PREDICTING THE IMPACT OF FUTURE LIGHT-RAIL EXPANSION ON URBAN PARK SOUNDSCAPES USING CNOSSOS-EU AND THE TRAPT MODEL

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Abstract

Potential environmental noise from future transportation expansion, driven by urbanization and traffic growth, poses significant risks to human health, making it urgent to predict and quantify. In contrast, urban parks serve as important spaces for escaping the increasingly noisy urban environment. Previous studies have applied the Tranquillity Rating Prediction Tool (TRAPT), integrating acoustic indicators with visual factors, to assess tranquillity in urban parks. However, with the rapid expansion of light-rail systems and the widespread adoption of the CNOSSOS-EU noise modelling framework in Europe, there is an urgent need to evaluate future soundscape conditions under projected scenarios. This study conducted sound pressure level measurements and photographic surveys at 57 locations within the park. The CNOSSOS-EU framework was applied to predict noise levels associated with the planned Dublin Luas light-rail extension in Tolka Valley Park. Tranquillity mapping was then performed using the TRAPT and Inverse Distance Weighting (IDW) under different traffic volume scenarios for 2035 and 2057. The results indicate a general decline in tranquillity ratings across the park. The most affected areas decrease by 5.33 in 2035 and 5.48 in 2057. The median L_{day} increases from 56.9 dB in 2026 to 59.4 dB in 2035 and 59.8 dB in 2057, with maximum predicted levels approaching 90 dB.

Keywords: *light-rail transit system expansion, rail-based noise modelling, urban park tranquillity, future soundscapes*

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1. Introduction

Noise 2050 is a national project funded by the Environmental Protection Agency (EPA) Ireland, aiming to shape Ireland's future noise environment through robust modelling of existing and emerging noise sources,citizen science, and mitigation interventions. With rapid urban expansion and increasing traffic density, transport-related environmental noise is a major yet often overlooked environmental pollutant affecting urban quality of life [1] [2] [3]. Environmental noise is associated with cardiovascular diseases, cognitive impairment in children, annoyance, tinnitus, and sleep disturbance, and is therefore an important public-health concern [4] [5]. In response, the World Health Organization (WHO) has developed guidance for environmental noise risk assessment based on European evidence [6]. Within the European Union, environmental noise is managed through the Environmental Noise Directive (END), which requires Member States to produce Strategic Noise Mapping (SNM) every five years [7]. Previous noise mapping initiatives in Europe have predominantly focused on major road and rail sources [8] [9] [10] [11]; however, limited attention has been directed toward the rapid expansion of light-rail transit (LRT) systems. These systems, commonly referred to as trams, increasingly connect urban and suburban areas and may increase noise exposure in nearby residential areas [12].

The Luas light-rail system is a key part of Dublin's long-term transport network, currently comprising the Green and Red Lines, with Transport Infrastructure Ireland (TII) proposing future expansion under the Luas 2050 vision, including Luas Finglas, Luas Lucan, and Luas Cork [13]. Among these, Luas Finglas [14] is the most advanced, representing a 3.9km extension of the Green Line from Broombridge to Charlestown, passing through the 140 ha Tolka Valley Park. Urban parks are widely recognized as important restorative environments and provide psychological benefits for stress reduction [15]. The planned expansion of the Luas Finglas corridor may alter the acoustic character of Tolka Valley Park, highlighting the need for proactive noise assessment. Furthermore, since 2018, the CNOSSOS-EU framework has been mandated by the European Commission as the standardized methodology for noise assessment, with full implementation in the fourth round of Strategic Noise Mapping (SNM) in 2022. Despite this regulatory transition, the application of CNOSSOS-EU to light-rail noise modelling within the Dublin context remains a significant research gap [16].

TRAPT integrates sound pressure levels with visual natural features to estimate perceived tranquillity and has been widely applied in soundscape studies [17] [18]. It combines the acoustic data with the proportion of natural elements in the visual scene to generate a Tranquillity Rating (TR). Unlike standard noise mapping (SNM), which primarily relies on quantitative indicators such as L_{day} and L_{den}, TRAPT provides a more intuitive and holistic assessment that better reflects people's perceived tranquillity. This makes it particularly useful for quantifying environmental noise, guiding noise management, addressing noise complaints, and supporting soundscape analysis.

This paper adopts the CNOSSOS-EU method to predict noise emissions for the Luas Light-rail expansion under the 2035 and 2057 scenarios and applies the TRAPT model to evaluate soundscape transformations in Tolka Valley Park by comparing tranquillity ratings before and after the expansion.

2. Methodology

2.1. Study area and Field measurement

Field measurements were conducted at 57 sampling points within Tolka Valley Park (Fig. 1). At each sampling point, two tripods (approximately 1.4 m in height) were used to mount a sound level meter (SLM) and a camera. The The A-weighted equivalent continuous sound pressure level (L_{Aeq}) was recorded over a 1-minute interval using the SLM, with corresponding timestamps logged. In addition, a 360° photograph was taken, and the geographic coordinates (latitude and longitude) were determined using Google Earth. For the baseline scenario, the measured 1-min L_{Aeq} values were used as an approximation of L_{day} at the sampling locations, acknowledging the limited temporal representativeness of the short-term measurements.

2.2. Noise Simulation Using CNOSSOS-EU

Noise simulations were implemented in iNoise V2026 (Enterprise Version) based on the CNOSSOS-EU framework. To ensure localized accuracy, the Luas light-rail system was decoupled into distinct railway vehicle and railway track models, with relevant parameters customized according to Luas-specific correction factors (Table 1).

Given that this study investigates park tranquil-

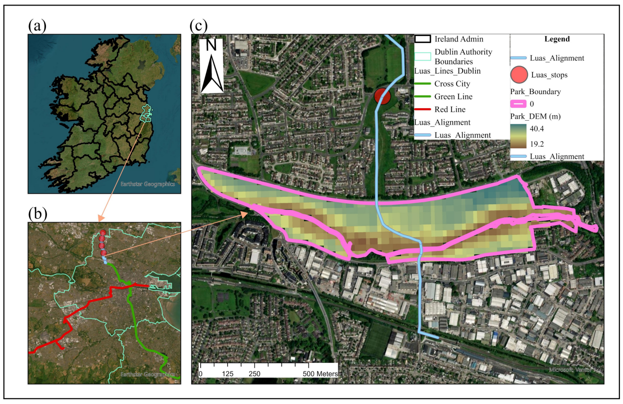

Figure 1: Study area overview: (a) Ireland administrative boundary; (b) Spatial distribution of Luas lines in Dublin; (c) Digital Elevation Model (DEM) of Tolka Valley Park.

Table 1: Classification of input parameters for the rail noise prediction model based on CNOSSOS-EU standard.

CNOSSOS Rail vehicle Input Parameters	CNOSSOS Rail track catalogue
Vehicle transfer	Rail Roughness
Contact filter	Track transfer
Traction noise	Impact noise
Wheel roughness	Bridge radiation
structure transfer	

lity based on daytime acoustic environments, the A-weighted daytime equivalent continuous sound pressure level (L_{day}) was employed as the primary noise indicator. The calculation follows the CNOSSOS-EU standard formula for L_{day}, defined as follows:

$$L_{\text{day}} = 10 \lg \left(\frac{1}{T_{\text{d}}} \int_0^{T_{\text{d}}} 10^{\frac{L_{p\text{A}}(t)}{10}} \, dt \right) \quad (1)$$

where T_{d} is the daytime reference period (typically defined as the 12-hour interval from 07:00 to 19:00). $L_{p\text{A}}(t)$ is the A-weighted instantaneous sound pressure level. According to Chapter 15 (Noise and Vibration) of the Luas Finglas Environmental Impact Assessment Report (2024), different traffic volumes were applied for the opening years 2035 and 2057, with variations across day, evening, and night periods (see Table 2).

Table 2: Projected Luas light-rail trip frequencies by period for 2035 and 2057 scenarios.

Opening Year	Daytime (07:00 to 19:00hrs)	Evening (19:00 to 23:00hrs)	Night-time (23:00 to 07:00hrs)
2035	83	21	13
2057	118	31	19

The calculation domain was defined by applying a 100-meter buffer around the park boundary, further constrained by a minimum bounding geometry to represent the extent of the noise modelling area. The GIS input datasets captured both the acoustic source and propagation environment; specifically, the Luas light-rail alignment was used to define the source geometry, while a Digital Elevation Model (DEM), building footprints, and vegetation barriers were incorporated to account for topographic and acoustic shielding. Additionally, relevant environmental and meteorological parameters were integrated under the CNOSSOS-EU framework to configuration atmospheric absorption (incorporating ambient temperature, relative humidity, and air pressure), ground effects, and meteorological corrections based on wind direction frequencies. In terms of track infrastructure, grass track systems were assigned to the majority of the alignment, whereas slab track construction was specified for the bridge section crossing the Tolka Valley River. The simulation utilized a 10-meter calculation grid with a step size of 1 meter.

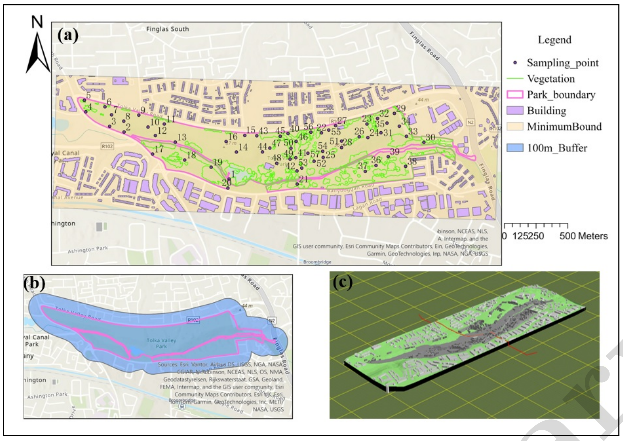

Figure 2: Acoustic modelling environment: (a–c) 3D perspective views of the noise simulation model; (d) spatial distribution of GIS datasets within the calculation domain.

2.3. TRAPT Model and Spatial Interpolation

The Tranquillity Rating Prediction Tool (TRAPT) was applied to estimate perceived tranquillity, as defined in Eq. (2). In this model, the baseline L_{day} is approximated by the measured L_{Aeq}, while for the future scenarios L_{day} values include the simulated Luas noise combined with the baseline environmental noise. NCF denotes the percentage of natural and contextual features (excluding the sky) within the visual scene. The NCF values were calculated in QGIS based on the 360° photographic data. The revised TRAPT equation also incorporates moderating factors (MF), accounting for positive influences (e.g., water sounds) and negative elements (e.g., litter or graffiti) within the environment. Considering that individuals in urban environments generally exhibit higher tolerance to noise compared to those in rural areas, a correction factor of +0.87 was adopted in this study for densely populated settings.

$$TR = 10.55 + 0.041\, NCF - 0.146\, L_{\text{day}} + MF \quad (2)$$

Finally, noise simulation outputs were spatially joined with the sampling points in ArcGIS Pro. Inverse Distance Weighting (IDW) interpolation was then applied to generate a continuous surface of predicted tranquillity ratings (TR).

3. Result

3.1. Characteristics of NCF at Sampling Points

As illustrated in Fig. 3, the NCF values exhibit significant spatial variability across the study area, ranging from a minimum of 31.12% to a maximum of 91.54%, with a mean value of approximately 61.5%. Specifically, the data reveals that: High NCF Areas: A total of 7 sampling points (e.g., Points 1, 19, 30, 38, 39, 50 and 56) recorded NCF values exceeding 80%, indicating a high density of vegetation and a dominant natural landscape, which are typically associated with the core ecological zones of the park. Low NCF Areas: Conversely, several points showed relatively low NCF (below 50%), notably at Point 2 (31.12%) and Point 27 (42.43%). These lower values often correspond to areas with higher proportions of man-made infrastructure or paved surfaces, possibly near the edges of the park. Overall Trend: Most of the sampling points maintain an NCF level between 50% and 75%, suggesting a moderately integrated landscape where natural greenery and urban elements coexist.

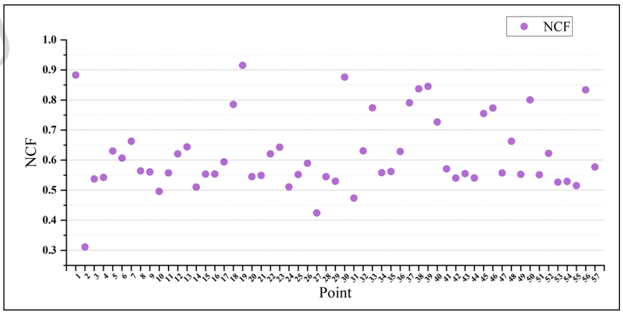

Figure 3: Scatter plot of NCF distribution across all sampling points in the study area.

3.2. Present-day Noise Mapping

Fig. 4a illustrates the baseline spatial distribution of road traffic noise around Tolka Valley Park, derived from the Round 4 Strategic Noise Mapping data using the day-evening-night noise indicator L_{den}. The highest noise levels (65–99 dB) are concentrated along the park boundaries and adjacent major roads, decreasing toward the park interior to 55–64 dB. Fig. 4b presents the baseline Tranquillity Rating (TR) derived from field measurements and spatial interpolation, indicating generally high tranquillity across the study area. Approximately 30% of the park falls within the “good” (5.0–6.0) or “excellent” (6.0–7.0) categories, mainly in areas near the Tolka River and central zones with dense vegetation, away from major traffic sources. More than half of the area is classified as “fairly good”.

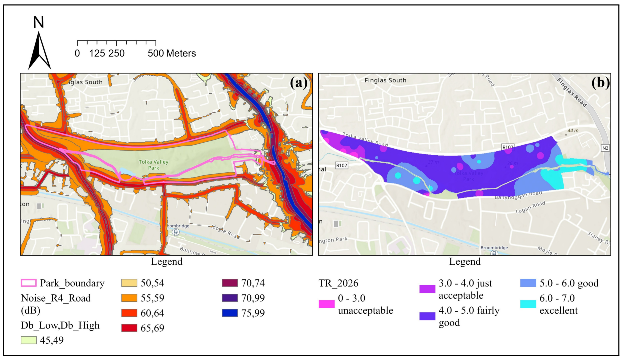

Figure 4: Present-day acoustic environment analysis: (a) Strategic Road noise mapping (L_{den}) surrounding the park (based on END Round 4 datasets); (b) Spatial distribution of the baseline Tranquillity Rating (TR) in 2026, derived from interpolated field measurements.

3.3. Noise Simulation and Tranquillity Rating analysis

Fig. 5 illustrate the simulated L_{day} for the 2035 and 2057 Luas expansion scenarios. Across both future scenarios, high-noise zones, with higest values reaching 85–90 dB, are predominantly concentrated along the rail alignment corridor and the northern boundary of the park. A temporal comparative analysis reveals a clear spatial expansion of noise pollution by 2057 (Fig. 5b): the high-noise corridors (> 70 dB) become substantially wider and more continuous. Concurrently, the moderate acoustic zones (50–69 dB) expand outward from the light-rail alignment, encroaching heavily into both the eastern and western sectors of the park.

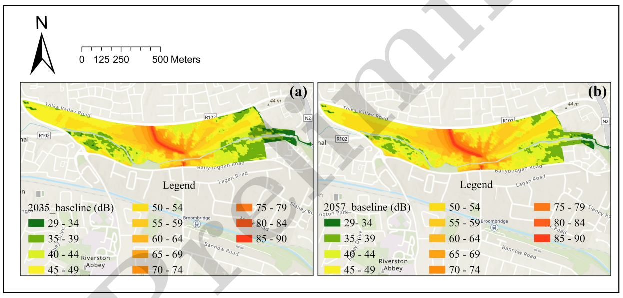

Figure 5: Comparative spatial distribution of (L_{day}) for 2035 and 2057 scenarios. (a) Simulation for 2035; (b) Simulation for 2057.

Statistical analysis of the noise contour areas for the three temporal scenarios (2026, 2035, and 2057) indicates a definitive and progressive upward trend in ambient noise levels (Fig. 6). Shift in Central Tendency and Median Levels: The overall distribution of L_{day} exhibits a systematic upward shift over time. The median noise level increases from 56.9 dB in the 2026 baseline scenario to 59.4 dB in 2035, ultimately reaching 59.8 dB in 2057. This steady elevation of the median reflects a widespread rise in background noise across the entire study area.

Expansion of the Interquartile Range (IQR): The IQR (the middle 50% of the dataset) shows both a higher baseline and a larger vertical span. In 2026, noise levels are tightly clustered between 55.1 dB and 58.4 dB. By 2057, this core concentration shifts significantly upward to 56.7–64.9 dB. The increased span in later years signifies greater variance and a more heterogeneous noise environment, indicating that broader park areas will experience higher noise levels.

Increase in High-Level Noise Exposure: The most significant degradation is observed in the upper whiskers and high values. The upper whisker (representing typical upper exposure limit) climbs sharply from 63.4 dB in 2026 to 76.0 dB in 2035, reaching its maximum at 77.1 dB in 2057. Peak localized outliers in 2057 approach nearly 90.0 dB. These trends indicate that alongside a moderate increase in average noise, the spatial extent of high-level noise exposure will expand markedly, posing critical challenges to acoustic comfort and ecological integrity.

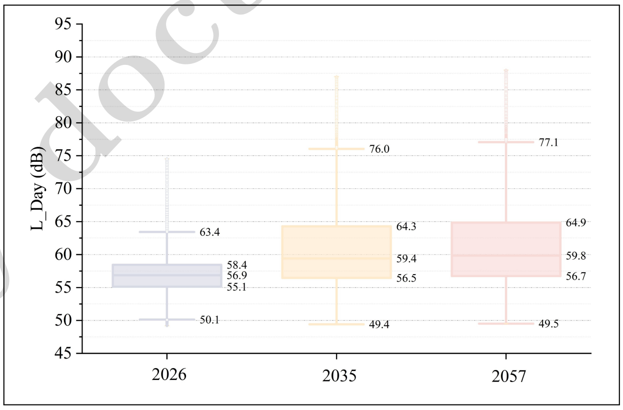

Figure 6: Boxplot comparing the statistical distribution of L_{day} across the 2026 baseline, 2035, and 2057 scenarios.

Fig. 7a and 7b project the spatial distribution of the Tranquillity Rating (TR) under the 2035 and 2057 scenarios, illustrating a distinct spatial gradient across the park. Higher TR values (5.0–7.0, corresponding to “good” to “excellent” quality) are localized in densely vegetated areas in the southwest, east, and isolated northern peripheries, with “excellent” zones specifically clustering at lower elevations along the Tolka River. Conversely, the central and southern corridors exhibit lower TR values within the “unacceptable” (0–3.0) and “just acceptable” (3.0–4.0) ranges. This degradation highlights acute noise vulnerability, exacerbated by structural radiation noise from the southern rail bridge that expands low-TR zones near the river corridor. Temporally, from 2035 to 2057, high-tranquillity zones contract noticeably, while unacceptable and barely acceptable zones spread outward from the park’s core.

Fig. 7c and 7d detail the spatial change in TR relative to the 2026 baseline (0 to –0.2). Minimal-to-slight change zones (TR diff between 0 and –0.2) account for approximately 50% of the study area, mostly confined to the eastern and western extremities. However, substantial portions of the park exhibit substantial decline, with maximum TR reductions reaching –5.33 in 2035 and extending to –5.48 in 2057. Spatially, this decline progresses from localized corridor-adjacent impacts into widespread territorial degradation. High-loss areas expand substantially along the light-rail extension, flanked by prominent transitional buffer zones. By 2057, high-loss zones broaden significantly, with previously unaffected southern regions exhibiting noticeable decreases. This dynamic demonstrates how long-term traffic growth shifts noise impacts from linear propagation along the rail corridor to broad spatial infiltration across the park landscape.

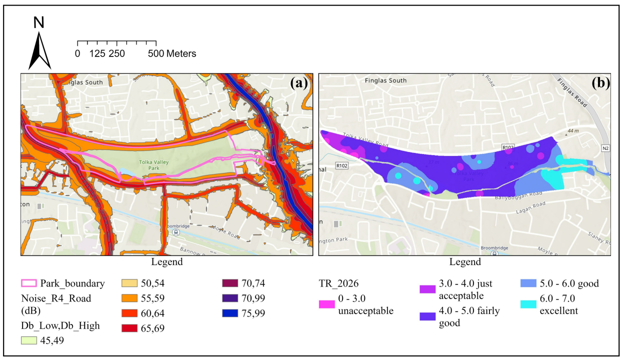

Figure 7: Spatiotemporal distribution of Tranquillity Rating (TR) and its future variations. (a) Predicted spatial distribution of TR under the 2035 scenario; (b) Predicted spatial distribution of TR under the 2057 scenario; (c) Spatial difference map of TR between the 2035 scenario and the 2026 baseline (TR_Diff_35-26); (d) Spatial difference map of TR between the 2057 scenario and the 2026 baseline (TR_Diff_57-26).

4. Discussion and Conclusions

4.1. Discussion

According to the Luas Finglas Environmental Impact Assessment Report 2024 (Chapter 15 Noise and Vibration), planned operational speeds for the extension range from a low-speed threshold of 20 km/h to a high-speed peak of 40km/h. These variations significantly influence both rolling noise and traction noise levels. Incorporating these specific velocity profiles into the 2035 and 2057 scenarios is critical for generating more accurate noise contours [19] [20]. Furthermore, the degree of rail maintenance post-commissioning serves as a decisive factor for the track model's acoustic output [21] [22]. Future work will involve a sensitivity analysis utilizing the Rail Roughness Spectra provided by Transport Infrastructure Ireland (TII) for "Well Maintained," "Normally Maintained," and "Not Maintained"
conditions, alongside minimum and maximum impact noise parameters to evaluate the long-term acoustic fluctuations of the system. The current field measurements encountered adverse meteorological conditions, specifically high wind speeds. Although Sound Level Meters (SLM) were equipped with windscreens, sampling points at higher elevations remained susceptible to wind interference. Such environmental noise may have artificially inflated L_{Aeq} values, subsequently leading to underestimated Tranquillity Ratings (TR) in certain areas. To ensure data integrity, subsequent measurements at these sensitive locations will be conducted under optimal weather conditions. Preliminary spatial analysis indicates that tranquillity levels are significantly lower in sparsely vegetated open areas compared to densely wooded regions, suggesting that strategic tree planting could serve as an effective mitigation measure to enhance the park's restorative quality [23]. However, a standardized definition for noise hotspots remains absent in current literature, and the deep coupling relationships between these hotspots and surrounding environmental factors—such as the Normalized Difference Vegetation Index (NDVI), distance to the road network, and elevation—have not yet been thoroughly investigated. Future research could address this gap by employing a Multi-Criteria Evaluation and Weighted Linear Combination (MCE–WLC) framework to systematically delineate noise hotspots and conduct comprehensive correlation analyses with spatial environmental variables.

4.2. Conclusion

By integrating the CNOSSOS-EU framework with the TRAPT model, this study addresses a critical research gap regarding noise prediction and tranquillity assessment for Dublin's Luas light-rail expansion. The findings demonstrate that the implementation of the Luas Finglas line will pose significant acoustic challenges to Tolka Valley Park, with predicted noise levels spanning a broad range of 29–90 dB across the area. The tranquillity mapping clearly illustrates the varying degrees of impact across different park zones, where TR difference maps reveal a distinct transition in noise intensity; specifically, as train trip frequency surges, the overall environmental tranquillity undergoes a substantial decline. These results provide a robust scientific foundation for policymakers to effectively balance the demands of urban transit expansion with the essential preservation of psychological well-being resources for citizens.

5. Acknowledgments

This research was funded by the Environmental Protection Agency (EPA) Ireland under the EPA Research Programme, Grant Reference No. 2025-HE-1299 (Noise 2050 https://www.noise2050.com/).

6. Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT and Gemini to improve the language, flow, and readability of the manuscript. After using these tools, the authors reviewed and edited the content as needed and took full responsibility for the technical accuracy and integrity of the published work.

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