DE GRUYTER Noise Mapping 2026; 13(1): 20250023

Special Issue

Omar Odeh* and Dénes Kocsis

From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise

https://doi.org/10.1515/noise-2025-0023
Received September 7, 2025; accepted December 9, 2025;
published online February 2, 2026

Abstract: Road traffic noise is a significant environmental risk factor to the human health, resulting in the necessity for accurate noise prediction models with less uncertainty. Several standards and methods are available in commercial noise modeling software to predict noise levels from road traffic noise, such as ISO 9613-2, CNOSSOS-EU, RLS 19, NMPB2008, RMG2012 and Nord2000. However, many of these standards were developed for specific national conditions and thus have limitations in wider applications. For instance, the RLS 19 standard is most suitable for the German road network, the NMPB2008 standard is tailored to French conditions, the RMG2012 is Dutch and the Nord2000 standard is predominantly applied in Northern Europe. Similarly, the use of CNOSSOS-EU is limited to European Union member states that have transposed the method into national law, as recommended by the Environmental Noise Directive (END), due to varying road surface characteristics across countries. In contrast, the ISO 9613-2 standard, entitled "Acoustics – Attenuation of sound during propagation outdoors – Part 2: Engineering method for the prediction of sound pressure levels outdoors" provides a general engineering framework for estimating noise levels from several sources, such as road traffic noise. This paper presents the results of a thorough investigation in which predicted noise levels from ISO 9613-2 and CNOSSOS-EU models were compared with measured data for a road section with relatively low traffic volume. The purpose of this study is to identify the modeling approach that delivers the most realistic predictions, offering guidance on selecting appropriate methods and techniques for similar traffic conditions. The findings contribute to a better understanding of the applicability of the evaluated methods for noise modeling of roads with low traffic volumes, highlighting their respective strengths and limitations. This comparison can support environmental authorities and acoustic consultants in selecting the most suitable prediction method for local and national assessments, and it provides a basis for improving model calibration and adaptation in future studies.

Keywords: environmental noise; road traffic noise; CNOSSOS-EU; noise modeling; ISO 9613-2; outdoor sound propagation

1 Introduction

Road traffic noise is a major source of environmental noise pollution; beyond its loudness, it causes a frequent annoyance that affects many aspects in our life [1]. Therefore, it is often called the second most significant environmental noise source [2–4]. In general, noisy urban environments tend to have adverse effects on our mental health, wellbeing and daily activities [5–7]. In Europe, road traffic noise is ranked as the second most common environmental risk factor to human health, after fine particle pollution [8]. Loud engines, vehicle horns and tire-road interaction noise can weaken both mind and body, in turn triggering unpleasant emotions [9]. Prolonged noise exposure can also lead to cardiovascular illnesses [10–12], including heart attacks and hypertension [13, 14]. It can also negatively influence work and educational environments, cognition, communication, and attention [15–17]. In addition, the overall burden of road traffic noise in the European Union, including healthcare costs and productivity losses, is estimated at 40 billion euros annually [18]. Consequently, the implementation of effective mitigation measures is essential to reduce road traffic noise pollution and its adverse effects.

***Corresponding author: Omar Odeh**, Doctoral School of Informatics, University of Debrecen, 1 Egyetem Square, Debrecen, 4032, Hungary; and Vibrocomp Ltd., 12 Bozókvár Str., Budapest, 1118, Hungary, E-mail: omarrodehh@gmail.com. https://orcid.org/0000-0001-9997-6422
Dénes Kocsis, Environmental Engineering Department, Faculty of Engineering, University of Debrecen, 2–4 Ótemető Str., Debrecen, 4028, Hungary, E-mail: kocsis.denes@eng.unideb.hu. https://orcid.org/0000-0002-5797-9016

Promoting quieter modes of transport, such as Electric Vehicles (EVs), encouraging the use of quiet tyres and low-noise pavements [19], reducing road speed limits [20] and building durable noise barriers [21] are among the key measures recommended for adoption by EU member states.

To evaluate the effectiveness and reduce the implementation costs of such measures, noise mapping methodologies are commonly applied by engineers through specialized computer software. However, outdoor noise propagation simulations pose significant challenges due to the diversity of noise sources, the variability of environmental conditions, and the complexity of urban geometries involving multiple reflective and absorptive surfaces [22].

A variety of techniques have been integrated into commercial software to support road traffic noise modeling, including ISO 9613-2, CNOSSOS-EU, RLS 19, NMPB2008, RMG2012, CoRTN and Nord2000. However, since these methods are based on different methodologies, their precision and accuracy in predicting noise levels can vary. Existing literature has studied and compared road traffic noise modeling standards and calculation methods. For instance, a study conducted in Ireland evaluated noise exposure results produced by CNOSSOS-EU and CoRTN against on-site measurements. The findings indicated that CNOSSOS-EU reflects the real noise situation more accurately than CoRTN, showing an average deviation of less than 2 dB(A) from roadside measurements [23]. Another study examined multiple road traffic modeling scenarios, such as variations in vehicle speed and source-receiver distance using CNOSSOS-EU, Nord2000 (2006 version) and TRANEX. Significant differences were observed across the models; however, the results showed that TRANEX and CNOSSOS-EU reproduced the Nord2000 L_{Aeq} values within 3–5 dB(A) for most scenarios [24]. Further differences between CNOSSOS-EU and Nord2000 noise predictions are also well documented in the literature. In Sweden, sound power levels calculated by the two models at various vehicle speeds indicated that CNOSSOS-EU systematically under-predicted noise levels by approximately 0.1–4 dB(A) [25]. Similarly, another research evaluated the suitability of CNOSSOS for implementation in Finland by comparing its predictions with those of Nord2000 for LDVs, MDVs, and HDVs across speeds ranging from 40 to 120 km/h. Their results showed model discrepancies of roughly 0.7–4.6 dB(A) [26, 27]. This study presents a unique comparison that focuses on CNOSSOS-EU and ISO 9613-2 as the most widely applied frameworks for road traffic noise prediction beyond national contexts [28–30].

The Commission Directive (EU) 2015/996 first introduced the Common NOise aSSessment methOdS (CNOSSOS-EU) in 2015 as a standardized method for modeling road traffic noise and supporting the development of solutions that consider environmental, economic and societal aspects. The directive was adopted to harmonize noise assessment across EU member states in line with the requirements of the Environmental Noise Directive (END) [8, 30, 31]. CNOSSOS-EU seeks to achieve a balance between conservation and development, which promotes the preservation of natural habitats and cultural settlements from the adverse effects of road traffic noise pollution [23]. For example, the framework incorporates nature-based solutions into urban planning, such as acoustic landscapes and green barriers. It also classifies noise emissions from internal combustion vehicles into four main categories, with a fifth 'open category' reserved for future needs, such as electric vehicles (EVs) [30, 32, 33]. Therefore, cooperation among environmentalists, lawmakers, and local EU communities is often essential to ensure the successful implementation of these solutions.

Generally, the CNOSSOS-EU road traffic noise model accounts for noise generated from tire-road surface interaction and from the vehicle driveline (engine, exhaust, etc.) [30, 32], the latter being zero for electric vehicles [33]. The model also incorporates the influence of 14 different road surface types, represented as correction coefficients ($\alpha_{i,m}$ and β_m) relative to a reference road for all vehicle categories, as detailed in Annex II of the documentation [30, 34–36]. However, since the acoustical characteristics of road surface types vary across EU countries [30], it is recommended that national coefficients be determined for each member state in order to increase the accuracy of the CNOSSOS-EU road traffic noise model [37].

The ISO 9613-2 standard, entitled "Acoustics – Attenuation of sound during propagation outdoors – Part 2: Engineering method for the prediction of sound pressure levels outdoors" was first released in 1996 and revised in 2024. It is applicable to noise from a wide variety of sources, including industrial plants, road traffic, railways and construction activities, and is intended for use in environmental noise impact assessments. The method accounts for the physical effects of geometrical divergence, atmospheric absorption, ground effect, reflections from surfaces and screening by obstacles [28, 29]. However, outdoor sound propagation studies have revealed certain limitations in the implementation of ISO 9613-2:1996 calculations, particularly with respect to the modeling of ground effect, multi-edge diffraction, and reflections from curved surfaces [38, 39]. Therefore, ISO 9613-2:2024 was developed to overcome these limitations.

The 2024 technical revision introduced several key improvements. These include a subdivision of extended sources to reduce uncertainty in software implementations, an improved determination of the ground factor (G), the integration of a correction for the ground effect (A_{gr}), a new strategy for calculating screening effects as recommended in ISO 17534-3:2015, and a modification of the barrier attenuation specification (D_z). Additional refinements include a correction for meteorological effects (K_{met}), the elimination of deficiencies for low barriers and large source-receiver distances, improved handling of reflections from cylindrical surfaces and the introduction of a directivity correction (D_c) for chimney stacks [29].

This paper presents the results of road traffic noise modeling using the CNOSSOS-EU and ISO 9613-2 approaches in comparison with measured noise levels. It further examines the influence of the ground effect correction factor and the improved screening calculations introduced in the second edition of ISO 9613-2 by comparing the results obtained from both versions. The findings are expected to identify the modeling approach that provides the most realistic predictions, which in turn offers guidance on the selection of appropriate standards for similar traffic conditions and paving the way for more comprehensive comparisons in future research.

2 Materials and methods

In this paper, the methodology of noise modeling combined with noise measurements was utilized to evaluate the accuracy of different road traffic noise modeling approaches. The following subsections summarize the materials, methods and parameters used in the noise modeling software for each approach.

2.1 Methodology

A noise measurement campaign was undertaken for 8 days during daytime (9 am–5 pm) along a road section with relatively low daily traffic volumes. Equivalent continuous sound pressure levels were recorded simultaneously at two measurement points (MP1 and MP2) at 15-min intervals ($L_{\mathrm{Aeq,15\,min}}$). The measurement points were positioned perpendicularly to the road section, as shown in Figure 2. MP1 was located 6 m from the centerline of the road at a height of 1.75 m above ground level, representing near-field propagation conditions. MP2 was located 65 m from the road centerline at a height of 4.65 m, capturing far-field propagation. It should be noted that the ground level at MP2 was approximately 2 m lower than at MP1 due to the road embankment. Figure 1 illustrates the distances of MP1 and MP2 from the centerline of the road.

The measured data were then processed to derive the hourly average noise levels ($L_{\mathrm{Aeq,1\,h}}$) for the daytime periods.

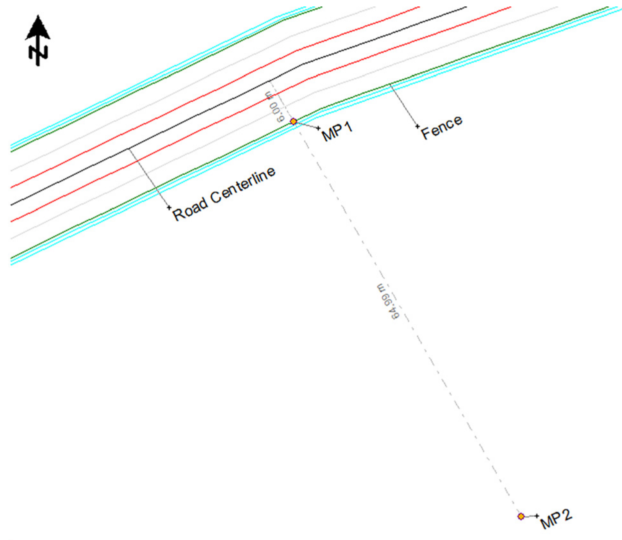

Figure 1: Measurement points (MP1 and MP2) distances from the road's centerline.

Figure 2: Measurement points (MP1 and MP2) adjustment.

An example of the data processing from $L_{\mathrm{Aeq,15\,min}}$ to $L_{\mathrm{Aeq,1\,h}}$ is presented in Table 1. The same process was followed to obtain the hourly average noise levels ($L_{\mathrm{Aeq,1\,h}}$) for all measurements. For the noise modeling exercise, 10 h corresponding to peak traffic periods on weekdays (Monday – Friday) during daytime were selected and considered representative of the overall measurement campaign, as the measured noise levels showed minimal variation across different days due to the low and uniform traffic volumes, confirming consistent weekday traffic patterns.

During the campaign, it was observed that the surrounding topography is mostly flat, with the exception of the road, which is elevated by approximately 2 m above the adjacent terrain with an embankment. The road surface consists of hard ground, while the adjacent agricultural land represents soft ground. Additionally, the galvanized steel safety fence shown in Figure 2 was measured, and found to have a thickness of approximately 0.3 m and a height of 0.5 m above the road surface. On average, the meteorological conditions measured during the campaign were 15 °C air temperature, 1,013.3 mbar air pressure, and 70 % relative humidity.

The collected data were then used to develop the base noise model. In the model, the road surface was assigned a ground factor of 0, representing acoustically hard ground with no absorption, while the surrounding agricultural land was assigned a ground factor of 1, representing acoustically soft ground with high absorption [28, 29, 40]. The main approaches studied in this paper include the CNOSSOS-EU model, the ISO 9613-2:1996 and ISO 9613-2:2024 Line Source models. The following subsections describe in detail the modeling setup and the parameters applied in each approach.

In this study, the simulations were performed using SoundPLAN 9.1, a professional environmental noise modeling software that supports multiple standardized calculation methods, including CNOSSOS-EU and both versions of ISO 9613-2 (1996 and 2024).

2.2 The CNOSSOS-EU model

In the CNOSSOS-EU documentation, vehicles are classified into five categories according to their noise emission characteristics. Category 1 covers light motor vehicles, including passenger cars, delivery vans up to 3.5 tons, sport utility vehicles, and multi-purpose vehicles with trailers or caravans. Category 2 includes medium-heavy vehicles, such as delivery vans over 3.5 tons, touring coaches, and two-axle buses with dual tires on the rear axle. Category 3 consists of heavy-duty vehicles, namely buses and coaches with three or more axles. Category 4 refers to powered two-wheelers, subdivided into 4a for mopeds, tricycles, and quadricycles up to 50 cc, and 4b for motorcycles, tricycles, and quadricycles exceeding 50 cc. Finally, Category 5 serves as an open class intended primarily for future needs, such as Electric Vehicles [30, 32, 33]. Additionally, the equivalent noise source for all categories is considered at 0.05 m above road level to represent the effective source height of the tire-road contact noise [30].

To predict the road traffic noise emissions in the CNOSSOS-EU model, the number of vehicles passing by a road section in 1 h (veh/h) is an essential input. Table 2 summarizes the traffic count for the 10 representative hours obtained from the measurement campaign.

Many other parameters influence the CNOSSOS-EU road traffic noise model, such as vehicle speed and road surface type [30, 37]. Therefore, to ensure a high level of accuracy, the required modeling parameters were collected during the measurement campaign and from official local sources. Table 3 summarizes the parameters used in the CNOSSOS-EU model.

Annex II in the latest version of CNOSSOS-EU contains tables with $\alpha_{i,m}$ and β_m coefficients for 14 road surface types based on the Dutch road network [41, 42]. Both coefficients account for the effect of a particular road surface on the noise emissions. However, road surface types and conditions vary considerably across Europe, resulting in significant differences in their acoustic properties [30, 37]. Therefore, all EU member states are required to implement the transposition of the CNOSSOS-EU method into their national law to comply with EU requirements. Hungary implemented this transposition and the road surface coefficients were published officially [43]. Table 4 presents $\alpha_{i,m}$ and β_m coefficients for the B217 SMA-11 crushed stone mastic asphalt road surface type which was considered in the CNOSSOS-EU model.

Then, the emission time slice was set to 1 h and the noise levels at MP1 and MP2 were calculated for the representative 10 h considering the traffic data in Table 2.

Table 1: Data processing for hour 1 measurement.

Measurement Point	Measurement time			
	9:00–9:15	09:15–09:30	09:30–09:45	09:45–10:00
MP1 – $L_{Aeq,15\ min}$	74.80	73.20	73.10	73.60
MP1 – $L_{Aeq,1\ h}$				73.73
MP2 – $L_{Aeq,15\ min}$	59.20	57.60	58.20	57.70
MP2 – $L_{Aeq,1\ h}$				58.20

2.3 The ISO 9613-2 models

ISO 9613-2, first published in 1996, has been widely utilized by acousticians worldwide as a tool to predict sound propagation in outdoor environments. The standard is commonly applied to estimate noise levels generated by diverse sources, such as industrial noise, road traffic noise and railway

Table 2: Traffic count for the representative measurements during peak periods in veh/h.

Vehicle category	Measurement hour									
	Hour 1 9:00–10:00	Hour 2 10:15–11:15	Hour 3 11:30–12:30	Hour 4 12:45–13:45	Hour 5 14:00–15:00	Hour 6 15:15–16:15	Hour 7 12:00–13:00	Hour 8 13:00–14:00	Hour 9 14:45–15:45	Hour 10 15:45-16:45
Category 1	326	293	317	378	353	550	360	380	474	636
Category 2	28	30	22	17	26	23	17	30	30	26
Category 3	53	49	49	37	33	38	30	40	29	13
Category 4a	0	0	0	0	0	0	0	0	0	0
Category 4b	0	0	0	0	0	0	0	0	0	0

Table 3: CNOSSOS-EU model inputs.

Parameter	Vehicle speed	Tyres	Road surface type	Lane width
Value	Constant, 80 km/h[a]	Non-studded Tyres	B217 SMA-11	3.9 m
Source	Measurement	Measurement	Hungarian Local Road Authority [37]	Measurement

[a]Average speed.

Table 4: $\alpha_{i,m}$ and β_m coefficients for B217 SMA-11 [44].

Road surface type	Vehicle category	$\alpha_{i,m}$								β_m
		63 Hz	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	8,000 Hz	
B217 SMA-11	**Category 1**	1.30	1.30	1.40	0.40	0.10	−1.10	−1.30	−0.50	4.90
	Category 2	2.20	2.60	2.70	1.50	0.70	0.40	0.70	1.50	5.70
	Category 3	1.70	1.60	3.10	0.70	0.70	0.80	1.10	1.40	4.20

noise. However, with advances in computational noise modeling, environmental acoustics, and prediction methodologies, the standard was revised in 2024. The updated ISO 9613-2:2024 introduced new correction factors, such as the ground effect correction factor (K_{geo}) and refined existing formulas, including improved barrier attenuation calculations (A_{bar}), in order to enhance the accuracy of noise predictions under a variety of environmental conditions [29]. Therefore, within the ISO 9613-2 framework, this study evaluates the effect of the revision on road traffic noise modeling utilizing the line source method and presents the results obtained from both the 1996 and 2024 versions, as follows:

– ISO 9613-2:1996 Line Source model
– ISO 9613-2:2024 Line Source model

The line source models were configured with a noise emission line representing multiple point sources extended along the centerline of the road, perpendicular to MP1, at a height of 0.05 m above ground level to maintain consistency with the CNOSSOS-EU model setup. The sound power level of the line source was back-calculated from the measured sound pressure level at MP1 for the 10 representative hours and then used to simulate the hourly equivalent noise levels ($L_{\text{Aeq,1 h}}$) at MP2. This setup was applied to assess the far-field propagation in both versions of ISO 9613-2.

In contrast, this study is limited to presenting the impact of the updates introduced in ISO 9613-2:2024 on the modeled results, focusing primarily on the differences arising from the ground effect correction factor (K_{geo}) and the barrier attenuation calculations (A_{bar}), compared with the 1996 version. The modeling exercise does not attempt to reassess the entire standard but rather focuses on how these refinements influence the accuracy of noise prediction approaches under the selected measurement conditions, with the ultimate aim of identifying the most realistic and representative approach when compared to the measured values at MP1 and MP2.

3 Results and discussion

This present section summarizes the results of this study. Table 5 presents the results at both measurement points, MP1 and MP2, for 10 measurement hours deemed representative after processing the 8-day campaign data.

The following sub-sections present the calculated noise levels obtained from the CNOSSOS-EU, ISO 9613-2:1996 and the ISO 9613-2:2024 for two modeling scenarios, to compare the impact of the fence on different modeling approaches.

3.1 Calculated noise levels without considering the fence

In this scenario, the galvanized steel safety fence that exists on both sides of the road at 0.5 m from the road level and is approximately 0.3 m thick, was not considered at first, to compare the results of sound propagation through modeling with the measured noise levels. Table 6 below presents the calculated noise levels with each approach without the fence.

The results above show that the CNOSSOS-EU model slightly over-predicted MP1 by +0.22 dB(A) on average and over-predicted MP2 by +2.76 dB(A). For the ISO 9613-2 Line Source models (both 1996 and 2024), the difference at MP1 is 0 dB(A). This is because the emission level was back calculated from the measured values at MP1, ensuring perfect alignment at this location to evaluate the free-field sound propagation. At MP2, ISO 9613-2 Line Source (both 1996 and 2024) over-predicted by an average of +2.96 dB(A). It was observed that the sound propagation of ISO 9613-2:2024 matches that of ISO 9613-2:1996 due to the fact that the noise source and receiver in are not as high above the ground compared to the distance between them [28, 29]. Figure 3 illustrates the Mean Average Error and Standard Deviation between the measured noise levels and the modeled noise levels.

In summary, the results without considering the fence indicate that the sound propagation of the CNOSSOS-EU and ISO 9613-2 line source models tend toward over-prediction.

3.2 Calculated noise levels considering the fence

The galvanized steel fence was modelled in this scenario and defined with a high reflection coefficient (0.9) [45–47] to evaluate its impact on the sound propagation regardless of its small surface area. Since MP1 is located at the barrier, no effect on its modeled noise levels was observed. Therefore, Table 7 below presents the modeled noise levels at MP2 only.

Table 5: Measured noise levels $L_{eq,1\,h}$ in dB(A).

Measurement Point	Measurement hour									
	Hour 1 9:00–10:00	Hour 2 10:15–11:15	Hour 3 11:30–12:30	Hour 4 12:45–13:45	Hour 5 14:00–15:00	Hour 6 15:15–16:15	Hour 7 12:00–13:00	Hour 8 13:00–14:00	Hour 9 14:45–15:45	Hour 10 15:45–16:45
MP1	73.73	73.60	73.22	73.18	73.20	74.11	72.54	73.43	73.79	74.15
MP2	58.20	58.11	57.82	57.50	57.90	59.10	57.00	58.10	58.80	58.72

Table 6: Calculated noise levels ($L_{eq,1\,h}$) without considering the fence in dB(A).

Method	Measurement Point	Measurement hour									
		Hour 1 9:00–10:00	Hour 2 10:15–11:15	Hour 3 11:30–12:30	Hour 4 12:45–13:45	Hour 5 14:00–15:00	Hour 6 15:15–16:15	Hour 7 12:00–13:00	Hour 8 13:00–14:00	Hour 9 14:45–15:45	Hour 10 15:45–16:45
CNOSSOS-EU	**MP1**	73.81	73.49	73.51	73.40	73.25	74.58	73	73.76	73.99	74.38
	MP2	60.99	60.67	60.68	60.57	60.42	61.75	60.17	60.93	61.16	61.55
ISO 9613-2:1996	**MP1**	73.73	73.60	73.22	73.18	73.20	74.11	72.54	73.43	73.79	74.15
line source	**MP2**	61.32	61.19	60.81	60.77	60.79	61.7	60.13	61.01	61.38	61.74
ISO 9613-2:2024	**MP1**	73.73	73.60	73.22	73.18	73.20	74.11	72.54	73.43	73.79	74.15
line source	**MP2**	61.32	61.19	60.81	60.77	60.79	61.7	60.13	61.01	61.38	61.74

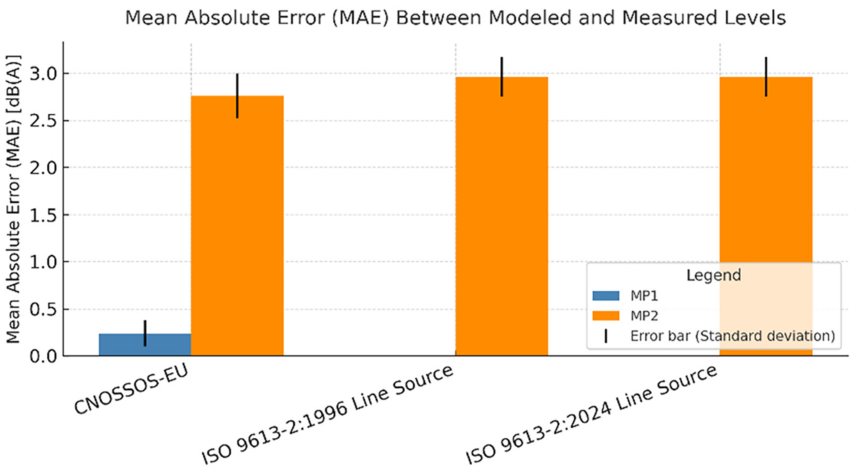

Figure 3: Mean average error without the fence in dB(A).

Table 7: Calculated noise levels ($L_{eq,1\ h}$) at MP2 considering the fence in dB(A).

Method	Measurement Point	Measurement hour									
		Hour 1 9:00–10:00	Hour 2 10:15–11:15	Hour 3 11:30–12:30	Hour 4 12:45–13:45	Hour 5 14:00–15:00	Hour 6 15:15–16:15	Hour 7 12:00–13:00	Hour 8 13:00–14:00	Hour 9 14:45-–15:45	Hour 10 15:45–16:45
CNOSSOS-EU	MP2	60.78	60.46	60.47	60.36	60.21	61.54	59.96	60.72	60.94	61.33
ISO 9613-2:1996 line source		56.83	56.7	56.32	56.28	56.3	57.21	55.64	56.52	56.89	57.25
ISO 9613-2:2024 line source		58.59	58.46	58.08	58.04	58.06	58.97	57.40	58.28	58.65	59.01

The fence was found to have a negligible impact in the CNOSSOS-EU model with a 0.21 dB(A) reduction, which can be linked to the definition of its sound propagation models [30]. However, the effect is much more pronounced in the ISO 9613-2 models, with a 4.49 dB(A) reduction in the ISO 9613-2:1996 Line Source model and a 2.73 dB(A) reduction in the ISO 9613-2:2024 Line Source model. In general, the largest reductions occurred in the ISO 9613-2:1996 Line Source model and the smallest reduction occurred in the CNOSSOS-EU model. The fluctuations in noise reduction between both ISO 9613-2 versions can be attributed to the improved screening calculations implemented in ISO 9613-2:2024 as developed in ISO 17534-3:2015 [28, 29, 48].

Table 8 presents a comparison between the modeled results of the fence scenario and the measured noise levels at MP2, where a negative value indicates a lower predicted noise level in comparison with the measurement.

The difference in noise levels from MP2 measurement values indicate that the fence scenario is more accurate for the free-field sound propagation in the CNOSSOS-EU and ISO 9613-2 Line Source models. On average, the differences in the CNOSSOS-EU results from the measurements dropped from +2.76 dB(A) to +2.55 dB(A). The ISO 9613:1996 Line Source model decreased the noise levels at MP2 significantly to −1.5 dB(A) below the measured value, while the ISO 9613-2:2024 Line Source model was found to be the most realistic, being only +0.23 dB(A) above the measured values at MP2.

3.3 General discussion

Tables 6 and 7 present road traffic noise modeling results for a road section with a relatively low hourly traffic volume, utilizing the CNOSSOS-EU and the ISO 9613-2 Line Source methods. The galvanized steel safety fence was modeled in one scenario and assumed to be negligible in the other scenario, to evaluate its influences on the predicted noise levels. In both scenarios, it was observed that the ISO 9613-2 Line Source models are realistic as they provide high accuracy and small difference compared to the measured values at MP2. Additionally, even though the CNOSSOS-EU method was intended primarily for strategic noise mapping purposes [30], the CNOSSOS-EU models in both scenarios showed almost no difference from the measurement results at MP1 and less than 3 dB(A) difference at

Table 8: Difference in noise levels at MP2 considering the fence in dB(A).

Method	Measurement Point	Measurement hour									
		Hour 1 9:00-10:00	Hour 2 10:15–11:15	Hour 3 11:30–12:30	Hour 4 12:45–13:45	Hour 5 14:00–15:00	Hour 6 15:15–16:15	Hour 7 12:00–13:00	Hour 8 13:00–14:00	Hour 9 14:45–15:45	Hour 10 15:45–16:45
CNOSSOS-EU	MP2	2.58	2.35	2.65	2.86	2.31	2.44	2.96	2.62	2.14	2.61
ISO 9613-2:1996 line source		−1.37	−1.41	−1.50	−1.22	−1.60	−1.89	−1.36	−1.58	−1.91	−1.47
ISO 9613-2:2024 line source		0.39	0.35	0.26	0.54	0.16	−0.13	0.40	0.18	−0.15	0.29

MP2, which is an accepted uncertainty of the model in comparison with the measurement [28, 29, 49]. The CNOSSOS-EU predicted noise levels at MP1 in both scenarios were found to be the same, as the receiver point is located at 1.75 m above ground level, which is well above the fence. However, it should be noted that the CNOSSOS-EU model is recommended for use only in EU member states that have already incorporated the CNOSSOS-EU method into their national road traffic noise law [37], as the road surface type has a significant impact on the road traffic noise emissions [30, 37].

In general, the results above revealed that the newly introduced ground effect correction factor (K_{geo}) in the ISO 9613-2:2024 has no impact on this study since the source and receiver heights are not as large compared to the distance between them [28, 29], which was advised by research that recommended the need for the ground effect correction factor to reduce the modeling uncertainty which existed in the ISO 9613-2:1996. On the other hand, the ISO 9613-2 Line Source model predicted results at MP2 are 1.76 dB(A) less in the 2024 update compared to the 1996 version due to the improved barrier calculations implemented in the ISO 9613-2:2024 [28, 29, 48].

Figures 4 and 5 present a comparison of the vertical sound propagation in the CNOSSOS-EU models utilizing Hour 1 measurement data. It is observed that at the MP2 location, the impact is more pronounced at around 9 m above the ground rather than the measurement height (4.65 m above ground level), resulting in nearly identical predicted noise levels at MP2 in both scenarios, with a 0.2 dB(A) difference.

Figures 6–8 illustrate the vertical sound propagation of the ISO 9613-2:1996 and the 2024 Line Source without the fence, the ISO 9613-2:1996 Line Source and the ISO 9613-2 Line Source with the fence for Hour 1 measurements. It was observed that in the no fence scenario both versions of the ISO 9613-2 have identical sound propagation since the impact of the ground effect correction factor (K_{geo}) is minimal [28, 29]. However, the impact of the improved screening algorithms is more pronounced in the fence scenario, where the predicted noise level of the 2024 version at MP2 is 1.8 dB(A) less than that of the 1996 version, resulting in higher accuracy and predicted noise levels which are closer to the measured value.

The results of both modeled scenarios expressed that in the case of a relatively light traffic volume, the most representative approach to use in the noise modeling software is the ISO 9613-2:2024 Line Source model. However, this method requires a known sound power level or sound

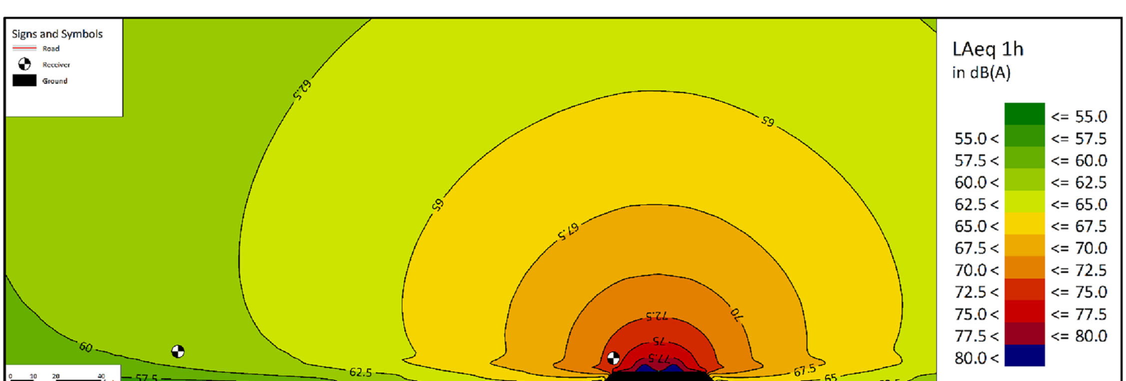

Figure 4: Cross-section noise map – no fence scenario: CNOSSOS-EU.

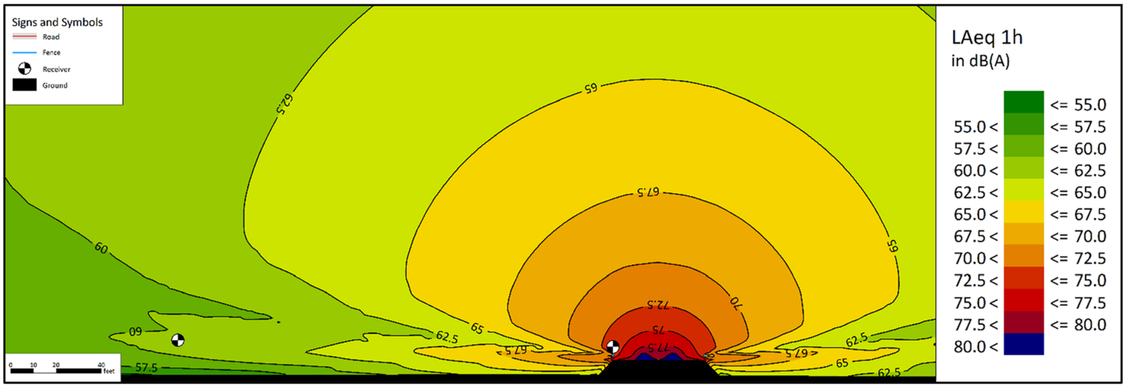

Figure 5: Cross-section noise map – fence scenario: CNOSSOS-EU.

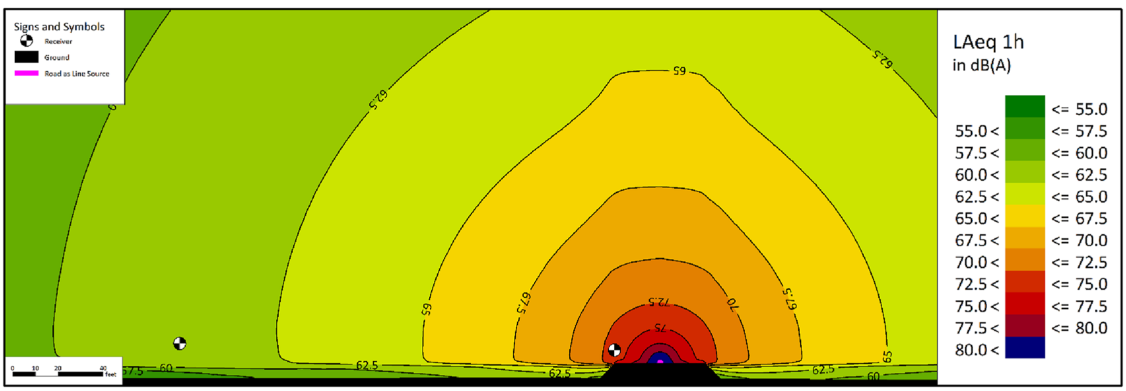

Figure 6: Cross-section noise map – no fence scenario: ISO 9613-2:1996 and 2024 line source.

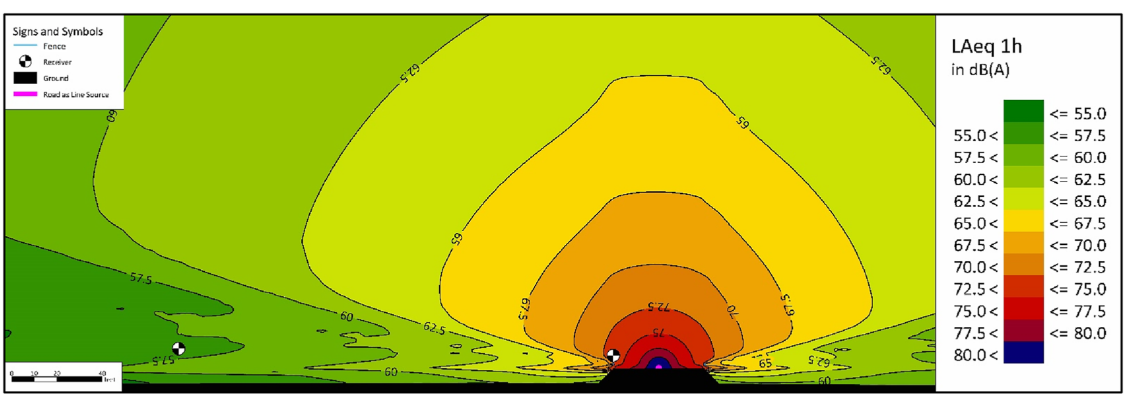

Figure 7: Cross-section noise map –fence scenario: ISO 9613-2:1996 line source.

pressure level. Moreover, the CNOSSOS-EU method provides less accuracy with the distance from the source but maintains ease of use if the road surface type's parameters are known [30, 37] as it only requires the traffic count to generate the sound power level of the road.

Although the modeling and measurement campaign were carefully planned, this study has certain limitations. The analysis was conducted on a single road section characterized by low and relatively uniform traffic volumes, which may not fully represent conditions on higher-capacity or more complex road networks. Moreover, the comparison focused on weekday peak hours under favorable meteorological conditions, excluding potential effects of night-time propagation and seasonal variability. These factors may

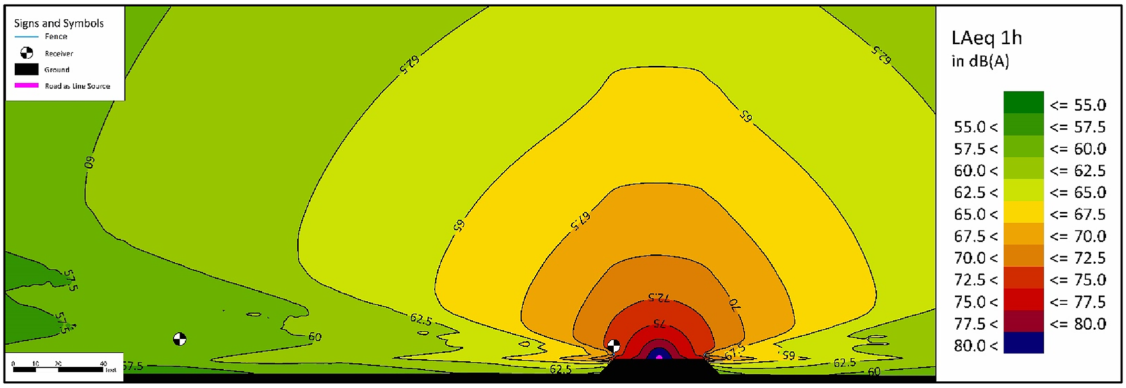

Figure 8: Cross-section noise map –fence scenario: ISO 9613-2:2024 line source.

introduce some uncertainty in the noise levels and limit the broader applicability of the results. Nevertheless, the findings provide a reliable baseline for future studies aiming to evaluate the performance of CNOSSOS-EU and ISO 9613-2 methods under more diverse traffic and environmental scenarios.

4 Conclusions

In this paper, road traffic noise levels predicted by two approaches, namely: the CNOSSOS-EU, and the ISO 9613-2 Line Source models were studied for a road section with relatively low daily traffic volume. Two scenarios were modeled in the study to evaluate the impact of a thin safety fence located across the road section on both sides and to compare the modeling results to the measurement to select the most representative approach.

To increase the accuracy of the noise model, an 8-day measurement campaign was carried out and all necessary parameters for the model were collected from the site, such as meteorological conditions, traffic count, vehicle speed, etc. The measurement results were then processed and 10 measurements –each lasting for 1 h– were considered representative and used for the comparison with the modeled noise levels. Based on the results, it was observed that the inclusion of the fence in the models led to a better alignment with the measured noise levels, indicating that the fence had a beneficial influence on the accuracy of the predictions.

Although this paper focuses on comparing predicted noise levels of the ISO 9613-2 and CNOSSOS-EU with the measured noise levels, it also paves the way for more comprehensive analyses on roads with higher traffic volumes and the potential inclusion of additional national road noise standards, such as RLS-19, NMPB2008, RMG2012 and Nord2000. Such extensions would contribute to identifying the most suitable road traffic noise modeling technique for different contexts.

In summary, the ISO 9613-2:2024 Line Source model was found to provide the most realistic representation of road traffic sound propagation. However, the CNOSSOS-EU model can also serve as a valid alternative, but only if road surface correction factors are available and the method has been formally transposed into national legislation within the respective EU country [37].

Acknowledgment: The authors acknowledge Karam Katw for his indispensable assistance in the noise measurement campaign.
Funding Information: Authors state no funding involved.
Author Contribution: All authors have accepted responsibility for the entire content of this manuscript and consented to its submission to the journal, reviewed all the results and approved the final version of the manuscript. **Omar Odeh**: Formal analysis, Investigation, Methodology, Visualization, Writing -original draft, **Dénes Kocsis**: Conceptualization, Supervision, Validation, Writing – review & editing.
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.
Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Juhani P. A-weighted sound pressure level as a loudness/annoyance indicator for environmental sounds – could it be improved? Appl Acoust 2007;68:58–70.
2. European Environwmental Agency. Managing exposure to noise in Europe; 2017. Available from: https://www.eea.europa.eu/themes/

human/noise/sub-sections/noise-in-europe-updatedpopulation-exposure.
3. Ablenya B, Jarl K, Kampen CV. Noise barriers as a mitigation measure for highway traffic noise: empirical evidence from three study cases. J Environ Manag 2024;367:121963.
4. Hänninen O, Knol AB, Jantunen M, Lim TA, Conrad A, Rappolder M, et al. Environmental burden of disease in Europe: assessing nine risk factors in six countries. Environ Health Perspect 2014;122:439–46.
5. World Health Organization. Environmental health inequalities in Europe: second assessment report. Copenhagen, Denmark: Regional Office for Europe; 2019.
6. Mac Domhnaill C, Douglas O, Lyons S, Murphy E, Nolan A. Road traffic noise and cognitive function in older adults: a cross-sectional investigation of the Irish longitudinal study on ageing. BMC Public Health 2021;21:1814.
7. Clark C, Paunovic K. WHO environmental noise guidelines for the European region: a systematic review on environmental noise and quality of life, wellbeing and mental health. Int J Environ Res Publ Health 2018;15:2400.
8. Murphy E, Faulkner JP, Douglas O. Current state-of-the-art and new directions in strategic environmental noise mapping. Curr Pollut Rep 2020;6:54–64.
9. Hume K, Ahtamad M. Physiological responses to and subjective estimates of soundscape elements. Appl Acoust 2013;74:275–81.
10. World Health Organization. Environmental noise guidelines for the European region. Regional Office for Europe, Copenhagen: World Health Organization; 2018. Available from: https://www.who.int/europe/publications/i/item/9789289053563.
11. Cai Y, Ramakrishnan R, Rahimi K. Long-term exposure to traffic noise and mortality: a systematic review and meta-analysis of epidemiological evidence between 2000 and 2020. Environ Pollut 2021;269:116222.
12. Ndrepepa A, Twardella D. Relationship between noise annoyance from road traffic noise and cardiovascular diseases: a meta-analysis. Noise Health 2011;13:251–9.
13. Lee PJ, Park SH, Jeong JH, Choung T, Kim KY. Association between transportation noise and blood pressure in adults living in multi-storey residential buildings. Environ Int 2019;132:105101.
14. Bodin T, Albin M, Ardö J, Stroh E, Östergren P-O, Björk J. Road traffic noise and hypertension: results from a cross-sectional public health survey in southern Sweden. Environ Health 2009;8:38.
15. Thompson R, Smith RB, Karim YB, Shen C, Drummond K, Teng C, et al. Noise pollution and human cognition: an updated systematic review and meta-analysis of recent evidence. Environ Int 2022;158:106905.
16. Schubert M, Hegewald J, Freiberg A, Starke K, Augustin F, Riedel-Heller S, et al. Behavioral and emotional disorders and transportation noise among children and adolescents: a systematic review and meta-analysis. Int J Environ Res Publ Health 2019;16:3336.
17. Śliwińska-Kowalska M, Zaborowski K. WHO environmental noise guidelines for the European region: a systematic review on environmental noise and permanent hearing loss and tinnitus. Int J Environ Res Publ Health 2017;14:1139.
18. Džambas T, Ivančev A, Dragčević V, Bezina Š. Analysis of road traffic noise in an urban area in Croatia using different noise prediction models. Noise Mapp 2024;11:20240003.
19. LIFE E-VIA. LIFE E-VIA final report: covering the project activities from 01/07/2019 to 31/01/2023 (project no. LIFE18 ENV/IT/000201). European Commission, LIFE Programme; 2023. Available from: https://life-evia.eu/wp-content/uploads/2023/10/Final-report_EVIA_final.pdf.
20. European Commission. Report from the commission to the European Parliament and the council on the implementation of the environmental noise directive in accordance with article 11 of directive 2002/49/EC. Brussels, Belgium: European Commission; 2023.
21. Leiva C, Arenas C, Vilches LF, Arroyo F, Luna-Galiano Y. Assessing durability properties of noise barriers made of concrete incorporating bottom ash as aggregates. Eur J Environ Civil Eng 2017;23:1485–96.
22. Attenborough K, Li KM, Horoshenkov K. Predicting outdoor sound, 1st ed. London: CRC Press; 2007.
23. Faulkner J-P, Murphy E. Road traffic noise modelling and population exposure estimation using CNOSSOS-EU: insights from Ireland. Appl Acoust 2022;192:108692.
24. 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.
25. Larsson K. Updated road traffic noise emission models in Sweden. In: Proceedings of the INTER-NOISE 2016 – 45th international congress and exposition on noise control engineering: towards a quieter future; 2016:1329–40 pp. Available from: https://www.diva-portal.org/smash/get/diva2%3A1059678/FULLTEXT01.pdf.
26. Kokkonen, J. CNOSSOS-EU noise model implementation in Finland and experience of it in 3rd END round. In Proceedings of the 11th European Congress and Exposition on Noise Control Engineering (Euronoise 2018). Crete, Greece; 2018:6 p. Available from: https://www.euronoise2018.eu/docs/papers/207_Euronoise2018.pdf.
27. Kokkonen J, Kontkanen O, Maijala P. CNOSSOS-EU noise model implementation in Finland. (7-page report); 2017.
28. International Organization for Standardization. ISO 9613-2:1996: Acoustics — Attenuation of sound during propagation outdoors — Part 2: Engineering method for the prediction of sound pressure levels outdoors. Geneva, Switzerland: ISO; 1996.
29. International Organization for Standardization. ISO 9613-2:2024: Acoustics — Attenuation of sound during propagation outdoors — Part 2: Engineering method for the prediction of sound pressure levels outdoors. Geneva, Switzerland: ISO; 2024.
30. 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. Off J Eur Union 2015;168:1–823.
31. European Union. Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. Off J Eur Communities, L 2002;189.
32. Tombolato A, Brambilla G, Troccoli A, Sanchini A, Bonomini F. Basics of meteorology for outdoor sound propagation and related modelling issues. Noise Mapp 2024;11:20240006.
33. Licitra G, Bernardini M, Moreno R, Bianco F, Fredianelli L. CNOSSOS-EU coefficients for electric vehicle noise emission. Appl Acoust 2023;211:109511.
34. Ledee FA, Goubert L. The determination of road surface corrections for CNOSSOS-EU model for the emission of road traffic noise. In: Proceedings of the 23rd international congress on acoustics; 2019.
35. Commission Delegated Directive (EU). 2021/1226 of 21 December 2020 amending, for the purposes of adapting to scientific and technical progress, Annex II to directive 2002/49/EC of the European Parliament and of the Council as regards common noise assessment methods. Off J Eur Union 2021;269:65–142.
36. Larsson K. Swedish input data for road traffic noise in CNOSSOS-EU. Proc BNAM 2021.
37. Odeh O, Khayyat A, Kocsis D. CNOSSOS-EU road surface types: evaluation of the influence of different national values on noise emissions. Noise Mapp 2025;12:20250017.

38. Bérengier M, Gauvreau B, Blanc-Benon P, Juvé D. Outdoor sound propagation: a short review on analytical and numerical approaches. Acta Acustica United Acustica 2003;89:980–91.
39. Vercammen MLS. Sound concentration caused by curved surfaces (Doctoral dissertation, Technische Universiteit Eindhoven). Eindhoven: Technische Universiteit Eindhoven; 2012.
40. Attenborough K, Van Renterghem T. Adequacy of engineering predictions of soft ground effect. In: Proceedings of Forum Acusticum 2020; 2020.
41. Transport Infrastructure Ireland. Common noise assessment methods in Europe (CNOSSOS-EU): interim road surface correction factors for national roads in Ireland. In: Technical report RE-ENV-07006. Dublin, Ireland: Transport Infrastructure Ireland (TII); 2022.
42. Minister of Infrastructure and the Environment in Netherlands. RMG2012 - Reken- en meetvoorschrift geluid 2012 (Noise calculation and measurement regulations 2012). The Hague, Netherlands: Ministerie van Infrastructuur en Waterstaat. Reken- en meetvoorschrift geluid (Ministry of Infrastructure and Water Management); 2023.
43. Ministry of Justice of Hungary. Hungarian Gazette (Magyar Közlöny). 2025. Available from: https://magyarkozlony.hu/dokumentumok/b92c0692a0f0f8fd7af3c2c791e2549cd9894584/megtekintes.
44. Hungarian Public Road Nonprofit Ltd. KIRA – Közlekedési információs Rendszer és adatbázis (Hungarian national road network information and data bank); 2022. Available from: https://kira.kozut.hu.
45. Forouharmajd F, Nassiri P, Monazzam MR, Yazdchi M. Predicted sound absorption coefficients of absorber materials lined in a chamber. Int J Environ Health Eng 2014;3:13.
46. Federal Highway Administration. Highway noise barrier design handbook. U.S. Department of Transportation, FHWA. Section 3 2020: 3–15.
47. Klingner RE, McNerney MT, Busch-Vishniac I. Design guide for highway noise barriers (research report 0-1471-4). Center for Transportation Research, University of Texas at Austin; 2002, revised 2003.
48. ISO 17534-3:2015 – acoustics – software for the calculation of sound outdoors – part 3: recommendations for quality assured implementation of ISO 9613-2 in software according to ISO 17534-1.
49. Federal Highway Administration. Highway traffic noise: analysis and abatement guidance (FHWA-HEP-18-015). Washington, D.C.: U.S. Department of Transportation; 2018:2419 p.