

Short thesis for the degree of Doctor of Philosophy (PhD)

**Development Possibilities of Environmental Noise
Propagation Modelling**

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Abbreviations & Acronyms

A_{bar}	Barrier Attenuation
A_{curv}	Curved Surface Attenuation
ACS	Asphalt Concrete Surface
AGL	Above Ground Level
A_{gr}	Ground Effect Attenuation
CCS	Cement Concrete Surface
CNOSSOS-EU	Common NOise aSSessment methOdS
DAC	Dense Asphalt Concrete
dB	Decibel
dB(A)	A-weighted Decibel
D_c	Chimney Stack Directivity Correction Factor
EU	European Union
ISO	International Organization for Standardization
K_{geo}	Ground Effect Correction Factor
$L_{\text{Aeq},15\text{min}}$	15 Minutes Equivalent Continuous Sound Pressure Level
$L_{\text{Aeq},1\text{h}}$	1 Hour Equivalent Continuous Sound Pressure Level
L_w	Sound Power Level
MP	Measurement Point
PBS	Paving Block Surface
SMA	Stone Mastic Asphalt

1. Introduction

Noise pollution poses a critical issue in today's world. In Europe, road traffic noise is considered a major environmental pollutant in urban areas [1], being a continuous nuisance source impacting several aspects of life [2]. Road traffic noise is ranked as the second most significant environmental noise source [1,3] affecting the mental health and daily activities of individuals in noisy environments, thereby influencing their wellbeing [4,5,6]. Following fine particle pollution, road traffic noise is the most common environmental risk factor to human health in Europe [7]. Its mental and physical adverse health effects are mainly caused by the loud engine sounds, the continuous interaction between the tyre and the road surface, which is noisier at higher speeds, and vehicle horns, leading to a fatigued body and spirit and triggering unpleasant feelings [8]. In addition, this contributes to potential long-term risks of cardiovascular problems [9,10,11], such as heart attacks and hypertension [12,13]. In general, prolonged exposure to high noise levels can affect work and educational environments, as it can weaken our overall cognition, communication, and attention [14,15,16]. Conversely, the total burden of road traffic noise in the European Union - including direct costs and impacts, such as medical treatments and lost productivity - is estimated at 40 billion euros annually [17]. Therefore, implementing effective measures to counter these adverse effects is essential to reducing road traffic noise pollution.

- **Motivation**

In Europe, Member States are required to generate strategic noise maps every five years [18,19], and the accuracy and comparability of these maps depend on harmonised methods and reliable parameters. Differences in national road surface

correction coefficients and uncertainties in propagation standards motivate a focused investigation that connects European-scale harmonisation with local, measurement-based validation.

- **Research Questions**

This work aims to answer the following research questions in regards with modelling environmental noise propagation.

1. How do national road surface correction coefficients for Asphalt Concrete Surfaces (ACS), Cement Concrete Surfaces (CCS) and Paving Block Surfaces (PBS) compare with the CNOSSOS-EU defaults for light, medium-heavy, and heavy vehicles, and how do these differences influence total sound power levels?
2. How might these emission differences affect comparability of strategic noise maps and predicted population exposure across borders?
3. Under which geometric and structural conditions do the ISO 9613-2:2024 outdoor propagation predictions differ from the ISO 9613-2:1996, particularly regarding ground effect, screening, and curved surface reflections?
4. For distributed road traffic sources, what is the impact of Point Source versus Line Source representations on alignment with measured near-field and far-field noise levels?
5. Given typical data availability (traffic counts versus known source power levels) and site features (barriers, embankments), what practical guidance emerges for selecting between the CNOSSOS-EU and the ISO 9613-2?

- **Research Objectives**

The main objectives of this research is to:

1. Compare the CNOSSOS-EU default values with the official national values published in Austria, Germany, and Finland, and demonstrate that inconsistencies in national coefficients can lead to significant differences in predicted exposure and affected population by road traffic noise, which in turn undermines the comparability and policy relevance of strategic noise mapping.
2. Review the 2024 updates of the ISO 9613-2, highlighting key parameters that are expected to improve the standard's accuracy in modelling outdoor sound propagation.
3. Evaluate the performance of the CNOSSOS-EU method alongside the ISO 9613-2 standard in road traffic noise modelling using a case study from Hungary. This analysis not only supports the selection of appropriate modelling standards for similar traffic and environmental conditions but also positions the CNOSSOS-EU and the ISO 9613-2 within a broader international context, acknowledging their effective roles in environmental noise assessment.
4. Emphasize the importance of harmonized, transparent, and empirically validated methods for environmental noise management and policymaking.

2. Thesis Points and Novelty

- **Thesis 1:** Influence of Asphalt Concrete Surfaces (ACS) on Noise Emissions in the CNOSSOS-EU Method

Thesis Point. It is shown that ACS surfaces provide the highest noise reduction potential, reaching up to -6.6 dB for light vehicles and -5.75 dB for heavy vehicles compared to the Reference Road. Porous and multilayer asphalt surfaces significantly enhance noise reduction due to increased air void content and absorption properties. It is further proven that similar asphalt mixtures exhibit different acoustic behaviour across countries, demonstrating that the CNOSSOS-EU default coefficients are insufficient without national calibration.

Contributing Paper. Odeh, O., Khayyat, A., & Kocsis, D. (2025). *CNOSSOS-EU road surface types: Evaluation of the influence of different national values on noise emissions*. *Noise Mapping*, 12(1), 20250017 (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. Road surface corrections in the CNOSSOS-EU are assumed to be harmonized across the EU, yet the real acoustic performance of asphalt pavements varies significantly.

Approach. A systematic analysis of Asphalt Concrete Surfaces (ACS) was conducted using the CNOSSOS-EU formulations by comparing multiple European surface types and national coefficients to a Reference Road surface under controlled conditions.

Novelty. First controlled, cross-national comparison of the CNOSSOS-EU defaults versus national Asphalt Concrete road surface correction coefficients (Austria, Germany, Finland) under identical assumptions, by vehicle category and pavement type, quantifying $\Delta L_{W,road,m}$ differences relevant to a Reference Road.

- **Thesis 2: Acoustic Behaviour of Cement Concrete Surfaces (CCS) in the CNOSSOS-EU Method**

Thesis Point. It is shown that CCS surfaces exhibit high variability in noise emissions, ranging from slight reductions to increases of up to 2–3 dB, depending on surface finishing techniques. It is proven that surface texture and treatment, such as brushed, washed, or worked concrete, strongly influence noise generation, making CCS less predictable and less efficient than ACS for noise mitigation.

Contributing Paper. Odeh, O., Khayyat, A., & Kocsis, D. (2025). *CNOSSOS-EU road surface types: Evaluation of the influence of different national values on noise emissions*. *Noise Mapping*, 12(1), 20250017 (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. Concrete pavements are widely used in road construction, yet their acoustic behaviour is not consistently represented in the CNOSSOS-EU.

Approach. Different Cement Concrete Surface (CCS) types were evaluated using the CNOSSOS-EU correction coefficients and compared to the Reference Road across vehicle categories and national implementations.

Novelty. First controlled, cross-national comparison of the CNOSSOS-EU defaults versus national Cement Concrete road surface correction coefficients (Austria, Germany, Finland) under identical assumptions, by vehicle category and pavement type, quantifying $\Delta L_{W,road,m}$ differences relevant to a Reference Road.

- **Thesis 3: Noise Impact of Paving Block Surfaces (PBS) in the CNOSSOS-EU Method**

Thesis Point. It is shown that PBS surfaces generate the highest noise emissions among all surface categories, with increases of up to +8.4 dB for heavy vehicles. It is proven that low air void ratios and surface discontinuities increase tyre–road interaction noise, making PBS unsuitable for noise-sensitive environments. The results demonstrate that PBS should be avoided in urban noise mitigation strategies, especially in areas with significant heavy traffic.

Contributing Paper. Odeh, O., Khayyat, A., & Kocsis, D. (2025). *CNOSSOS-EU road surface types: Evaluation of the influence of different national values on noise emissions. Noise Mapping, 12(1), 20250017* (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. Paving Block Surfaces are commonly used in urban areas, yet their impact on road traffic noise is often underestimated.

Approach. PBS types from multiple European datasets were analysed within the CNOSSOS-EU framework and compared to the Reference Road.

Novelty. First controlled, cross-national comparison of the CNOSSOS-EU defaults versus national Paving Block road surface correction coefficients (Austria, Germany, Finland) under identical assumptions, by vehicle category and pavement type, quantifying $\Delta L_{W,road,m}$ differences relevant to a Reference Road.

- **Thesis 4: Impact of the ISO 9613-2:2024 Updates on Outdoor Sound Propagation**

Thesis Point. It is shown that the ISO 9613-2:2024 introduces significant improvements in modelling representation of real-world conditions, particularly in complex environments involving barriers and reflections. It is proven that enhanced screening (A_{bar}) improves prediction accuracy, while the ground correction factor (K_{geo}) has limited impact in low-height road traffic scenarios. The updated standard provides a more physically consistent representation of sound propagation.

Primary Contributing Paper. Odeh, O., Khayyat, A., & Kocsis, D. (2026). *Key Updates in ISO 9613-2:2024 — What's New in Outdoor Noise Prediction Standards? Proceedings of Forum Acusticum / EuroNoise 2025*, 1259–1264 (Scopus).

Secondary Contributing Paper. Odeh, O., & Kocsis, D. (2026). *From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise. Noise Mapping*, 12(1), 20250023 (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. The ISO 9613-2:1996 standard has known limitations in modelling ground effects, reflections, and screening.

Approach. The updated ISO 9613-2:2024 model was implemented and compared with the 1996 version to evaluate the effect of new parameters such as K_{geo} , A_{bar} , A_{curv} , and D_c .

Novelty. Early practice-oriented evaluation of the ISO 9613-2:2024 vs 1996 within a commercial software implementation, focusing on K_{geo} , A_{bar} , A_{curv} , D_c , and foliage attenuation, clarifying when the updates affect predictions.

- **Thesis 5: Comparative Validation of the CNOSSOS-EU and the ISO 9613-2 Models**

Thesis Point. It is shown that the CNOSSOS-EU model provides stable and reliable results, with deviations within +3 dB(A). It is proven that the ISO 9613-2 Line Source model, particularly the 2024 version, achieved the highest accuracy, with deviations as low as +0.23 dB(A) under realistic conditions.

Contributing Paper. Odeh, O., & Kocsis, D. (2026). *From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise*. *Noise Mapping*, 12(1), 20250023 (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. The accuracy of environmental noise models depends on their ability to represent real-world conditions.

Approach. A field measurement campaign was conducted, and predictions from the CNOSSOS-EU and the ISO 9613-2:1996 and the ISO 9613-2:2024 Point and Line Source models were compared against measured data.

Novelty. Integrated measurement and modelling validation using an eight-day campaign on a Hungarian road segment to test the CNOSSOS-EU road traffic noise model and the ISO 9613-2 Line Source models performance, revealing the improved screening performance in the ISO 9613-2: 2024 update.

- **Thesis 6:** Practical Applicability of the CNOSSOS-EU and the ISO 9613-2 for Road Traffic Noise Modelling

Thesis Point. It is shown that the CNOSSOS-EU is most suitable for large-scale strategic noise mapping, as it relies on traffic data and standardized inputs. It is proven that the ISO 9613-2:2024 is more suitable for detailed local-scale modelling, particularly in the presence of barriers and complex propagation paths. The findings demonstrate that model selection should be based on data availability, modelling scale, and environmental complexity.

Contributing Paper. Odeh, O., & Kocsis, D. (2026). *From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise*. *Noise Mapping*, 12(1), 20250023 (Walter de Gruyter, Scopus, Q2, IF: 2.4).

Problem Statement. Selecting an appropriate noise modelling method is critical for reliable environmental assessments.

Approach. The performance, input requirements, and prediction accuracy of the CNOSSOS-EU and the ISO 9613-2 were evaluated under identical conditions.

Novelty. Practical guidance for model selection in noise mapping software: the CNOSSOS-EU when traffic counts and national surface parameters are available; the ISO 9613-2:2024 Line Source for structure-sensitive propagation. **As well as,** Policy-relevant insight that without validated, up-to-date national road surface coefficients, cross-border exposure comparisons risk systematic bias; software databases should make provenance/versioning transparent.

3. **Thesis 1-3: Influence of Road Surfaces (ACS, CCS and PBS) on Noise Emissions in the CNOSSOS-EU Method**

- **Overview**

Thesis 1-3 focus on evaluating how different road surface types influence predicted noise levels within the CNOSSOS-EU framework. Road surface characteristics play a significant role in traffic noise levels, particularly in the interaction between tires and pavement, which directly affects rolling noise emissions. Understanding these effects is essential for improving the accuracy of strategic noise maps and for supporting effective noise mitigation strategies in urban planning. Therefore, this section investigates the extent to which variations in road surface properties impact modelled noise levels and highlights their importance within the CNOSSOS-EU methodology.

- **Methods Summary**

The CNOSSOS-EU defaults were compared against national coefficients for ACS, CCS and PBS from Austria, Germany, and Finland implemented in noise mapping software databases, particularly SoundPLAN, IMMI and CadnaA. Rolling noise (L_{WR}) and propulsion noise (L_{WP}) components were computed at reference conditions, road surface corrections ($\alpha_{i,m}$ and β_m) applied, and total $L_{W,road,m}$ obtained by category. Differences $\Delta L_{W,road,m}$ relative to the CNOSSOS-EU Reference Road were calculated for category 1 (light motor vehicles), Category 2 (medium-heavy motor vehicles) and Category 3 (heavy duty vehicles) by pavement class under identical assumptions (temperature, tyres, speed). Table 1 provides an overview of the road surface types identified in Germany

[20,21], Austria [21,22], and Finland [23,24], alongside those listed in the CNOSSOS-EU documentation [25], which is based on the Dutch road surface network [26].

Table 1: Road Surface Types in the Examined Countries.

Surface Type/Country	CNOSSOS-EU	Germany	Austria	Finland
Reference	Reference surface - 0	National reference (non-fluted mastic asphalt) – G0	Reference surface – A0	Reference surface – F0
Bituminous Mixes/ Asphalt Concrete Surface - ACS	Single layer porous asphalt ZOAB – NL01	Open-pored asphalt PA 0/11 – G-ACS-1	Open porous asphalt – A-ACS-1	SMA/DAC 16 – F-ACS-1
	Two-layer porous asphalt ZOAB – NL02	Open-pored asphalt PA 0/8 – G-ACS-2	Noise-reducing stone mastic asphalt – A-ACS-2	SMA 8 – F-ACS-2
	Two-layer porous asphalt (fine) ZOAB – NL03	Stone mastic asphalt SMA 0/5 and SMA 0/8 – G-ACS-3	Stone mastic asphalt – A-ACS-3	
	Stone mastic asphalt SMA-NL5 – NL04	Stone mastic asphalt SMA 0/8 and SMA 0/11 – G-ACS-4	Asphalt concrete – A-ACS-4	
	Stone mastic asphalt SMA-NL8 – NL05	Low-noise mastic asphalt – G-ACS-5		
	Thin layer A – NL13	Noise-optimised asphalt SMA LA 0/8 – G-ACS-6		
	Thin layer B – NL14	Thin asphalt wearing courses in hot application (≥ 70 km/h) – G-ACS-7		
		Asphalt concrete AC 11 (≥ 70 km/h) – G-ACS-8		
		Noise-optimised asphalt AC D LOA – G-ACS-9		
		Concretes according to ZTV Beton-StB 07 with washed concrete – G-CCS-10		
Cement Concrete Surface – CCS	Brushed down concrete – NL06		washed concrete – A-CCS-5	

Thesis 1-3: Influence of Road Surfaces (ACS, CCS and PBS) on Noise Emissions in the CNOSSOS-EU Method

Surface Type/Country	CNOSSOS-EU	Germany	Austria	Finland
Cement Concrete Surface – CCS	Optimized brushed down concrete – NL07		Noise-reducing washed concrete GK8 – A-CCS-6	
	Fine broomed concrete – NL08		Noise-reducing washed concrete GK11 (2019) – A-CCS-7	
	Worked surface – NL09			
Paving Block Surface or Setts – PBS	Hard elements in herring bone – NL10	Hard elements with flat surface with $b \leq 5$ mm and $b+2f \leq 9$ mm – G-PBS-11		Even paving stones – F-PBS-3
	Hard elements not in herring bone – NL11	Hard elements with $b > 5$ mm or $f > 2$ mm or other hard elements – G-PBS-12		Uneven paving stones – F-PBS-4
	Quiet hard elements – NL12			

• Results Summary

The results show that Asphalt Concrete Surfaces provide the greatest reduction in noise relative to the Reference Road. Moreover, thin layer road surfaces, such as NL13, NL14 and G-ACS-7 are more suitable for road sections with a higher share of light vehicle traffic. Additionally, ACS exhibit little to no effect on noise emissions relative to the Finnish Reference Road for all categories. Porous asphalt surfaces, such as NL02, G-ACS-1, G-ACS-2 and A-ACS-1 show high noise reduction capabilities. The two-layer porous asphalt (fine) ZOAB – NL03 reduces noise by 6.6 dB for light motor vehicles and by an average of 5.75 dB for Category 2 and Category 3 vehicles compared to the Reference Road, which is the highest calculated noise reduction performance for an ACS. These reductions are influenced by structural properties such as air void ratio, layer thickness, and texture configuration.

On the other hand, Cement Concrete Surfaces exhibit significant variability in noise reduction performance compared to the Reference Road. For example, optimized brushed down concrete – NL07 reduces noise emissions for Category 2 and Category 3 vehicles, whereas fine broomed concrete – NL08 increase them. Similarly, ZTV Beton-StB 07 with washed concrete – G-CCS-10 also lead to increased noise emissions for Category 2 and Category 3 vehicles. Noise-reducing washed concrete GK11 (2019) – A-CCS-7 demonstrates the weakest CCS performance, increasing noise emissions by 2.3 dB for Category 1 vehicles and by an average of 3.95 dB for Category 2 and Category 3 vehicles compared to the Reference Road. On the other hand, it was observed that the Finnish road network does not contain any Cement Concrete Surfaces in the transposition. These findings indicate that CCS are less predictable and less effective than ACS for noise mitigation.

In general, all PBS lead to increased noise emissions compared to the Reference Road. Hard elements not in herring bone – NL11 can increase emissions by 6.1 dB for Category 1 vehicles and by an average of 8.3 dB for Categories 2 and 3. It was also observed that the Austrian road network does not contain any PBS in the transposition. Given that the maximum permitted speed on Paving Block Surfaces is 60 km/h, the use of such surfaces is generally discouraged in densely populated urban areas, particularly in new developments.

Figure 1, Figure 2 and Figure 3 illustrate the ACS, CCS and PBS noise reduction performance for light, medium and heavy motor vehicles compared to the Reference Road.

Thesis 1-3: Influence of Road Surfaces (ACS, CCS and PBS) on Noise Emissions in the CNOSSOS-EU Method

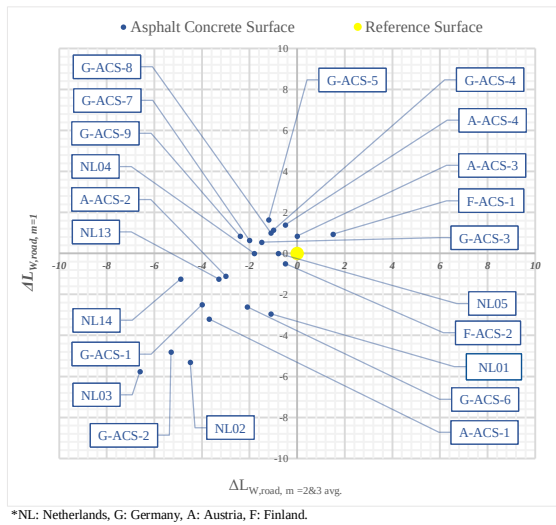


Figure 1: Noise Reduction Capabilities of ACS in dB.

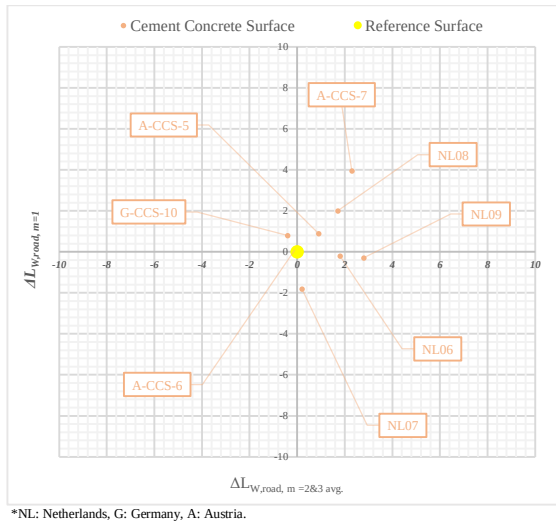


Figure 2: Noise Reduction Capabilities of CCS in dB.

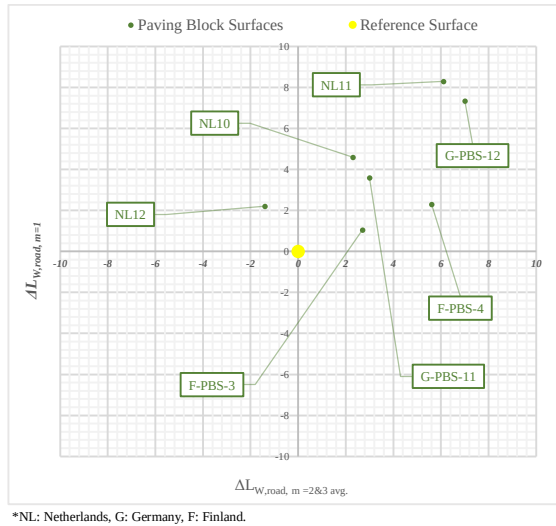


Figure 3: Noise Reduction Capabilities of PBS in dB.

In summary, Thesis 1-3 showed multi-decibel differences in $\Delta L_{w,road, m}$ between the CNOSSOS-EU defaults and national sets for similar pavement types. Double-layer porous surfaces showed the strongest reductions; PBS increased emissions in comparison with the Reference Road. Differences category-wise were observed by country, reflecting local measurement derivations. These differences can shift populations across exposure thresholds in strategic noise mapping, limiting cross-border comparability without transparent coefficient provenance and uncertainty bands.

4. **Thesis 4: Impact of the ISO 9613-2:2024 Updates on Outdoor Sound Propagation**

- **Overview**

This section examines the impact of the ISO 9613-2:2024 updates on outdoor sound propagation. Sound propagation models are essential for predicting how noise travels from a source to a receiver under varying environmental conditions, including ground and obstacles effects. With the recent updates to the ISO 9613-2, it is important to assess how these modifications influence prediction accuracy and overall model behaviour. Therefore, this section analyses the differences between previous and updated formulations, focusing on the resulting changes in sound attenuation and their implications for environmental noise assessment.

- **Methods Summary**

The work begins with a review of the revised ISO 9613-2 methodology, which relies on octave band calculations to predict outdoor sound levels while accounting for ground effects, atmospheric absorption, geometrical divergence, reflections, and screening by obstacles [27,28]. The review highlights the introduction and practical role of K_{geo} , A_{bar} , A_{curv} and D_c . It also clarifies where the 2024 edition aligns with the 1996 version (e.g., free-field with low source/receiver heights relative to horizontal distance) and where it differs (e.g., free-field with high source/receiver heights relative to horizontal distance and barrier-affected paths). This comparison was made using SoundPLAN 9.1 noise modelling software and the results are presented in the form of noise maps.

- **Results Summary**

The impact of the updated K_{geo} formula on outdoor sound propagation is pronounced when the source was positioned 50 m above ground. At short horizontal distances and at the same height as the source, a difference of approximately 3 dB was observed. This behaviour is consistent with the fact that K_{geo} eliminates the ground effect contributions when both source and receiver heights are large relative to their separation distance. In contrast, the difference between the two ISO 9613-2 versions becomes negligible when the source is close to the ground as presented in Figure 4 and Figure 5.

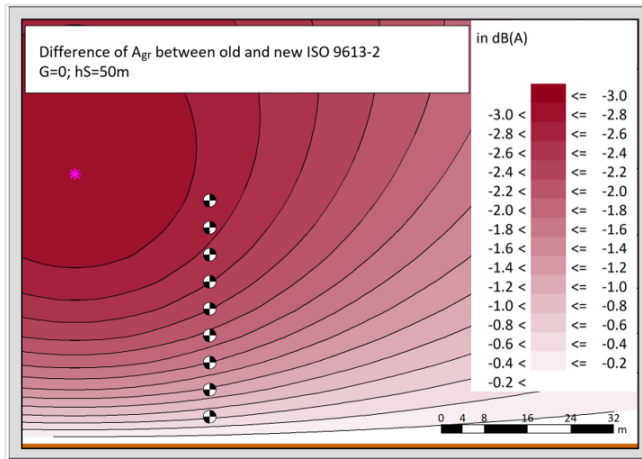


Figure 4: A_{gr} Difference between the 1996 and 2024 ISO 9613-2. Source Height: 50 m AGL.

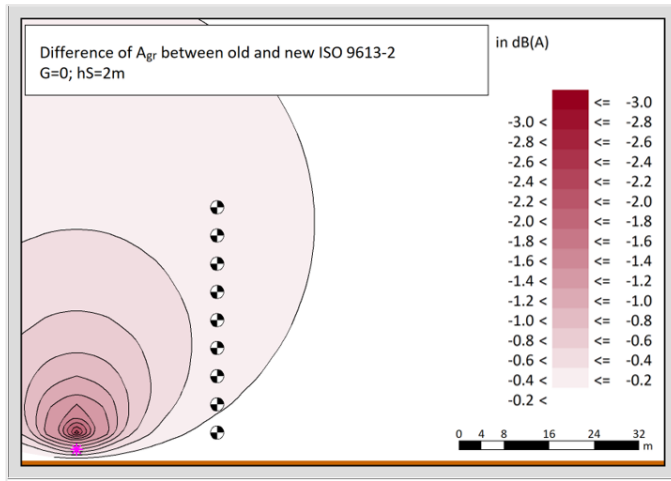


Figure 5: A_{gr} Difference between the 1996 and 2024 ISO 9613-2. Source Height: 2 m AGL.

The parameter A_{curv} was not defined in the 1996 version, meaning that cylindrical surfaces had to be modelled as polygons. With the introduction of A_{curv} in the ISO 9613-2:2024, full cylindrical objects can now be implemented, allowing additional reflection points to be considered. The maps confirm that cylinders produce continuous reflections across all frequencies, whereas polygons show very limited reflections up to 500 Hz and then generate straight line reflection patterns from 1 kHz to 8 kHz due to their multi-edge geometry as presented in Figure 6 and Figure 7.

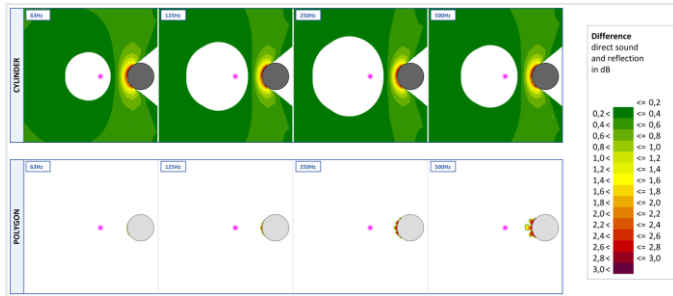


Figure 6: Direct Sound and Reflection Difference for 1/1 Octave Bands from 63 Hz to 500 Hz at Polygon and Cylinder Objects.

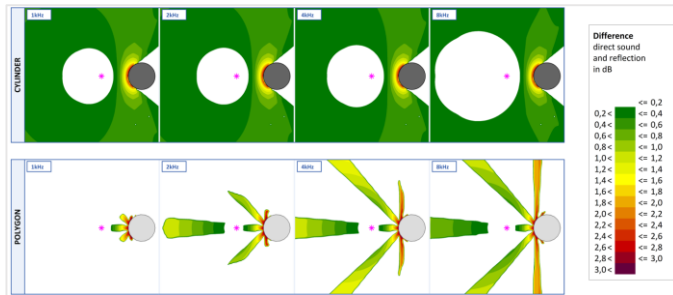


Figure 7: Direct Sound and Reflection Difference for 1/1 Octave Bands from 1 kHz to 8 kHz at Polygon and Cylinder Objects.

Chimney stacks and other vertical, upward-facing openings are modelled as point sources located at the centre of the opening in the ISO 9613-2:1996, with the assumption of omnidirectional radiation. However, a frequency-dependent directivity correction factor, D_c , is introduced in the ISO 9613-2:2024. Figure 8 shows the resulting sound propagation patterns at 125 Hz and 4000 Hz after applying D_c in SoundPLAN 9.1.

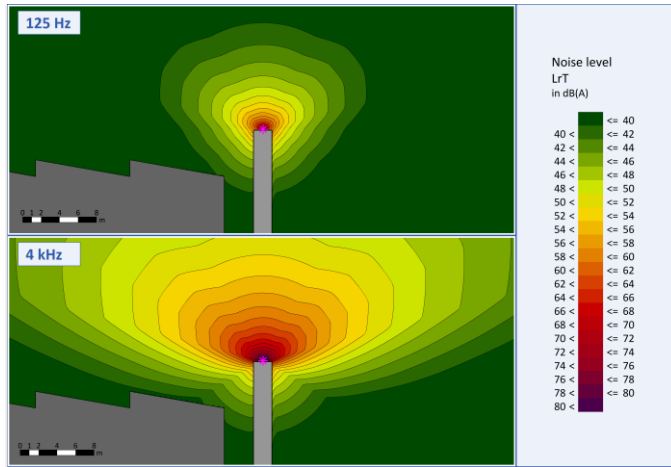


Figure 8: Sound Propagation of a Chimney Stack with 1 m Radius Implementing Directivity Correction at 125 Hz and 4 kHz.

In summary, the results of the ISO 9613-2:2024 review indicate that the accuracy of outdoor noise modelling improved by introducing key updates that are directly relevant to outdoor sound propagation. Applying these updates in noise mapping software, such as SoundPLAN, confirm that parameters like K_{geo} , A_{bar} , D_c and A_{curv} influence sound propagation and visualise how source and receiver heights and distances impact ground attenuation. These improvements are expected to strengthen noise mapping practices and increase the reliability of environmental noise assessments.

5. **Thesis 5: Comparative Validation of the CNOSSOS-EU and the ISO 9613-2 Models & Thesis 6: Practical Applicability of the CNOSSOS-EU and the ISO 9613-2 for Road Traffic Noise Modelling**

- **Overview**

This section presents a comparative evaluation of the CNOSSOS-EU and ISO 9613-2 noise prediction models against real-world field measurements. Accurate validation is essential to determine how well these models represent actual environmental noise conditions under varying traffic and propagation scenarios. Therefore, this section outlines the measurement setup, data collection procedures, and modelling approaches applied to both methods, followed by an analysis of the differences between predicted and observed noise levels. The comparison provides insight into the accuracy, reliability, and practical applicability of each model, as well as identifying potential sources of deviation and areas for improvement in environmental noise prediction.

- **Methods Summary**

An eight-day field campaign in Hungary provided $L_{Aeq,15min}$ data transformed to $L_{Aeq,1h}$ at two receivers (MP1 near-field and MP2 far-field). This process was carried out for ten representative weekday hours. SoundPLAN 9.1 was used to implement the ISO 9613-2:1996 and 2024 standards, each as Point Source and Line Source models, and the CNOSSOS-EU road traffic noise model. To emphasise propagation, source sound power level for the ISO 9613-2 cases was back-calculated at MP1 and validated at MP2. The CNOSSOS-EU road traffic noise model was configured to mirror the actual site conditions so that the comparison with the

ISO 9613-2 standard is meaningful. Traffic counts were assigned per category (light, medium-heavy and heavy) with the observed average speeds from the measurement days. The road surface correction coefficients were set using the available national values in Hungary, while meteorology and ground settings were kept consistent with the ISO 9613-2 models. The geometry of the site (e.g., road height along the carriageway on embankment, receiver positions at MP1 and MP2, and the presence/absence of the thin roadside safety fence) was represented as observed from the measurements.

This setup ensures that the CNOSSOS-EU model predictions in the case study reflect the same inputs used in the ISO 9613-2 model, so any differences in predicted noise levels arise from the emission formulation and the method's treatment of propagation, rather than from mismatched boundary conditions. In this case study, two scenarios were assessed: without the roadside safety fence and with the fence modelled as reflective. Parameters of interest included K_{geo} , A_{bar} , with focus on road traffic geometry.

• Results Summary

It was observed that for road traffic noise representation, the ISO 9613-2 Line Source models provided better agreement with far-field measurements at MP2 than the ISO 9613-2 Point Source models calibrated at near-field (MP1). With relatively low source/receiver heights compared to horizontal distance, K_{geo} had minimal practical impact, leading to ISO 9613-2:2024 $\approx$ ISO 9613-2:1996 in free-field.

Figure 9 presents the Mean Absolute Error of the model predictions against the measurements at MP2 without the fence.

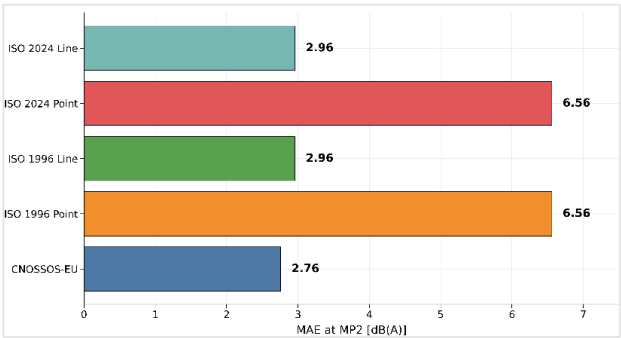


Figure 9: Mean Absolute Error at MP2 (no fence).

On the other hand, implementing the fence in the noise model led to improved ISO 9613-2:2024 Line Source model alignment with measurements compared to the ISO 9613-2:1996, indicating benefits of the revised screening formulas (A_{bar}). Figure 10 presents the Mean Absolute Error of the model predictions against the measurements at MP2 in the presence of the fence within the noise model.

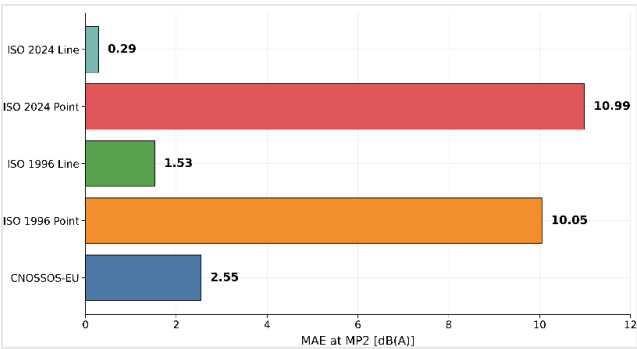


Figure 10: Mean Absolute Error at MP2 (with fence).

The CNOSSOS-EU road traffic noise model predictions remained close to measurements near the source and within an acceptable deviation at the far receiver (MP2), with limited sensitivity to a thin safety fence. The results from both modelled scenarios indicate that, under relatively light traffic volumes, the ISO 9613-2:2024 Line Source model is the most accurate approach within noise modelling software to represent the measured conditions. However, this method requires the sound power level or sound pressure level of the source to be known. In contrast, the CNOSSOS-EU method offers lower accuracy with increasing distance from the source but remains straight-forward to apply when the parameters of the road surface type are available, as it relies primarily on traffic counts to derive the road's sound power level.

Figure 11 and Figure 12 illustrate the difference between the measured and predicted noise levels at MP2 for the ten representative hours.

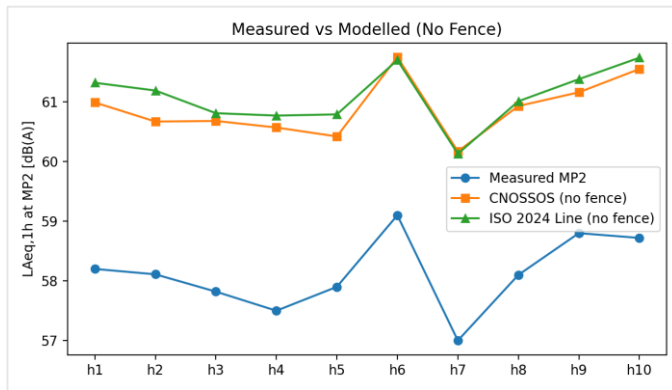


Figure 11: Measured vs. Modelled $L_{Aeq,1h}$ at MP2 (no fence).

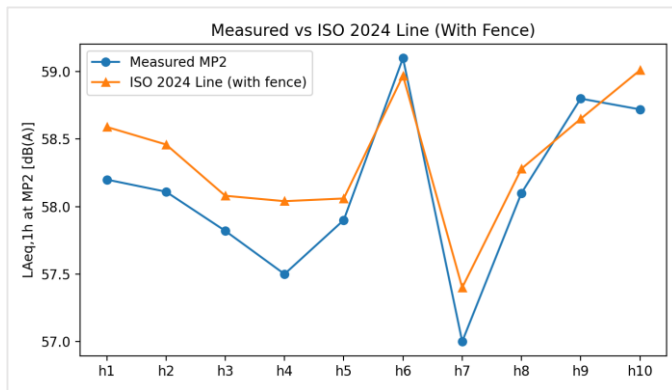


Figure 12: Measured vs. Modelled $L_{Aeq,1h}$ at MP2 (with fence).

In summary, including the fence in the model leads to an improved accuracy of the CNOSSOS-EU and ISO 9613-2 Line Source models' predictions for far outdoor sound propagation. However, the ISO 9613-2 Point Source models do not reflect the measured conditions well.

6. Discussion and Summary

This section brings together the two parts of the dissertation and combines the results in a common frame. On the one hand, the cross-national comparison around the CNOSSOS-EU shows that what is often presented as a harmonised framework still depends on national road surface correction coefficients that were developed under different measurement conditions, vehicle fleet compositions, and pavement types. The results confirm that, even for similar road surface classes, the total sound power from road traffic can differ by several decibels when comparing the CNOSSOS-EU defaults with the official national sets for Austria, Germany, and Finland. This matters because strategic noise maps and exposure classifications are sensitive to shifts in the 1–3 dB range near typical assessment thresholds, so the adoption of a given coefficient set is not only a technical choice but a comparability decision. The implication is that EU-level harmonisation cannot be achieved by a single reference table: it also requires up-to-date, validated national coefficients and transparent software databases that indicate provenance and versioning.

On the other hand, the case study clarifies how methodological differences in the noise modelling approaches can impact sound propagation. For the studied geometry and traffic, representing the road as a line source consistently improved agreement with the measured far-field noise levels compared to the point source representation, which tends to under-predict significantly. This is not a software limitation but a source representation issue: road traffic radiates along the carriageway, so the cumulative diffraction and ground effect interactions over distance are better captured by a line source model. The comparison between the ISO 9613-2:1996 and the ISO 9613-2:2024 indicates that, in simple free-field conditions with low source/receiver heights relative to the horizontal

distance, the updated geometry factor for the ground effect (K_{geo}) does not introduce large changes, and both editions effectively align. However, once a structural element is introduced, here it was the thin galvanized safety fence on the embankment, the 2024 version's screening treatment provides a more realistic attenuation and brings predictions closer to the measured values at MP2. This aligns with the intention of the revision: not to change predictions everywhere, but to reduce known limitations in geometry-sensitive paths.

Another practical point emerging from the discussion is that the CNOSSOS-EU road traffic noise model can align with the measurements relatively well in the near field and remain within an acceptable deviation at the far receiver when the road surface parameters and traffic composition are correctly specified. However, the method's sensitivity to the road surface correction coefficients means that different national sets lead to different outcomes even under matched conditions. Therefore, when the purpose is comparability across Member States, the analysis supports the need to define the exact coefficient set used, to reflect the associated uncertainty band, and where possible, to prefer nationally maintained values that are consistent with the CNOSSOS-EU derivation guidance.

Finally, by placing the Hungarian case study inside the European comparison, the dissertation concludes that there is no single "best model" in abstract terms. The appropriate choice depends on what is known (traffic counts versus source power), which structures are present (barriers, curved surfaces, embankments), and what is being compared (local compliance versus cross-border exposure statistics). If traffic data and official surface parameters are available, the CNOSSOS-EU is straightforward and sufficiently robust for strategic assessments, if uncertainty and provenance are reported. If the task is to model sound propagation with relevant structural elements, the ISO 9613-2:2024 with a line source representation

is often preferable. In all cases, transparent assumptions, harmonised inputs where possible, and validation with measurements remain essential to maintain a high level of accuracy and precision in the model predictions.

- **Summary**

The dissertation shows that reliable and comparable environmental noise assessments require both harmonised noise emission models and well-defined geometry conditions for accurate sound propagation modelling. Cross-national differences in road surface correction coefficients lead to multi-decibel emission variability under the CNOSSOS-EU framework, while the ISO 9613-2:2024 offers methodological refinements that enhance propagation accuracy where structures and geometry are dominant. For road traffic noise, Line Source representations are preferable, and the CNOSSOS-EU road traffic noise model remains effective when national road surface parameters and traffic counts are known.

- **Future Work**

Future work should extend validation to roads with higher traffic volumes, more complex geometries, night-time conditions, as well as a cross-national comparison that includes more EU Member States, when official national data are available to support transparent national procedures for deriving and maintaining road surface coefficients.

7. List of Publications

1. Odeh, O., & Kocsis, D. (2026). From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise. *Noise Mapping*, 12(1), 20250023 (Walter de Gruyter, Scopus, Q2, IF: 2.4).
2. Odeh, O., Khayyat, A., & Kocsis, D. (2026). Key Updates in ISO 9613-2:2024 — What's New in Outdoor Noise Prediction Standards? *Proceedings of Forum Acusticum / EuroNoise 2025*, 1259–1264 (Scopus).
3. Odeh, O., Bite, M., & Kocsis, D. (2026). Case Study: Noise Source Analysis Through Environmental Noise Measurements. *Proceedings of Forum Acusticum / EuroNoise 2025*, 943–947 (Scopus).
4. Odeh, O., Khayyat, A., & Kocsis, D. (2025). CNOSSOS-EU road surface types: Evaluation of the influence of different national values on noise emissions. *Noise Mapping*, 12(1), 20250017 (Walter de Gruyter, Scopus, Q2, IF: 2.4).
5. Odeh, O., Bite, M., & Kocsis, D. (2024). NOISE BARRIER DESIGN OF A RAILWAY VIADUCT. In *Proceedings of the International Congress on Sound and Vibration* (Scopus).
6. Odeh, O., Bite, M., & Kocsis, D. (2023). COMPLEX INDOOR NOISE MODELLING CASE STUDY. In *Proceedings of the International Congress on Sound and Vibration* (Scopus).

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28. ISO 9613-2:2024 — Acoustics — Attenuation of sound during propagation outdoors — Part 2: Engineering method for the prediction of sound pressure levels outdoors.



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List of publications related to the dissertation

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1. **Odeh, O. F. M.**, Khayyat, A., Kocsis, D.: Key Updates In ISO 9613-2:2024 - What's New In Outdoor Noise Prediction Standards?
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Foreign language scientific articles in international journals (2)

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In: Proceedings of the International Congress on Sound and Vibration. Szerk.: van Keulen, W.; Kok, J, Society of Acoustics, [s. l.], 1-8, 2024. ISBN: 9789090390581
6. **Odeh, O. F. M.**, Bite, M., Kocsis, D.: Complex Indoor Noise Modelling Case Study.
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Idegen nyelvű, külföldi könyvrészletek (1)

1. **Odeh, O. F. M.**, Khayyat, A., Kocsis, D.: Key Updates In ISO 9613-2:2024 - What's New In Outdoor Noise Prediction Standards?
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2. **Odeh, O. F. M.**, Kocsis, D.: From models to reality: how CNOSSOS-EU and ISO 9613-2 perform against measured road traffic noise.
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