***}
$\%Q_H$	-	0.59^{**}	0.58^{***}	0.68^{***}	0.27^{**}	0.36^{***}	-	-	0.73^{***}	0.75^{***}	0.70^{**}	0.63^{***}
$\%Q_{mh}$	-	0.63^{**}	0.58^{***}	0.62^{***}	0.18^{*}	0.33^{***}	0.61^{**}	-	0.73^{***}	0.76^{***}	0.73^{***}	0.17^{*}
$\%Q_{hd}$	-	-	-	0.40^{**}	-	0.20^{**}	-	-	-	-	-	-
$\%Q_M$	-	-	-	-	-	-	-	-	-	-	-	-
$\%Q_{ma}$	-	-	-	-	-	-	-	-	-	-	-	-
$\%Q_{mb}$	-	-	-	-	-	-	-	-	-	-	-	-

- Non-significant correlation ($p > 0.05$).
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

The errors (averages and percentages) decreased from Category 5 to Category 1, as presented in Tables 1 and 2. Categories 1 and 2 are the main roads of the city and, therefore, represent high traffic flow (light and heavy vehicles). However, Categories 4 and 5 represent residential roads, where there is low flow of vehicles. Thus, the increase in light vehicle flow in Talca and Moraleja leads to a reduction in errors owing to the overestimation in the XPS 31-133 method, as presented in Table 5 under the general results. In addition, this general decrease (without distinction by road category) occurs for the increase in the flow of heavy vehicles in Moraleja. Therefore, the results presented in Tables 1, 2, and 4 are consistent.

Considering those sound sources that produce an increase in the positive errors, heavy traffic indicates a significant correlation. The increase in heavy traffic flow produces an increase in the errors of overestimation in the XPS 31-133 method in Categories 2 and 4 in Talca and Categories 1 and 2 in Moraleja. However, the effect of heavy traffic on the overestimation of noise levels in the different road categories is more evident when its percentage is analysed. A high flow of heavy traffic can also lead to a high flow of light traffic, which occurs on the main roads in the cities (Categories 1 and 2). Therefore, the possible effect of heavy traffic on the positive error can be masked by the increase in light traffic.

The effect of the percentage of heavy traffic on positive errors in the XPS 31-133 method, in general, is also considered. As the percentage of heavy and light traffic is related, an increase in one indicates a decrease in the other. For this reason, the percentage of light vehicles is negatively correlated.

Considering heavy vehicles, medium heavy vehicles are responsible for a significant correlation with positive errors for most road categories. The overestimation of the sound levels emitted by medium heavy vehicles in the XPS 31-133 method may have been one of the reasons why the CNOSSOS-EU method differentiates between the two types of heavy vehicles. In fact, the medium heavy vehicles modelled by the CNOSSOS-EU method are those that presented the largest differences with respect to the heavy vehicles modelled by XPS 31-133 [39]. These differences are even larger when the percentage of heavy vehicles increases.

Powered two-wheelers had no significant correlation with the positive errors in both the cities. Therefore, the sound level of the motorcycles was not overestimated by the XPS 31-133 method.

The relationships among the negative errors obtained using the XPS 31-133 method (underestimation) and the road traffic variables are presented in Table 5. A significant correlation exists among the medium heavy vehicles and negative errors in Talca city. However, in this case, the increase in the flow and percentage of medium heavy vehicles leads to a decrease in the underestimation errors in the XPS method in Categories 1–4. These results are related to those presented in Table 4. When the XPS 31-133 method produces underestimation errors, the increase in medium heavy vehicles reduces this negative error because this method overestimates the sound levels of these vehicles.

Table 5

Relationship among positive uncertainties in XPS 31-133 method and flow of various vehicle types recorded under each type of road category

Pearson's *r*	**Variable 1: Negative Error**											
Variable 2	**Road categories in Talca**						**Road categories in Moraleja**					
	1	**2**	**3**	**4**	**5**	**Overall**	**1**	**2**	**3**	**4**	**5**	**Overall**
$\log(Q_L)$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\log(Q_H)$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\log(Q_{mh})$	-	0.61^{*}	0.34^{*}	0.53^{*}	-	0.24^{*}	n.d.	0.65^{*}	-	-	-	-
$\log(Q_{hd})$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\log(Q_M)$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\log(Q_{ma})$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\log(Q_{mb})$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\%Q_L$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\%Q_H$	-	-	-	0.40^{*}	-	-	n.d.	-	-	-	-	-
$\%Q_{mh}$	0.47^{**}	0.68^{**}	0.58^{***}	0.43^{**}	-	0.17^{*}	n.d.	-	-	-	-	-
$\%Q_{hd}$	-	-	-	-	-	-	n.d.	-	-	-	-	-

$\%Q_{M}$	-	-	-0.32^{*}	-	-	-	n.d.	-	-	-	-0.48^{*}	-
$\%Q_{ma}$	-	-	-	-	-	-	n.d.	-	-	-	-	-
$\%Q_{mb}$	-	-	-0.32^{*}	-0.34^{*}	-	-	n.d.	-	-	-	-0.42^{*}	-

n.d. No data
- Non-significant correlation ($p > 0.05$).
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

Further, Table 5 presents significant relationships among two-wheelers and negative errors. The increase in two-wheelers, primarily motorcycles, produces an increase in the negative errors in Categories 3 and 4 in Talca and Category 5 in Moraleja. The negative effects of motorcycles are widespread in countries with a Mediterranean climate [40]. These motorcycles often have manipulated exhausts and produce noise above the permitted sound level. The underestimation of motorcycle noise in the XPS 31-133 method seems to be more noticeable on roads with lower vehicle flow.

Finally, the uncertainties in the CNOSSOS method were analysed, as presented in Table 6. Only the results obtained for the negative errors are presented in Table 6. Categories 1, 2, and 3 in Talca and Categories 1 and 2 in Moraleja did not record positive errors. The remaining categories also did not record significant correlations between the positive errors and road traffic variables.

Table 6

Relationship among negative uncertainties in CNOSSOS-EU method and flow of various vehicle types recorded under each type of road category

Pearson's *r*	**Variable 1: Negative Error**											
Variable 2	**Road categories in Talca**						**Road categories in Moraleja**					
	1	**2**	**3**	**4**	**5**	**Overall**	**1**	**2**	**3**	**4**	**5**	**Overall**
$\log(Q_{L})$	-0.44^{*}	-0.63^{***}	-	-	-	-0.19^{***}	-	-	-	-	-	-0.45^{***}
$\log(Q_{H})$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{mh})$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{hd})$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{M})$	-	-0.38^{*}	-	-	-	-	-	-	-	-	-	-
$\log(Q_{ma})$	-	-	-	-	-	-	-	-	-	-	-	-
$\log(Q_{mb})$	-	-0.38^{*}	-	-	-	-	-	-	-	-	-	-
$\%Q_{L}$	-	-	-	-	-	-	-	-	-	-	-	-
$\%Q_{H}$	-	-	-	-	-	-	-	-	-	-	-	-
$\%Q_{mh}$	-	-	-	-	-	-	-	-	-	-	-	-

% Q_{hd}	-	-	-	-	-	-	-	-	-	-	-	-
% Q_{M}	-	-	-	–0.21*	-	-	–0.51*	–0.19*	-	-	-	-
% Q_{ma}	-	-	-	-	-	-	-	-	-	-	-	-
% Q_{mb}	-	-	-	–0.20*	-	-	–0.54*	-	-	-	-	-

- Non-significant correlation ($p > 0.05$).
* Significant at $p \leq 0.05$.
*** Significant at $p \leq 0.001$.

The effect of heavy traffic on errors in the CNOSSOS-EU method is not significant. Only Category 2 presents a significant correlation in Talca, but with a p-value ≤ 0.05. This relationship may be affected by the high flow of vehicles in Categories 1 and 2. Therefore, the differentiation of heavy vehicles into two types may be a solution to avoid the overestimation of these vehicles.

Categories 1 and 2 presented the highest average errors in the CNOSSOS method (see Tables 1 and 2). Cars in Talca and motorcycles in Moraleja are strongly related to underestimation errors when this method is used. However, this underestimation seems to be more related to the flow than to the vehicle type. The CNOSSOS-EU propagation model divides noise sources into corresponding point sources and generates point-to-point estimations considering the distance between the point source and the receiver [10,11]. Therefore, a spherical divergence attenuation is considered for these urban roads with high vehicle flows. The operational characteristics of vehicles (speed, acceleration, etc.) are fairly constant on main roads. Vehicle density and proximity to each other on these roads could be influencing the propagation of sound levels. Perhaps, divergence attenuation is better fitted to a linear source under these conditions. Therefore, the decrease in sound levels with distance would be smaller than a spherical source and could contribute to decreasing uncertainty.

4. Conclusions

A large number of sampling points and sound measurements (216 sampling points and 555 sound measurements) were performed on various types of urban roads in two cities of different countries to analyse the estimates obtained using the XPS 31-133 and CNOSSOS-EU calculation methods. The following conclusions have been drawn as a result of this study.

Both calculation methods provide a good estimate of the noise levels registered on different types of urban roads. Moreover, the uncertainties are similar even though this study was conducted in two cities of different size and location. Therefore, these noise models can be applied in non-European countries and in small cities.

The uncertainty bias is different according to the calculation method. The XPS 31-133 method tends to overestimate the noise values, whereas the CNOSSOS method tends to underestimate them. When considering urban road types, the XPS-133 method has a higher overestimation error for residential streets. However, the CNOSSOS method has a higher underestimation error on main streets. Therefore, calibration points should be considered on these types of urban roads.

Analysing the relationships between road traffic and the uncertainties in the calculation methods, a positive effect of heavy vehicles is observed on the overestimation made by the XPS 31-133 method. Medium heavy vehicles have the greatest influence on this overestimation. Differentiation of sound power between medium heavy-duty vehicles and heavy-duty vehicles could improve the estimates.

Motorcycles have a significant effect on the underestimation of noise levels in the XPS 31-133 method on residential streets. Manipulated motorcycles are common in Mediterranean countries.

The increase in light vehicles flow significantly influences the underestimation error of the CNOSSOS-EU method. Uncertainty on main urban roads could perhaps be decreased if these roads with high vehicle flow were considered as linear rather than point sources in their divergence attenuation.

Despite the limitations of this study as it was carried out in small and medium-sized cities and in different countries, the large number of points sampled in different types of urban roads provides relevant information for the application and validation of these calculation methods in any agglomeration.

Acknowledgements

This study was funded by the Chilean National Commission for Scientific and Technological Research (CONICYT), now referred to as the National Agency for Research and Development (ANID), through the Project FONDECYT Regular No. 1180547. This work was also supported by Project GR18107 (*Junta de Extremadura*, Spain, and European Regional Development Funds, EU) and by *Consejería de Economía, Ciencia y Agenda Digital* of *Junta de Extremadura* through grants for attracting and returning research talent to the R&D&I centres belonging to the Extremadura Science, Technology and Innovation System (TA18019); the University of Extremadura is the beneficiary entity.

References

[1] END. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (END). Brussels: The European Parliament and the Council of the European Union; 2002.

[2] do Nascimento EO, de Oliveira FL, de Oliveira LN, Zannin PHT. Noise prediction based on acoustic maps and vehicle fleet composition. Appl Acoust 2021;174:107803. https://doi.org/10.1016/j.apacoust.2020.107803

[3] Bastián-Monarca NA, Suárez E, Arenas JP. Assessment of methods for simplified traffic noise mapping of small cities: Casework of the city of Valdivia, Chile. Sci Total Environ 2016;550:439–48. https://doi.org/10.1016/j.scitotenv.2016.01.139.

[4] Murillo Gómez DM, Jaramillo AM, Ochoa J. Analysis of the measurement uncertainty and its effects on noise mapping validations. J Environ Manage 2020;266:110606. https://doi.org/10.1016/j.jenvman.2020.110606.

[5] Wang B, Kang J. Effects of urban morphology on the traffic noise distribution through noise mapping: A comparative study between UK and China. Appl Acoust 2011;72:556–68. https://doi.org/10.1016/j.apacoust.2011.01.011

[6] WHO. Results from the research for available systematic reviews and meta-analyses on environmental noise. Denmark: World Health Organization (WHO), Regional Office for Europe; 2018.

[7] Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V. Analysis of noise exposure in two small towns. Acta Acustic 2012;98(6):884–93. https://doi.org/10.3813/AAA.918572.

[8] Gómez Escobar V, Barrigón Morillas JM, Rey Gozalo G, Vílchez-Gómez R, Carmona del Río FJ, Méndez Sierra JA. Analysis of the grid sampling method for noise mapping. Archives of Acoustics 2012;37:499–514. https://doi.org/10.2478/v10168-012-0062-z

[9] Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council. Brussels: The European Parliament and the Council of the European Union; 2015.

[10] Kephalopoulos S, Marco P, Fabienne AL. Common noise assessment methods in Europe (CNOSSOS-EU). Luxembourg: Publications Office of the European Union; 2012. https://doi.org/10.2788/31776

[11] Murphy E, Faulkner JP, Douglas O. Current state-of-the-art and new directions in strategic environmental noise mapping Current Pollution Reports 2020;6:54–64. https://doi.org/10.1007/s40726-020-00141-9

[12] Rey Gozalo G, Aumond P, Can A. Variability in sound power levels: implications for static and dynamic traffic models. Transport Res D-Tr E 2020;84:102339. https://doi.org/10.1016/j.trd.2020.102339

[13] WG-AEN. Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure. European Commission Working Group- Assessment of Exposure to Noise (WG-AEN); version 2, 13th August 2007.

[14] Bertellino F, Cicoira P, Gerola F, Clementel M, Scaramuzza P, Nardelli M. Noise mapping of agglomerations: a comparision of interim standards vs new CNOSSOS-EU method in a real case study. Proceeding in 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future, INTER-NOISE 2016; Hamburg, Germany, 21–24 August 2016, 1356–1366.

[15] Bakowski A. Validation of Cnossos-EU urban traffic noise model. Proceedings in 20th International Carpathian Control Conference, ICCC 2019; Krakow – Wieliczka, Poland; 26–29 May 2019.

[16] Khan J, Kakosimos K, Jensen SS, Hertel O, Sørensen M, Gulliver J, Ketzel M. The spatial relationship between traffic-related air pollution and noise in two Danish cities: Implications for health-related studies. Sci Total Environ 2020,726:138577. https://doi.org/10.1016/j.scitotenv.2020.138577.

[17] Khan J, Ketzel M, Jensen SS, Gulliver J, Thysell E, Hertel O. Comparison of Road Traffic Noise prediction models: CNOSSOS-EU, Nord2000 and TRANEX. Environ Pollut 2021;270:116240. https://doi.org/10.1016/j.envpol.2020.116240

[18] Manvell D, Hartog van Banda E. Good practice in the use of noise mapping software. Appl Acoust 2011;72(8):527–33. https://doi.org/10.1016/j.apacoust.2010.10.002.

[19] Ausejo M, Recuero M, Asensio C, Pavón I. Reduction in calculated uncertainty of a noise map by improving the traffic model data through two phases. Acta Acust united Ac 2011;97(5):761–8. https://doi.org/10.3813/AAA.918456.

[20] Rey Gozalo G, Suárez E, Montenegro AL, Arenas JP, Barrigón Morillas JM, Montes González D. Noise estimation using road and urban features. Sustainability 2020;12:9217. https://doi.org/10.3390/su12219217

[21] Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V, Vílchez-Gómez R, Méndez Sierra JA, Carmona del Río FJ, Prieto Gajardo C. Study of the categorisation method using long-term measurements. Arch Acoust 2013,38(3):397–405. https://doi.org/10.2478/aoa-2013-0047.

[22] ISO 1996-2. Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. Switzerland: International Organization for Standardization; 2007.

[23] Paiva KM, Cardoso MRA, Zannin PHT. Exposure to road traffic noise: Annoyance, perception and associated factors among Brazil's adult population. Sci Total Environ 2019;650:978–86. https://doi.org/10.1016/j.scitotenv.2018.09.041.

[24] Barrigón Morillas JM, Gómez Escobar V, Rey Gozalo G. Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain). Appl Acoust 2013,74(4):526–34. https://doi.org/10.1016/j.apacoust.2012.10.001.

[25] Probst W. Accuracy and precision in traffic noise prediction. Proceeding in 39th International Congress on Noise Control Engineering 2010, INTER-NOISE 2010; Lisbon, Portugal, 13–16 June 2010.

[26] CEDR. Best practice in strategic noise mapping. France: Conference of European Directors of Roads (CEDR); 2013.

http://www.fomento.gob.es/NR/rdonlyres/CB0F3D92-E801-47AD-9028-FC7E306D3E97/120805/1CEDRJRNoiseMapping_August_2013.pdf

[27] Sonaviya DR, Tandel BN. Prediction and limitations of noise maps developed for heterogeneous urban road traffic condition: A case study of Surat city, India. Sound & Vibration 2021;55:57–68. https://doi.org/10.32604/sv.2021.010715

[28] Suárez E, Barros JL. Traffic noise mapping of the city of Santiago de Chile. Sci Total Environ 2014;466-467:539–46. https://doi.org/10.1016/j.scitotenv.2013.07.013.

[29] Guarnaccia C, Bandeira J, Coelho MC, Fernandes P, Teixeira J, Ioannidis G, Quartieri J. Statistical and semi-dynamical road traffic noise models comparison with field measurements. AIP Conference Proceedings 2018,1982:020039. https://doi.org/10.1063/1.5045445.

[30] Morley DW, Gulliver J. Methods to improve traffic flow and noise exposure estimation on minor roads. Environ Pollut 2016,216:746–54. https://doi.org/10.1016/j.envpol.2016.06.042.

[31 Morley DW, de Hoogh K, Fecht, D, Fabbri F, Bell M, Goodman PS, Elliott P, Hodgson S, Hansel A, Gulliver J. International scale implementation of the CNOSSOS-EU road traffic noise prediction model for epidemiological studies. Environ Pollut 2015,206:332–41. https://doi.org/10.1016/j.envpol.2015.07.031.

[32] Manojkumar N, Basha K, Srimuruganandam B. Assessment, prediction and mapping of noise levels in Vellore city, India. Noise Mapp 2019,6(1):38–51. https://doi.org/10.1515/noise-2019-0004.

[33] Fiedler PEK, Zannin PHT. Evaluation of noise pollution in urban traffic hubs—Noise maps and measurements. Environ Imp Asses 2015,51:1–9. https://doi.org/10.1016/j.eiar.2014.09.014.

[34] Zannin PHT, do Valle F, do Nascimento EO. Assessment of noise pollution along two main avenues in Curitiba, Brazil. Open Journal of Acoustics 2019;9:26–38. https://doi.org/10.4236/oja.2019.92003.

[35] Zytoon M. Opportunities for Environmental Noise Mapping in Saudi Arabia: A Case of Traffic Noise Annoyance in an Urban Area in Jeddah City. Int J Environ Res Public Health 2016,13(5):496. https://doi.org/10.3390/ijerph13050496.

[36] Bastián N, Álvarez J, Moreno F. Evaluación de modelos de predicción de ruido de tránsito vehicular en ciudades pequeñas: casos ciudad de Valdivia y Osorno. Proceeding in IX Congreso Iberoamericano de Acústica, FIA 2014; Valdivia, Chile, 1–3 December 2014.

[37] Murphy E, Douglas O. Population exposure to road traffic noise: Experimental results from varying exposure estimation approaches. Transportation Res D – Tr E 2018,58:70–9. https://doi.org/10.1016/j.trd.2017.11.006.

[38] Rey Gozalo G, Gómez Escobar V, Barrigón Morillas JM, Montes González D, Atanasio Moraga P. Statistical attribution of errors in urban noise modeling. Appl Acoust 2019;153:20–9. https://doi.org/10.1016/j.apacoust.2019.04.001.

[39] Aspuru Soloaga I, García Pérez I, Fernández Alcalá P, Santander Pantioso A. Implicaciones del uso del método CNOSSOS-EU: necesidades de datos de entrada y comparativas de resultados. Jornada técnica de Aplicación de la Directiva 2002/49/CE sobre Evaluación y Gestión del Ruido Ambiental 2017, 14 November in Madrid. http://sicaweb.cedex.es/docs/jornadas/2017-11-14/4_ItziarAspuru_CNOSSOS.pdf

[40] Vogiatzis K, Paviotti M. Noise and annoyance from motorbikes, scooters and mopeds in urban areas. Proceeding in 19th International Congress on Sound and Vibration 2012, ICSV 2012; Vilnius, Lithuania, 8–12 July 2012, 387–94.

Declaration of interests

☒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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Author Statements:

Guillermo Rey Gozalo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. **Valentín Gómez Escobar**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Resources, Writing - Original Draft, Writing - Review & Editing, Supervision, Funding acquisition.