COMPARATIVE STUDY OF LD SOUND LEVELS FROM ROAD TRAFFIC NOISE IN COTONOU: IN SITU MEASUREMENT AND SIMULATION USING THE CNOSSOS-EU MODEL

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Abstract

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Road traffic noise represents a major source of environmental nuisance in rapidly growing urban areas. This study analyzes the performance of the CNOSSOS-EU acoustic model in estimating the Ld indicator, through a comparison between in situ acoustic measurements and numerical simulations conducted in the city of Cotonou. Measurement campaigns were carried out on several roadways characterized by varying traffic levels, while the corresponding sound levels were simulated using the CNOSSOS-EU model, incorporating parameters related to traffic, road geometry, and the built environment. The results reveal a parallel trend between measured and simulated values of the Ld indicator, indicating that the model correctly reproduces the spatial patterns of road traffic noise. Nevertheless, a systematic overestimation of sound levels by the model compared to experimental measurements is observed, with discrepancies dependent on the local characteristics of the study sites. These results underscore the relevance of the CNOSSOS-EU model for comparative analyses and urban road noise mapping, while highlighting the need for local adjustments to improve estimation accuracy in the urban context of Cotonou.

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INTRODUCTION

Road traffic noise has been recognized as a serious problem affecting urban regions [1]. It constitutes one of the primary sources of noise pollution in these environments, with significant impacts on human health and quality of life. To quantify this exposure, standardized acoustic indicators have been developed, among which is Ld, defined as the A-weighted average sound level over the daytime period, generally considered from 06:00 to 18:00 [2,3]. Ld is used to characterize exposure during daily activity hours and is an essential element in the development of noise maps and noise prevention plans according to the European Directive 2002/49/EC concerning the assessment and management of environmental noise [3].
The directive also establishes other indicators such as Lden (Level day-evening-night), which combines noise levels measured during the day (Ld or Level day), evening (Le or Level evening), and night (Ln or Level night), to account for the varying sensitivity of the population at different times of the day [2,3]. Within this framework, the CNOSSOS-EU method was developed to provide harmonized procedures for calculating acoustic levels from traffic parameters, infrastructure geometry, and environmental conditions [4]. To assess the performance of acoustic prediction models, it is essential to conduct direct comparisons between levels estimated by simulation and levels measured in situ. The use of Ld in a comparative measurement–simulation study allows for the verification of the extent to which models, such as CNOSSOS-EU, faithfully reproduce real exposure to daytime road traffic noise. This approach is particularly relevant in urban contexts where measured data serve as a reference for validating prediction tools and informing acoustic planning.

MATERIALS AND METHODS

MATERIALS

Sound level measurements were conducted using a BSWA 308 Class 1 sound level meter, shown in Photo 1. The MATLAB software is used for simulation. The values recorded by the sound level meter are processed using the VA-SLM BSWA TECH software (Photo 2).

Photo 1: *BSWA 308 Class 1 sound level meter*

Photo 2: *Processing of sound level meter data*

METHODS

MEASUREMENTS

Data collection and measurements were carried out from Monday to Friday, on working days from 6 a.m. to 6 p.m., at thirty-five sites on roads in the city of Cotonou. The selected site areas include activities related to schools, colleges, hospitals, commercial zones, and residential areas. Sound levels were measured in accordance with ISO 1996-1 and ISO 1996-2 standards, using a Class 1 integrating sound level meter compliant with IEC 61672-1 standard, configured with A-frequency weighting and in integrating mode. The microphone was positioned at a height of 1.4 m above the ground using a tripod on which the sound level meter was placed, and at a minimum distance of 3.5 m from any reflecting surface other than the ground to approximate free-field conditions [5,6]. Measurements were conducted under favorable meteorological conditions, in the absence of precipitation and with acceptable wind speeds to limit uncertainties related to acoustic propagation [6,7]. Simultaneously, the traffic parameters required for the CNOSSOS-EU model were collected alongside the acoustic measurements. Traffic was characterized by a count of vehicles by category (light vehicles, medium-duty trucks, heavy-duty trucks, motorized two-wheelers and three-wheelers), expressed in vehicles$\cdot$h^{-1}, and by estimating the average speed for each category. Traffic data and road geometric characteristics (number of lanes, slope, pavement type) were used as input parameters for the CNOSSOS-EU model to simulate road sound levels and compare the simulated results with the measured levels.

Calculation of Sound Levels Using the CNOSSOS-EU Model

To perform these calculations, the collected data were integrated into the model's calculation chain to simulate road sound levels. This calculation requires a classification of vehicles. The vehicles are grouped into five distinct categories based on their sound emission characteristics [8], as presented in the following table:

Table1: Vehicle classification

Vehicle category	Characteristics
Category 1	Light motor vehicles (LV) (Passenger cars, delivery vans <3.5 tonnes, sport utility vehicles, multi-purpose vehicles)
Category 2	Medium-duty vehicles (delivery vans >3.5 tonnes, buses, coaches, vehicles with a two-axle configuration and twin-tire mounting on the rear axle)
Category 3	Heavy-duty vehicles (heavy utility vehicles, coaches, buses, vehicles with three axles or more)
Category 4	4-a) Powered two-wheel mopeds
	4-b) Powered three-wheel mopeds
Category 5	Open category (to be defined according to future needs)

The first four categories must be used and the fifth is optional. The latter is intended for new vehicles that may be designed in the future and whose sound emissions would be sufficiently different to justify defining an additional category. This category could cover, for example, electric or hybrid vehicles, or any other future vehicle substantially different from those in categories 1 to 4.
The long-term average A-weighted sound pressure level for the day, evening, and night periods is calculated by the summation over all frequencies for road vehicles of categories 1, 2, and 3 using the following equation [9]:

$$L_{Aeq,m} = 10 \times log \sum_{i=1}^{n} 10^{(10 \times log(10^{(A_{R,i,m}+B_{R,i,m} log\frac{V_m}{V_{ref}}+\Delta L_{WR,i,m})/10} + 10^{(A_{P,i,m}+B_{P,i,m}\frac{V_m - V_{ref}}{V_{ref}}+\Delta L_{WP,i,m})/10}))+10 \times log\frac{Q_m}{1000 \times V_m}+A_i)/10} \quad (1)$$

For category 4, where only propulsion noise is considered for the source, the following equation is used:

$$L_{Aeq,m} = 10 \times log \sum_{i=1}^{n} 10^{(10 \times log(10^{(A_{P,i,m}+B_{P,i,m}\frac{V_m - V_{ref}}{V_{ref}}+\Delta L_{WP,i,m})/10+10 \times log\frac{Q_m}{1000 \times V_m}+A_i)/10}))} \quad (2)$$

where A_i represents the A-weighting according to IEC standard 61672-1
i is the frequency band index
V_m is the speed due to tire-road interaction; V_{ref} is the reference speed V_{ref} = 50 km/h; $A_{P,i,m}$ and $B_{P,i,m}$ are on one hand the coefficients related to propulsion noise and on the other hand $A_{R,i,m}$ and $B_{R,i,m}$ are the coefficients related to rolling noise for each octave band i and each vehicle category m
$\Delta L_{WP,i,m}$ and $\Delta L_{WR,i,m}$ correspond respectively to the sum of correction coefficients to be applied to propulsion noise and rolling noise:

$$\Delta L_{WP,i,m} = \Delta L_{WP,road,i,m} + \Delta L_{WP,grad,i,m} + \Delta L_{WP,acc,i,m} \quad (3)$$

$\Delta L_{WP,road,i,m}$ represents the effect of road surface on propulsion noise via absorption,
$\Delta L_{WP,grad,i,m}$and $\Delta L_{WP,acc,i,m}$represent respectively the effect of road gradients and vehicle acceleration/deceleration at intersections.

$$\Delta L_{WR,i,m} = \Delta L_{WR,road,i,m} + \Delta L_{studdedtire,i,m} + \Delta L_{WR,acc,i,m} + \Delta L_{W,temp} \quad (4)$$

$\Delta L_{studdedtire,i,m}$ is a correction coefficient that reflects the higher rolling noise of light vehicles equipped with studded tires. This coefficient is not used in our study as these types of tires are rarely used in our context.
$\Delta L_{WR,acc,i,m}$represents the effect of rolling noise at a signalized intersection or a roundabout. It incorporates the effect of speed variation on noise.
$\Delta L_{W,temp}$ is a correction term for an average temperature t different from the reference temperature $t_{ref} = 27°C$.

RESULTS

The simulated data allowed the determination of sound levels by vehicle category.

Table 2: Sound level by category in dB(A) for the period 6 a.m.-6 p.m.

Intersection	Category 1	Category 2	Category 3	Category 4-a	Category 4-b
DEDOKPO (C1)	65.55	74.42	79.90	76.66	71.64
SOBEBRA (C2)	63.72	79.35	82.12	81.15	60.50
DEGAKON (C3)	65.84	77.89	75.80	81.72	60.50
LE BELIER (C4)	64.34	75.67	77.35	80.35	56.82
BENIN MARCHE (C5)	67.63	80.68	82.26	85.11	70.25
FEU STADE DE L'AMITIE (C6)	66.75	81.11	80.57	84.95	68.07
AGLA PYLONE (C7)	66.64	81.69	77.76	84.45	69.13
CICA TOYOTA (C8)	66.08	80.32	81.33	83.11	69.46
ECHANGEUR HOUEYIHO (C9)	62.92	75.29	75.80	82.74	63.19
CADJEHOUN (C10)	65.10	77.43	80.77	80.47	65.06
CNHU (C11)	60.88	69.65	0.00	77.23	52.05
PHARMACIE CAMP GUEZO (C12)	61.20	64.88	0.00	77.13	52.05
3 BANQUES (C13)	61.12	70.90	81.82	74.20	56.82
DERRIERE STADE (C14)	61.31	79.19	67.35	79.34	61.60
CEG ZOGBO (C15)	61.67	79.03	74.34	81.72	61.08
ZOGBO CHABIGON (C16)	60.24	76.02	73.37	81.63	56.82
ETOILE ROUGE (C17)	61.70	77.18	67.35	82.43	62.05
LA VIE (C18)	63.66	81.11	84.16	83.90	69.04
STE RITA (C19)	61.99	77.67	76.38	83.01	64.09
CINE OKPE OLUWA (C120	63.01	77.67	73.37	80.08	62.05
GBEDJROMEDE (C21)	59.58	78.30	67.35	80.88	56.82
16 AMPOULES (C22)	59.07	78.10	70.36	82.07	62.05
JERICHO (23)	59.40	80.44	76.89	84.18	63.19
MARINA (C24)	63.31	78.68	82.53	84.15	68.39
AIDJEDO (C25)	48.40	69.65	0.00	74.12	52.05
LEGBA (26)	62.48	79.50	79.65	82.00	63.51
MISSEBO (27)	62.43	81.51	75.13	80.76	59.04
ADJAHA (28)	61.99	81.60	76.89	82.40	65.28
HOUENOUSSOU (C29)	62.37	81.41	0.00	79.98	60.50
FIDJROSSE FIN PAVE (C30)	62.99	76.02	0.00	77.41	62.85
CLUB DES ROIS (C31)	62.56	80.06	72.12	76.36	62.47
GODOMEY GARE (C32)	63.68	82.20	79.65	82.62	66.37
CEG ENTENTE (C33)	64.72	75.67	74.34	80.86	61.08
AKOGBATO (C34)	62.62	81.11	74.34	80.23	59.04
SAINT MICHEL (C35)	66.22	82.66	82.53	64.24	81.61

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The above values enabled the simulation leading to Table 3.

Table 3: Measured and Calculated Sound Levels for the Period 6 a.m.-6 p.m.

Intersection	**Ld measured (dB(A))**	**Ld calculed (dB(A))**	**Ld meas - Ld cal (dB(A))**
C1	74.80	82.79	-7.99
C2	78.10	85.831	-7.73
C3	70.70	84.03	-13.33
C4	70.40	83.07	-12.67
C5	75.00	87.97	-12.97
C6	78.50	87.54	-9.04
C7	80.30	86.98	-6.68
C8	75.10	86.64	-11.54
C9	72.50	84.21	-11.71
C10	72.00	84.67	-12.67
C11	66.50	78.03	-11.53
C12	67.70	77.50	-9.80
C13	71.60	82.84	-11.24
C14	71.20	82.48	-11.28
C15	76.10	84.12	-8.02
C16	71.70	83.20	-11.50
C17	76.00	83.73	-7.73
C18	77.90	88.10	-10.20
C19	74.30	84.86	-10.56
C20	70.90	82.69	-11.79
C21	72.40	82.94	-10.54
C22	66.20	83.78	-17.58
C23	71.10	86.28	-15.18
C24	77.70	87.18	-9.48
C25	59.20	75.48	-16.28
C26	70.60	85.36	-14.76
C27	67.60	84.71	-17.11
C28	74.60	85.71	-11.11
C29	68.90	83.81	-14.91
C30	68.20	79.95	-11.75
C31	70.30	82.16	-11.86

C32	70.30	86.51	-16.21
C33	68.10	82.79	-14.69
C34	71.10	84.22	-13.12
C35	74.00	87.12	-13.12

Using these values, we were able to obtain the curve in Figure 1.

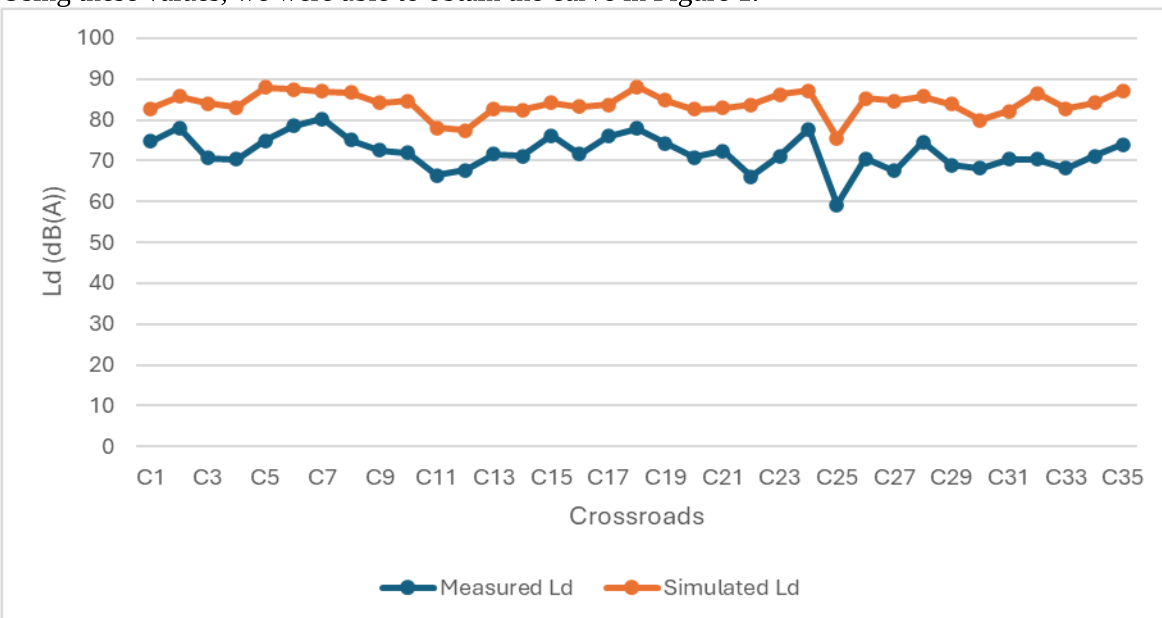

Figure 1: Comparative curves of the two types of measurements for the period 6 a.m.-6 p.m.

DISCUSSION

From Table 2, acoustic modeling based on the CNOSSOS-EU model shows sound levels in Cotonou ranging from 48 to 85 dB(A), with a dominant contribution from utility vehicles, heavy trucks, and especially motorized two-wheelers. These results are consistent with those obtained in other African cities: in Abidjan, high levels were measured using mobile data collection [10], while in Lagos, residents' exposure to noise pollution frequently exceeds recommended thresholds [11]. Studies in Dakar and several Nigerian cities also show average road noise levels often exceeding WHO standards [12,13]. This convergence with the literature confirms the reliability and robustness of the results obtained in Cotonou and underscores the importance of targeted traffic management strategies, particularly for motorized two-wheelers and heavy vehicles, to reduce sound exposure in urban areas [8,14].

The measured equivalent sound levels (Ld) at the studied intersections vary between approximately 59 and 80 dB(A) during the daytime period (6 a.m.-6 p.m.), indicating high sound exposure characteristic of urban environments dominated by road traffic. The calculated levels, ranging from approximately 75 to 88 dB(A), are systematically higher than the measured levels, with ΔLd discrepancies ranging from −6,7 to −17,6 dB(A). This overestimation can be attributed to the simplifying assumptions of the model, notably the idealized representation of propagation conditions and the limited consideration of urban geometry [15,16,17]. Despite these discrepancies, a clear spatial consistency is observed, with intersections experiencing high traffic flow presenting the highest sound levels. This convergence with the literature in environmental acoustics confirms the qualitative robustness of the results and the relevance of the approach for identifying high-noise exposure zones [18,19].

The comparison between measured and simulated Ld acoustic levels shows good consistency in spatial trends, indicating that the model broadly reproduces the relative distribution of sound levels among the different points. However, the simulated values show a systematic overestimation compared to measurements, with variable discrepancies depending on the site. This behavior aligns with observations reported in the literature, where acoustic propagation models tend to overestimate actual levels due to simplifying assumptions about propagation conditions, source characterization, and incomplete representation of local effects [19-22]. These results highlight the need for model calibration using in situ data to improve the accuracy of simulations and their suitability to real conditions.

CONCLUSION

The analysis of measured and simulated Ld acoustic levels shows that the model broadly reproduces the spatial trend of sound levels, confirming its ability to represent the relative distribution of noise. However, the simulations show a systematic overestimation compared to measurements, reflecting the limitations of the model's simplifying assumptions and the partial consideration of local effects such as topography, obstacles, and traffic variability. These results highlight the need for precise model calibration using in situ data to improve the match between simulations and real observations, thereby strengthening the reliability of acoustic assessments for environmental planning and management [19-22].

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