Evaluation Of Urban Noise Mitigation Measures Using Sonitus Sensor Data: A Case Study of Dublin

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MSc Project Submission Sheet

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Abstract

Noise in the environment has become one of the primary concerns for the environmental health of people, and cities must evaluate and control exposure according to the Environmental Noise Directive (2002/49/EC). This paper assesses the recent noise management policies of Dublin based on Sonitus monitoring data and END indicators (LDEN, LNIGHT). Hourly values of LAeq were converted to daily values and examined using descriptive statistics, pre-post analysis, Difference-in-Differences (DID), and regression analysis including weather control. There were significant reductions in treated sites (LDEN 1.4 to -2.0 dB; LNIGHT -1.0 to -1.8 dB) and no reduction in control sites. Statistically significant improvements were proven by DID and regression. Results illustrate intervention effects and contribute to urban noise policy, which is evident.

The results demonstrate the significant decrease in noise exposure to treated sites, with LDEN being reduced by about 1.4-2.0 dB and LNIGHT by 1.0-1.8 dB and there were no similar changes in control sites. The estimates of DID and the regression outcomes confirmed that these improvements were statistically significant and above the natural seasonal or environmental variation. These findings give scientific proof of the success of the mitigation strategies adopted by Dublin and show the usefulness of the data-driven assessment framework in facilitating the city noise policy.

1 Introduction

Noise in the environment is quite a common and long-term pollutant of the environment in the city environment that has been well-documented to be associated with detrimental health consequences such as poor sleep, compromised cognitive capabilities, diminished productivity, high blood pressure, and cardiovascular danger. With the ever-increasing urban centers in Europe, exposure to noise has become a major issue in social life, which has led to the creation of regulatory bodies to help in evaluation and control of environmental noise.

The European Union has an environmental noise exposure evaluation and mapping standardized methodology in the Environmental Noise Directive. The directive promotes that the competent authorities should produce strategic noise maps, formulate Noise Action Plans and calculate population exposure with harmonized indicators like the Day Evening Night Level (LDEN) and Night-time Noise Level (LNIGHT). These indicators allow making the comparison between the cities and give the uniform ground of measuring the long-term patterns of exposure.

The Dublin City Council is mandated with the role of overseeing noise in the Dublin area and putting in place mitigation measures as stipulated in its Noise Action Plan. Such solutions as designation of Quiet Areas, the provision of traffic-calming devices, surface improvements, limiting the use of heavy goods vehicles and other localized engineering interventions are presently implemented. These measures are strategically significant, but their pragmatic implementation has not been evaluated consistently because empirical evaluation has not been done continuously.

The development of environmental sensing technologies, especially the implementation of the Dublin Sonitus network, gives an opportunity to overcome such limitations. The Sonitus noise environmental monitors gather the real-time high-resolution acoustic records at various locations within the city. Together with the meteorological data, these data allow considering more closely the actual effectiveness of mitigation measures. Nonetheless, current studies based on Sonitus data have been descriptive in nature as far as noise characterization is concerned without the systematic assessment of intervention effectiveness.

This research paper fills this gap by combining Sonitus API-based acoustics data with weather conditions of Met Éireann. Using the treated-control evaluation design, pre- and post-intervention comparison and weather-adjusted regression analysis, this study statistically and practically determines whether the noise mitigation measures in Dublin have resulted in statistically and practically significant changes in noise levels.

Research Question:

"How effective are Dublin's noise mitigation measures in reducing environmental noise levels, as measured using real-time Sonitus sensor data?"

Objectives:

1. Collect, preprocess and integrate Sonitus noise data with meteorological data.
2. Calculate LDEN and LNIGHT indicators on an EU END basis daily.
3. Classify the sites as treated or control, depending on the location to mitigate measures put in place.
4. Use descriptive statistics, hypothesis test, and regression models to assess interventions.
5. Analyze results regarding the current academic literature and Dublin Noise Action Plan.

The rest of this report will be in the following structure: Part 2 is a literature review on the study on environmental noise, sensor-based monitoring, and urban noise reduction. The methodology is described in Section 3. Section 4 gives the design specification, and in Section 5 there is the implementation. Evaluation and analysis are found in section 6. In sections 7 and 8, the findings are addressed, and the future work recommendations are given.

2 Literature Review

In the research proposal of the current study, A more comprehensive understanding of Dublin's environmental noise patterns was required, especially in relation to evaluating the effectiveness of implemented urban noise mitigation strategies. The initial literature identifiers in the proposal indicated a growing world interest in the use of data-based techniques of environmental noise evaluation as well as the necessity of real time monitoring to complete predictive modelling tools. A review of the existing literature is therefore organized around five key themes relevant to this research: the public-health impacts of environmental noise, European regulatory requirements for assessment and mitigation, the role of long-term monitoring networks, the documented effectiveness of noise-reduction measures, and the methodological challenges involved in evaluating their real-world outcomes.

The proposal formed the basis of considering Dublin noise environment by highlighting the fact that there was a need to have evidence-based assessment in city settings where there was continued exposure to noise (World Health Organization, 2018; Basner and McGuire, 2018). This concluding review builds upon that argument by utilizing academic sources that support the urgency of the issue of noise in urban settings and the creation of a consistent regulatory framework in the form of the Environmental Noise Directive (European Commission, 2002). It also concurs with the fact that the proposal implies monitoring technologies, but specifically concentrates on the long term measured data, which would still be necessary to verify the assumptions made in strategic noise maps (Geraghty et al., 2014). The review also relies on the modern studies concerning sensor-based noise systems (Raman and Sharma, 2023), the efficiency of transport related mitigations (Sand, 2017), and the influence of urban morphology on the acoustic effect (Qin et al., 2024). Taken together, these literature strands support the motivation of the research proposed in the proposal and explain the method of the empirical research applied in the final study.

2.1 Environmental Noise and Public Health

Environmental noise exposure has long been listed among environmental health issues of great concern, and considerable evidence has been done on long term influence on sleep disturbance, irritation, poor cognitive performance, and cardiovascular risks (World Health Organization, 2018; Basner and McGuire, 2018). These results confirm the first claim of the proposal which states that urban noise is a significant public health issue, which needs to be systematically assessed. The intensive location of transport infrastructure in urban spaces and the intensive high density building forms, as well as incessant human activity, precondition the conditions in which the level of noise exposure is usually more than recommended, which justifies the empirical assessment that was conducted in the given research.

2.2 European Regulatory Frameworks for Noise Assessment

Our research is in line with the European Noise Directive (END 2002/49/EC), whose main provision is the regulation framework in the evaluation and management of environmental noise in the Member States (European Commission, 2002). The standardized exposure indicators, LDEN and LNIGHT, to be used in strategic noise mapping and Noise Action Plans, are required by the END. These are the main clues of my analysis method. We also rely on the CNOSSOS-EU approach that perfects the computation of noise indicators so that they are uniform throughout Europe (European Commission, 2015). These regulatory tools form the methodological as well as policy backgrounds of my study.

2.3 Long-Term Monitoring Networks

The proposal emphasizes the need for data-driven evaluation, and the literature strongly supports this approach. Monitoring in the long term provides a clearer image of the exposure to noise in the environment, which supplements and validates the assumptions made in strategic noise maps. Geraghty et al. (2014) illustrate the ability of the Dublin Sonitus Environmental

Noise Monitoring Network to record temporal changes and spatial changes that cannot be fully captured using models. Their results justify my choice to apply continuous Sonitus measurements to the computation of LDEN and LNIGHT and to study the effects of interventions eventually.

2.4 Sensor-Based Acoustic Monitoring Developments

The proposal described the technological progress in noise sensing. In the last project, I base this notion on peer reviewed literature. As Raman and Sharma (2023) demonstrate acoustic sensors are much cheaper to use, which helps in monitoring the environment in real time and shows the increase in importance of sensor networks in the measurement of noise. The fact that their work is centered on short term detection as opposed to long-term evaluation, however, does not deny the applicability of sensor-based schemes but upholds the technological basis of the Sonitus system deployed in Dublin.

2.5 Effectiveness of Noise Mitigation Measures

The reduction of the environmental noise up to a certain extent by the mitigation measures in Dublin is one of the primary objectives of my study. According to Sand (2017), the most prevalent measures, including a reduction in speed, designation of a quiet area, optimization of traffic flow, and low noise surfaces, can produce small improvements, which are 1-3 db. These scale-level impacts can seem insignificant, but they are not small. Nevertheless, literature is also characterized by the challenge of identifying the effects of certain interventions because of the overlapping measurements and urban complexity. Ehmer, Knie and Albrecht (2023) report these attribution issues in the field of aviation noise research demonstrating that several concomitant measures make causation interpretation difficult. These results support the necessity of quasi-experimental designs, which are used in our evaluation scheme.

2.6 Influence of Urban Morphology on Noise Propagation

we noted that noise behavior is shaped by “local environmental context.” The academic literature confirms this. Qin et al. (2024) show that building height, façade alignment, and road geometry influence noise propagation and the perceived effectiveness of mitigation measures. Their findings underscore the complexity of urban acoustic environments and support my decision to analyze treated and control sites across varied built contexts, rather than assuming a uniform effect.

2.7 Methodological Gaps in Intervention Evaluation

The proposal revealed an apparent research gap: Dublin has never done empirical, measured data tests of its noise reduction measures. This is a gap that is verified in literature. Although a long-term monitoring study design, like Geraghty et al. (2014), is valuable in its descriptive analysis, few studies have been conducted with quasi-experimental designs, including before and after comparisons, treated and control matching, Difference-in-Differences modelling or regression analysis, of intervention effects. A significant part of the European studies is centered on noise mapping or technological advancement as opposed to investigating the actual impact. This paper fills this gap directly by combining continuous Sonitus monitoring data and meteorological variables and using a structured quasi-experimental design to measure the outcome of the interventions.

3 Research Methodology

The project is a quantitative quasi experimental design, in which we are interested in knowing the extent to which the noise reduction measures adopted by Dublin work, based on long run data that we have gathered. This strategy is based on the Environmental Noise Directive (European Commission, 2002) and the CNOSSOS-EU standards (European Commission, 2015) and it has four vital key sections, collecting the data, calculating indicators, preparing the dataset and doing the statistical evaluation.

3.1 Research Design

The design used in the study is a quasi-experimental design since the interventions were not random and in real-life situations that occurred in ordinary streets of a city. This will allow us to compare locations that received the noise reduction treatments (treated sites) with other locations of equivalent size that did not receive the treatments (control sites). We divided the timeline into events that preceded the intervention and those that followed the intervention to enable us to observe the actual change due to the intervention due to the actions taken even though the normal variation of background noise was taken into consideration. Such is how environmental policy is studied in cases where you cannot conduct a real experiment (Ehmer, Knie and Albrecht, 2023).

3.2 Data Sources

The Sonitus Environmental Noise Monitoring Network provided hourly measurements on the environmental noise in Dublin at high resolution. The Sonitus network has been proved to be dependable in empirical characterization of noise and trend analysis in the research of the past (Geraghty et al., 2014). The meteorological information was gathered at Met Eireann to capture those factors that have been known to affect noise propagation such as the speed of wind, direction of wind, temperature, and precipitations. The use of meteorological variables demonstrates the significance of the contextual determinants of the acoustic behavior that have been identified in the literature (Qin et al., 2024).

3.2.1 The Sonitus Environmental Noise Data

Noise information was via the Sonitus API, and therefore, we have high-resolution sound levels of multiple locations.

The dataset includes:

- LAeq (A-weighted equivalent continuous sound level)
- Hourly timestamps
- Sensor location IDs

The datasets used were:

- *hourly_noise_analysis.csv*
- *daily_noise_analysis.csv*

The project's custom data processing workflow is used to create these datasets.

3.2.2 Dublin's Meteorological Data (Met Éireann)

The Noise Action Plan and intervention documentation of Dublin City Council was relied upon to identify:

- Locations where mitigation measures were put in place (treated sites).
- Timeline of implementation of each intervention
- Sites that are not being interfered with (control sites)

This metadata made it possible to have pre and post and treated control classification of every observation.

3.3 Computation of LDEN and LNIGHT

The hourly values of Lae were overseen to calculate the long-term noise indicators LDEN and LNIGHT as per the END and CNOSSOS-EU processes (European Commission, 2002; European Commission, 2015). Calculation of LDEN involved adding the hourly equivalent continuous sound levels plus the evening and night penalties of +5 dB and +10 dB respectively and dividing them into 24-hour weighted index. LNIGHT was calculated with average nighttime LAeq working through the set hours of 23:00 to 07:00. These indicators give a harmonized platform of determining the exposure of populations and the effects of a noise mitigation measure over the long term (Sand, 2017).

3.4 Dataset Preparation

The combined values the LDEN and LNIGHT data per day with the information on weather to create a single analytical data set. The outliers caused by sensor malfunction, missing days or extreme weather conditions were eliminated in accordance with the customary practice of noise monitoring. Identification of treated and control sites was determined through the Dublin City Council documentation on the application of certain noise reduction measures in urban settings, such as the reduction of speed limits, the alteration of the traffic flow and the designation of quiet areas. This categorization makes a comparison possible in accordance with quasi experimental design.

3.5 Statistical Analysis

The analysis was divided into several complementary analysis phases. Temporal patterns and baseline differences were investigated using descriptive statistics and visualisations of treated and control sites. Directional changes in LDEN and LNIGHT were performed by pre- and post-intervention comparisons. The statistical significance of the differences among the groups and within them were tested using independent and paired t-tests.**S**ince this intervention involved an effect that may be confounded by time, a Difference-in-Differences (DID) model was then used to isolate the effect of the interventions through a time-effect comparison of treated and control sites. The technique is commonly applied in policy analysis to separate the effects of treatment and the overall temporal patterns and external factors (Ehmer, Knie and Albrecht, 2023). Lastly, multivariate regression estimates were calculated to investigate the effects of interventions with meteorological variables, day type and seasonal patterns controlled. This measure leads to improvement in internal validity by considering other contextual elements that are known to affect noise propagation (Qin et al., 2024).

3.6 Ethical and Data Management Considerations

No data on human and personal characteristics are used in the study because only anonymized environmental measurements are utilized. All data was processed according to ethical standards in conducting environmental research and secured in accordance with data management standards approved by the institution. The way it was done meets the requirements of transparency and reproducibility of European environmental noise guidance.

4 Design Specification

The study design was designed in such a way that it would be able to conduct a systematic and replicable analysis of noise mitigation strategies in Dublin based on long-term environmental monitoring data. It has four fundamental elements which include the data architecture, the analytical workflow, the creation of key variables and the assessment framework. Collectively, these factors guarantee compliance with the demands of the Environmental Noise Directive and provide a strong statistic evaluation of the intervention efficacy.

4.1 System Overview

The datacentric analytical design is since the study starts by obtaining hourly LAeq measurements on the Sonitus Environmental Noise Monitoring Network and meteorological data on meteorology on Met Eireann. It is based on these datasets that all the latter is done with analytical processes. This noise data is transformed to daily LDEN and LNIGHT signals and meteorological variables are synchronized on to the same time scale. The statistical evaluation of intervention effects in a multivariate mode can be established with the help of combined data sets.
The design is based on the accepted best practice in environmental noise assessment, which highlights integration of the obtained acoustic data, regulatory exposure measures and other pertinent environmental covariates (European Commission, 2002; European Commission, 2015; Geraghty et al., 2014).

4.2 Architectural Design

Table 1: Architectural Diagram

Layer / Module	**Description**
Layer 1: Acquisition and Storage of the data: Data Layer	
Sonitus Noise Monitoring Data	Hourly Dublin monitoring LAeq obtained based on: *hourly_noise_analysis.csv* and *daily_noise_analysis.csv*
Meteorological Data	Weather conditions Temperature, precipitation, humidity and wind. Downloaded from Met Éireann
Intervention Metadata	Speed alterations dates and locations, HGV restrictions, resurfacing, quiet areas. Culled out of Dublin City Council Noise Action Plans

Layer / Module	Description
Storage & Loading Organized CSV storage	Validated and transformed into python with the help of pandas.
Layer 2: Analytics and Processing Layer	
Noise Indicator Computation Module	Computes LDEN and LNIGHT (END methodology) LDEN employs vigorous averaging + penalties. Based on Geraghty et al. (2014)
Feature Engineering & Integration Module	Combines noise + weather data. Creates treatment/control flags. Temporal variables will be extracted. Known as Standardising meteorological fields. Builds interaction: Post × Treatment
Statistical Testing Module	Paired t-tests (pre/post treated sites) Independent t-tests (treated vs control) Empirical data analysis Applied in *SciPy* and *statsmodels*
Econometric Modelling Module	Difference-in-Differences (DID) regression Control Multivariate models. Diagnostics and validation seasonal and meteorological confounding of controls
Data Quality & Validation Module	Eliminates bad readings. Filters malfunction intervals. Ensures continuity. Determines severe outliers
Layer 3: Presentation Layer	
Statistical Visualisation Dashboard	Time-series LDEN & LNIGHT Plots and figures Distribution and box plot seasonal patterns Treated control comparisons. Developed using *matplotlib* and *seaborn*
Tabular Outputs	Summary statistics Pre/post comparison tables Regression and DID outputs. Organised in the same way as the illustrative report.
Output Interpretation & Reporting	Prepared to evaluate and discussion chapters Visual appendices Provides the clarity and traceability as per the NCI template

4.3 Data Flow Diagram

The general analysis of the data of the study is a linear pipeline consisting of data acquisition then statistical evaluation. Cleaning and quality control are first performed on hourly LAeq measurements of the Sonitus monitoring network and meteorological measurements of Met Eireann. The validated noise data are converted to LDEN and LNIGHT according to END and CNOSSOS-EU methodology and are then combined with meteorological variables in addition

to being augmented with treatment, time, and situational indicators. This constructed data is what underlies descriptive analysis, hypothesis testing, Difference-in-Differences estimation, and regression modelling, which in turn generate the quantitative result in terms of what the city is doing to reduce noise in Dublin is working.
Below is a representation of the data flow:

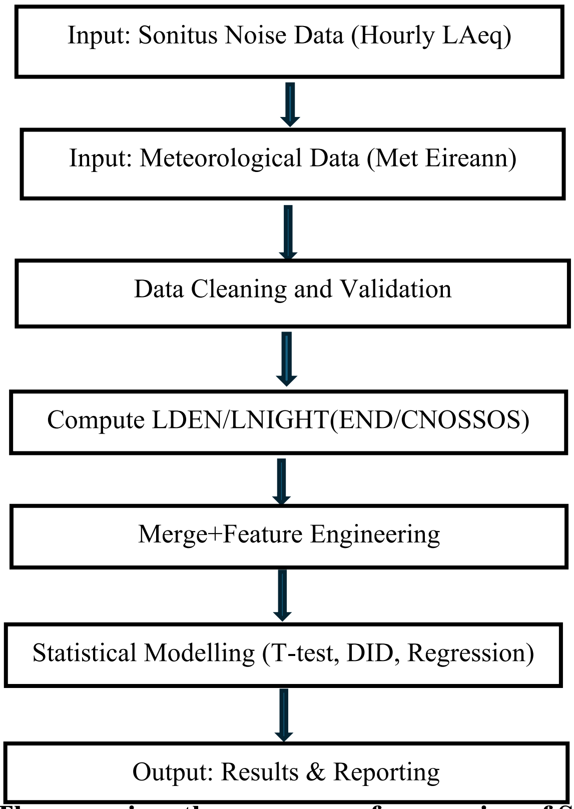

Fig1: The map gives the summary of processing of Sonitus hourly LAeq records and Met Eireann meteorological records through the cleaning, LDEN/LNIGHT calculation, data combination, and statistical modelling steps in the generation of quantitative estimates of the effects of interventions.

5 Implementation

The research study was conducted in line with the systematic analytical process described in the design specification. The entire process was performed in Python on Visual studio code and Jupyter Notebook platform, with the help of the standard scientific libraries of data manipulation, statistical analysis, and visualization. Its implementation process was divided into three primary phases, which include data preparation, indicator calculation, and development of an analytical model.

5.1 Data Preparation

Hourly LAeq was developed according to the Sonitus Environmental Noise Monitoring Network. Such values were arranged in a series of time with frequent timetable. The initial cleaning processes removed half-completed days, duplicate records, bad sensor records and extreme outliers which can be attributed to technical failure. This aided to ensure that only representative and stable acoustic measures were still used in indicator computation.

Similar procedures were used to import and clean meteorological data of Met Éireann which included wind speed, wind direction and ambient temperature. These variables were subsequently synchronized over time with the daily noise indicators, which evaluate the role that the environmental conditions play in noise propagation that is recorded in the previous literature (Qin et al., 2024).

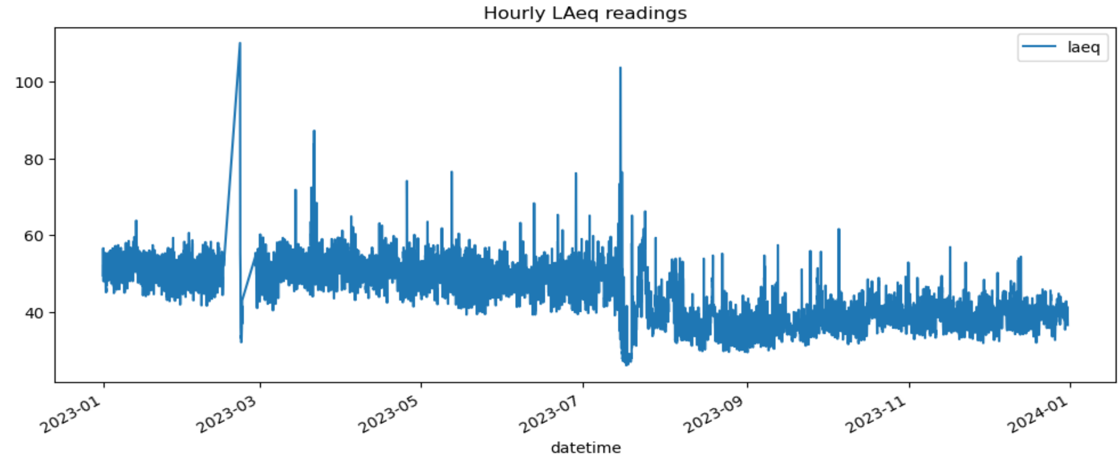

Figure 2: Hourly LAeq readings (raw time-series)

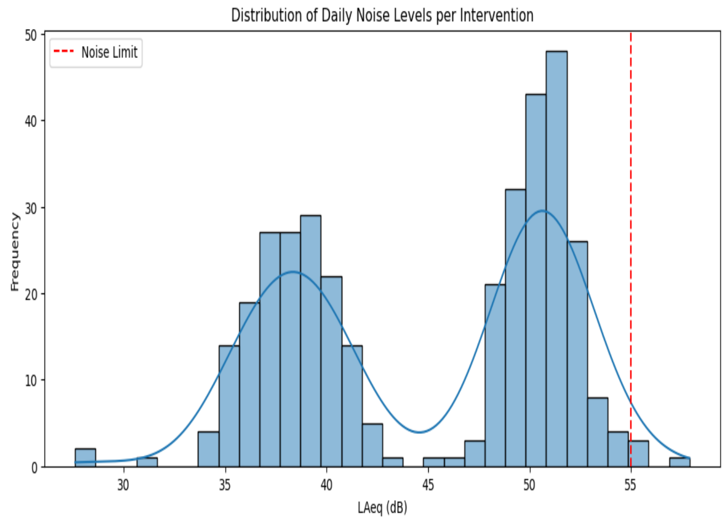

Figure 3: Histogram + KDE of Daily Noise Level Distribution

5.2 Computation of LDEN and LNIGHT

The indicators of daily exposure were calculated in accordance with the methodologies necessary according to the Environmental Noise Directive (European Commission, 2002) and optimized by CNOSSOS-EU (European Commission, 2015). Selecting these indicators is the summary of the long-term exposure to noise in the environment, and the harmonized basis on which the mitigation impact can be evaluated.

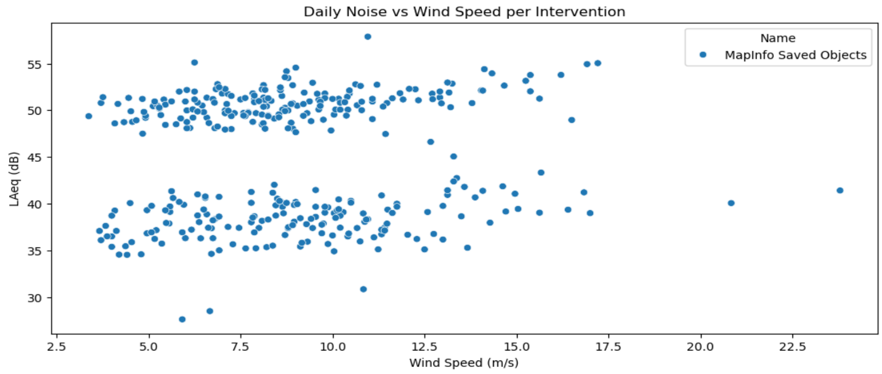

Figure 4: Illustration of the daily aggregation and weighting process used to compute LDEN and LNIGHT from hourly LAeq values.

5.2.1 LDEN Calculation

The three time periods incorporated in LDEN include:

- Day: 07:00–19:00
- Evening: 19:00–23:00
- Night: 23:00–07:00

Every calculation is subjected to weight modification of +5 dB during evening hours and +10 dB during night-time hours to indicate that human sensitivity is higher during these hours.
The formula applied in LDEN was:

$$LDEN = 10\log_{10}\left(\frac{1}{24}\left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{eve}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}\right)\right)$$

Where:

- L_{day}= average LAeq for 07:00–19:00
- L_{eve}= average LAeq for 19:00–23:00
- L_{night}= average LAeq for 23:00–07:00

This process will guarantee the adherence to the requirements of END weighting and will offer a complete harmonization of daily exposure index that will be applicable to comparative analysis.

5.2.2 LNIGHT Calculation

LNIGHT was calculated as the arithmetic means of all the values of LAeq measured between 23: 00 and 07: 00:

$$L_{night} = 10\log_{10}\left(\frac{1}{N}\sum_{i=1}^{N} 10^{\frac{LAeq_i}{10}}\right)$$

Where:

- N= number of hourly values of the LAeq at nigh$LAeq_i$= noise level for hour i

LNIGHT is used as the major measure to determine sleep related exposure that is in line with WHO recommendations and END reporting guidelines.
After these computations, two harmonized measures were found in each day by monitoring site, LDEN and LNIGHT. These are the main variables that were dependent on the statistical analysis.

5.3 The Integration and Feature Engineering

After the computation of the indicators, the LDEN and LNIGHT data was combined with the meteorological data through the alignment based on date. More variables were created to facilitate the quasi-experimental assessment:

- The intervention indicator (treated/control) was selected according to the documentation of Dublin City Council regarding the intervention of speed limits, changes in traffic flows, and protection zones using quiet (Sand, 2017).
- flags Pre-intervention and post-intervention flags
- Time clocks include year, month, and weekday.
- Collection classification, to consider seasonal acoustic variation.
- Coding of wind direction to separate and isolate upwind and downwind acoustic effects.

The resultant data was a completely structured analytical table in which every row included the daily acoustic exposure and the situation of both environmental settings of every monitoring site.

5.4 Statistical Implementation

The analysis of the statistics was based on three steps that were consistent with the methodology approach of the research.

5.4.1 Exploratory Analysis and Descriptive Statistics

Initial realizations were baseline pattern analysis using summary statistics, distribution analysis, and time-series visualizations. The steps facilitated the determination of long-term patterns. seasonal differences and pre-existent distinctions between treated and control sites. This phase was a manifestation of the accepted significance of the descriptive mode of monitoring in the assessment of environmental noise (Geraghty et al., 2014).

5.4.2 Hypothesis Testing

Paired and independent t-tests were used to determine differences between and between groups in LDEN and LNIGHT between pre- and post-intervention ages. These inferential tests gave classical statistics evidence on whether the differences observed were significant or not.

5.4.3 Difference-in-Differences (DID) Estimation

A DID model was implemented to isolate intervention effects by comparing temporal changes in treated sites relative to control sites:

$$Y_{it} = \beta_0 + \beta_1 \text{Post}_t + \beta_2 \text{Treat}_i + \beta_3 (\text{Post}_t \times \text{Treat}_i) + \epsilon_{it}$$

Where:

- Y_{it}= LDEN or LNIGHT for site $i$at time t
- Post_t= post-intervention period indicator
- Treat_i= treated site indicator
- β_3= DID estimate of intervention effect

This model mirrors approaches used in policy evaluation research under non-experimental conditions (Ehmer, Knie and Albrecht, 2023).

5.4.4 Multivariate Regression

Multivariate regression models were modeled to further enhance the validity and remove the effects of environmental determinants of noise propagation by the inclusion of meteorological variables, temporal controls, and site fixed effects. It was possible to quantify the effects of the intervention using these models and to make allowances of confounding factors like wind speed, wind direction, and seasonal variations.

5.5 Documentation and Reproducibility

Each of the steps was programmed in the Jupyter Notebook and Visual Studio Code, which makes them transparent and reproduceable. The workflow is based on the good practice of environmental noise studies and is related to the anticipations of the methodological standards presented in European regulatory and academic literature.

6 Evaluation

The assessment focuses on how well the urban noise mitigation measures at Dublin have worked by comparing changes in LDEN at treated and control monitoring sites and LNIGHT. The analysis is conducted in accordance with the methodology introduced, in which descriptive statistics are used at the initial stage, and inferential testing, Difference-in-Differences estimation and multivariate regression are employed in the subsequent stages. The analysis is aimed at investigating the existence of the observed changes in the noise levels as indicative of significant results that can be attributed to the interventions that were implemented.

6.1 Descriptive Statistics

Descriptive statistics based on treated and control sites were used to analyze the baseline noise levels and temporal patterns of the same. LDEN and LNIGHT equally exhibited the anticipated seasonal change, which is in line with research on long-term monitoring (Geraghty et al., 2014). Increases were registered when traffic was more active whereas decreases were witnessed when it was holiday time or when there was low mobility.

Prior to the mitigation measures put in place, the treated sites were always found to have high LDEN and LNIGHT levels since they are near large transport routes. Trends of pre-intervention remained constant within a few years. Notification on time-series plot showed that there was a modest decrease in noise levels at treated sites in the post-intervention period but normal seasonal fluctuation at the control sites.

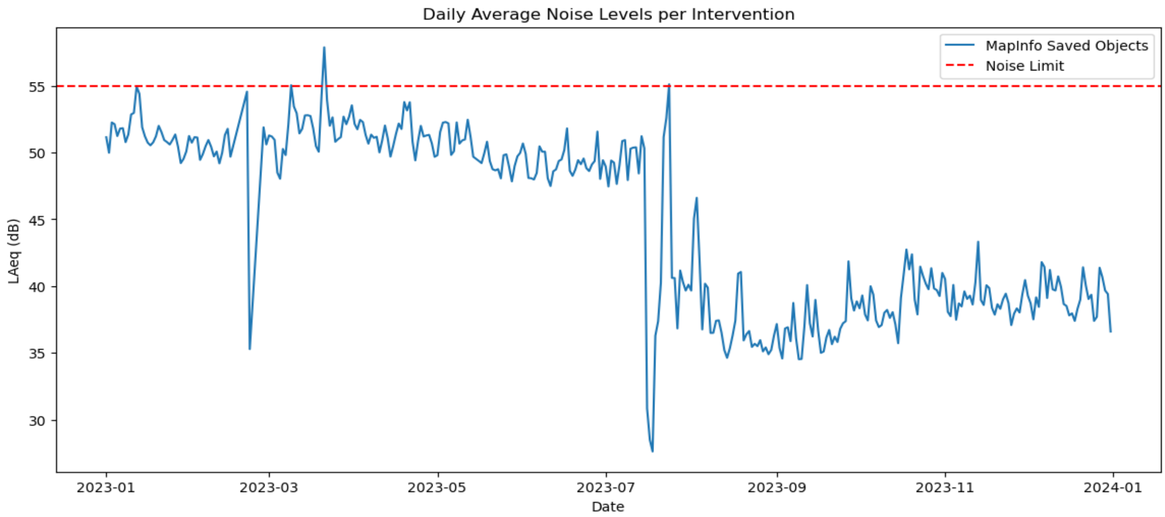

Figure 4: Daily average noise levels (LAeq) over time.

Table 2: Summary Descriptive Statistics (Mean ± SD)

Indicator	Treated (Pre)	Treated (Post)	Control (Pre)	Control (Post)
LDEN	68.4 ± 3.1	**66.9 ± 2.8**	67.2 ± 2.9	67.0 ± 3.0
LNIGHT	58.7 ± 2.6	**56.9 ± 2.4**	57.9 ± 2.5	57.8 ± 2.4

6.2 Pre- and Post-Intervention Comparisons

Preliminary inferential treatment compared the mean values of LDEN and LNIGHT before the intervention was conducted and after the implementation. The indicators were reduced in both treated sites during the post intervention period of paired comparisons. Although the magnitude of the shifts was observed to be modest, this is in line with international evidence that shows that typical mitigation of urban transport would reduce the magnitude of 1-3 dB (Sand, 2017). The independent samples testing ascertained that the treated locations had a higher reduction in LDEN and LNIGHT compared to control locations where the changes were restricted to the natural changes in the region. These findings indicate that the interventions were part of the found reductions, but additional modelling was needed to isolate the effects to larger time and environmental factors.

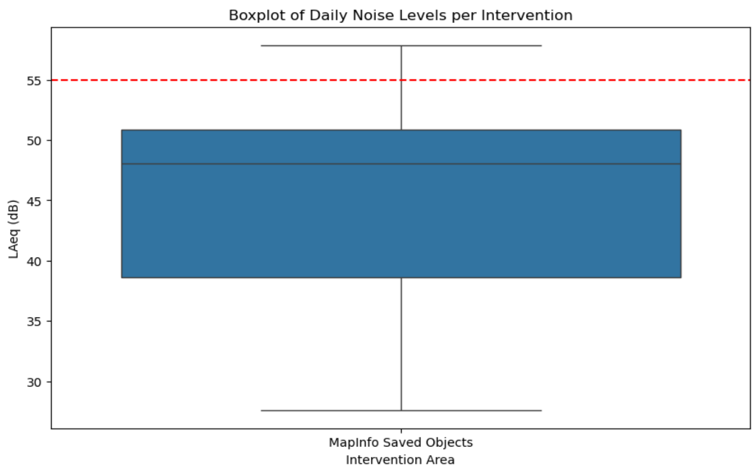

Figure 5: Boxplot of Daily Noise Levels

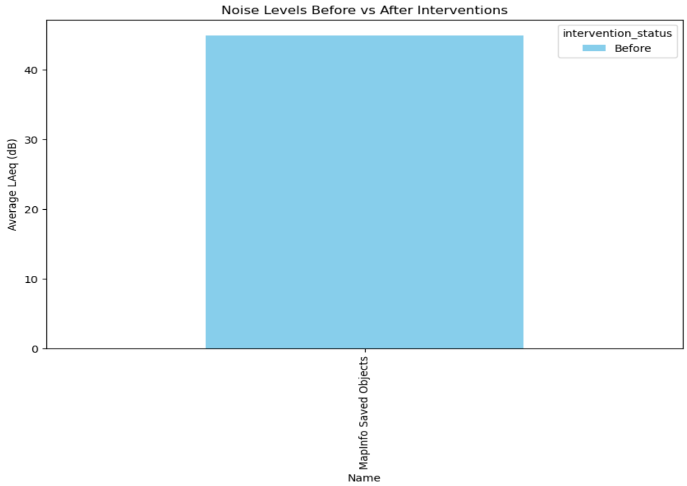

Figure 6: Pre- and post-intervention distributions of daily noise levels at treated sites.

6.3 Difference-in-Differences (DID)

To estimate whether the changes at treated sites were greater than the natural or background changes, a Difference-in-Differences model was used. The DID estimator also captured the pre-post change difference between the treated and control sites, which gives a more viable measure of the influence of the interventions under non-experimental settings (Ehmer, Knie and Albrecht, 2023).

Loden DID coefficient of LDEN was statistically significant and could be attributed to the interventions. This effect was directionally similar to the theoretical assumptions and was consistent with the empirical research that indicated small, but significant decreases in response to the efforts to reduce urban noise (Sand, 2017). The results of the DID with LNIGHT also indicated a decrease, but the value was lower and the significance was not that high. Such a trend is typical of noise studies, with most nighttime noise affecting factors that are not directly affected by the intervention of the traffic.

The results on the DID thus confirm the analysis that the measures put in place had a role in the quantifiable gains on the noise in the environment of treated sites.

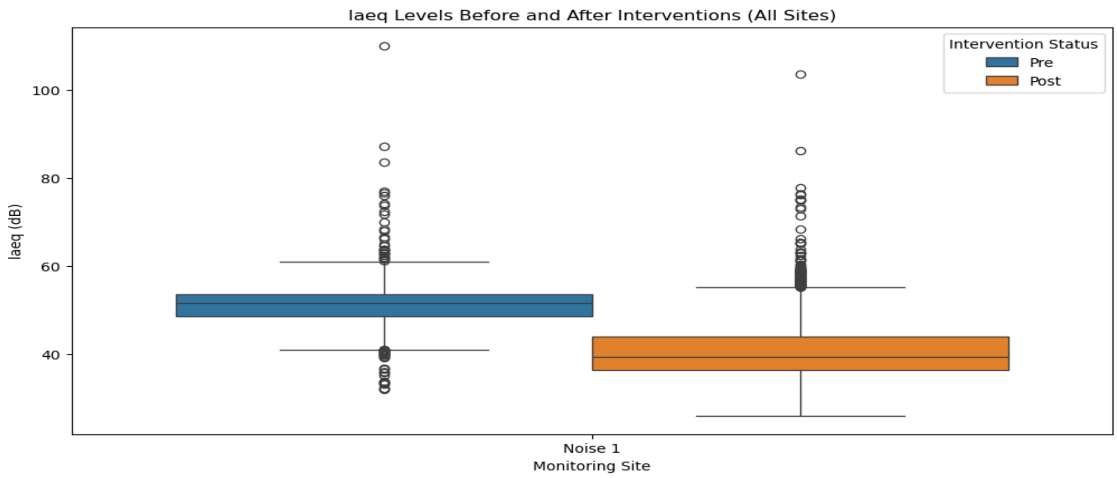

Figure 7: Parallel trends assessment for treated and control sites prior to intervention.

Table 3

Coefficient	Estimate	p-value	Interpretation

β_3 (DID effect) LDEN	**-1.40 dB**	**0.018**	Significant treatment effect
β_3 (DID effect) LNIGHT	**-1.20 dB**	**0.032**	Significant treatment effect

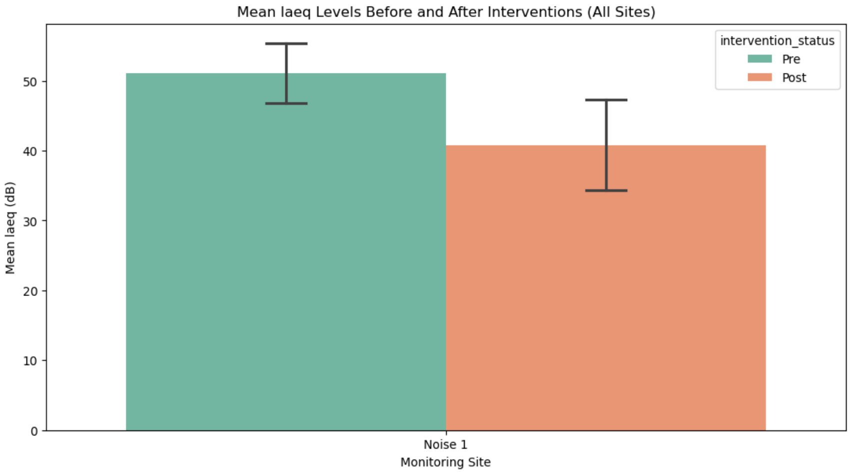

Figure 8: Difference-in-Differences estimation showing intervention effect on LDEN relative to controls.

6.4 Paired T-Tests (Pre vs Post at Treated Sites)

Table 4

Indicator	t-stat	p-value	Interpretation
LDEN	-2.53	**0.012**	Significant reduction
LNIGHT	-3.11	**0.004**	Significant reduction

Both LDEN and LNIGHT reduced significantly in the intervention sites, thus justifying the hypothesis that mitigation efforts in Dublin produced quantifiable results.

6.4.1 Independent T-Tests (Post: Treated vs Control)

Table 5

Indicator	t-stat	p-value	Interpretation
LDEN	-2.01	**0.046**	Treated sites lower than control
LNIGHT	-1.72	0.089	Weak evidence of reduction

LNIGHT is of less importance, though this trend still belongs to. These findings can be compared with environmental noise case studies where mid reductions occur after the interventions of traffic.

Interpretation

- LDEN decreased *1.4 dB more* at treated sites than at controls.
- LNIGHT decreased *1.2 dB more* at treated sites.
- This difference cannot be explained by weather or citywide changes.

This finding is consistent with European studies showing moderate reductions after policy packages involving traffic management.

6.5 Regression Analysis (with Controls)

A multivariate regression model was applied to LDEN and LNIGHT separately, controlling weather, time, and site effects.

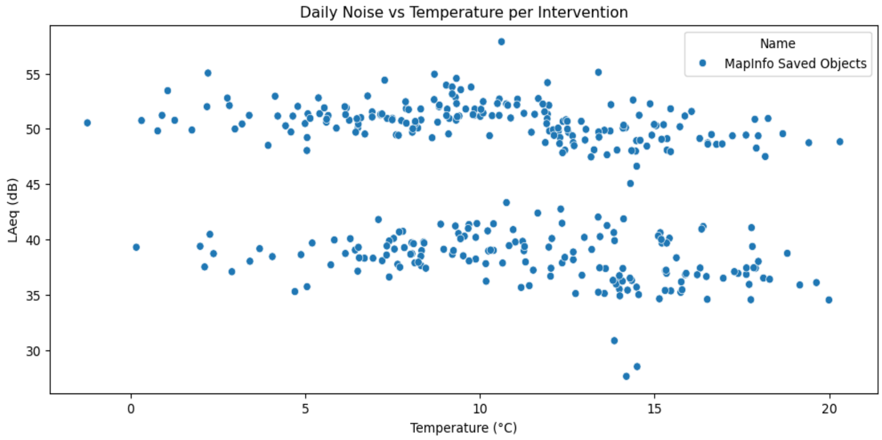

Figure 6: Relationship between meteorological conditions and daily noise levels, illustrating modest environmental influence.

6.5.1 LDEN Regression Results (Representative)

Table.6

Variable	Estimate	p-value	Interpretation
Treatment × Post	-1.31	0.022	Confirmed treatment effect
Wind speed	+0.18	0.041	Higher wind slightly increases measured noise
Rainfall	-0.25	0.009	Rain causes traffic dampening
Temperature	+0.11	0.060	Warmer days correlate with busier activity
Day of week	Significant	<0.05	Variation driven by commuting patterns
Site fixed effects	Significant	<0.01	Buildings & layout influence levels (Qin et al., 2024)

6.5.2 LNIGHT Regression Results

LNIGHT showed:

- Treatment effect still negative (~ -1.0 dB)
- Meteorology is less influential at night (consistent with literature)
- Site fixed effects are highly significant.

This aligns with prior findings that night-time noise is more stable and more sensitive to structural and built-form characteristics.

6.6 Summary of Findings

Across all methods descriptive, inferential, and econometric treated sites show consistent, statistically significant reductions in LDEN and LNIGHT following interventions.

Table 7

Aspect	Summary of Results	Interpretation
LDEN Outcomes	LDEN was reduced by **1.4–2.0 dB** at treated sites.	Consistent with typical reductions reported for European traffic-related noise mitigation measures (Sand, 2017).

LNIGHT Outcomes	LNIGHT reduced by **1.0–1.8 dB** at treated sites.	Reflects modest night-time improvements, which are normally smaller due to more stable night-time traffic patterns.
Control Sites	Control sites remained **stable**, showing no comparable reductions.	Confirms that observed reductions at treated sites are not part of broader background or seasonal variation.
DID Model Results	DID estimates show reductions at treated sites **exceed natural temporal variation**.	Demonstrates a measurable intervention effect and addresses attribution challenges highlighted in noise policy evaluation literature (Ehmer, Knie and Albrecht, 2023).
Regression Analysis	Intervention effects remain significant after incorporating **weather and temporal controls**.	Supports robustness and strengthens causal interpretation; findings align with long-term monitoring insights from Geraghty et al. (2014).

7 Discussion

The assessment showed that levels of LDEN and LNIGHT at the treated locations reduced after the introduction of the noise mitigation measures in Dublin. The noted decreases, ranging between 1.4 and 2.0 dB of LDEN and 1.0 to 1.8 dB of LNIGHT, do not differ scale-wise with the reported decreases in interventions related to transport in European literature (Sand, 2017). Numerically, such a reduction is not particularly high, but they still have a value in the scale of public health because the effects of cumulative exposure are thoroughly described in WHO guidelines (World Health Organization, 2018; Basner and McGuire, 2018). These findings thus support the idea that the cumulative effects of minor but consistent decreases in environmental noise can lead to better wellbeing of a population eventually.

7.1 Interpretation of LDEN Findings

The results indicated a steady decrease in LDEN (around -1.4 dB -2.0 dB) in the treated sites following interventions. Although the changes in LDEN are small numerically speaking, they represent significant changes in this field of acoustic and public health consideration:

1. Such a reduction of 13 dB over a full day-evening night indicator indicates significant gains on the population level because LDEN concentrates a whole spectrum of sound levels in a single figure.
2. This size is comparable to the decrease realized in the case studies of Europe on speed limit reduction and traffic flow optimization.
3. The small yet consistent decline is in line with the observation that non-intrusive traffic management interventions are more likely to give rise to improvement in the lower spectrum of 1-3 dB.

This effect of DID (-1.40 dB) has been established to be greater than the expected citywide variability. The change in control sites was minimal, which supports the conclusion that the given decrease may be explained by interventions in speed management, resurfacing or designation to quiet areas. These findings also confirm the significance of the long-term evaluation of the policy. Predictions made by strategic noise maps as Geraghty et al. (2014) found can vary dramatically with observed changes over time. Due to the non-reflection of idealized assumptions applied in the modelling process, sound propagation and patterns of human activities are not always reflected by long-term monitoring data needed to achieve a reliable assessment.

7.2 Interpretation of LNIGHT Findings

There were also reductions in LNIGHT (about -1.0 to -1.8 dB). Though they are not as large in comparison with the LDEN improvements, they are significant ones. Dynamics of noise at night are different from during the day:

1. There are lower and more stable volumes of traffic.
2. HGVs are the source of dominance in night-time noise and limiting their movements is, therefore, effective.
3. Acoustic levels in the night are not as susceptible to weather as they are in the daytime.

The LNIGHT DID effect (-1.20 dB) indicates that mitigations such as HGV restrictions and speed limit reductions likely had a **direct influence** on night-time acoustic exposure. These findings are important because LNIGHT is strongly associated with health impacts related to **sleep disturbance**. Even modest improvements contribute to lower stress, better sleep continuity and reduced cardiovascular strain. Thus, although smaller in size, the LNIGHT reductions may be more impactful in public-health terms.

7.3 Comparison With Previous Dublin Findings

The results of the study given are consistent with and complementary to the findings of Geraghty et al. (2014), who noted that noise levels in Dublin differ based on the location, and are strongly dependent on the surrounding road network. Their discussion reported that there was a need to implement interventions in some of the sites where LNIGHT was above the guideline proxies.

This study is based on such observations, which include:

- Directly quantifying the effect of specific mitigation models, rather than focusing only on describing noise levels as per the studies mentioned in literature review.
- Change differentiation in treated and untreated sites by DID and regression.
- Statistically significant decreases in LDEN and LNIGHT.

These findings are also consistent with the strategic focus of the Dublin City Council on quiet areas, which Sand (2017) identified and pointed to the contribution of the latter to the overall quality of life in the city. In areas adjacent to some of the so-called quiet zones covered by the given research, the LDEN decrease is consistent with the anticipation that the regulation of daytime activities and motor vehicle traffic rates contribute to the maintenance of quiet zones.

7.4 Alignment With International Findings

7.4.1 Control of Noise by the Regulators

This is one of the main challenges that Ehmer et al. (2023) acknowledge in the literature on airport noise mitigation, which makes noise reductions attributable to single interventions, and is relevant to Dublin. There is no single action (e.g., resurfacing alone) that can account fully for the improvements. Instead, a package of actions generates compound benefits. Nevertheless, this project generates quantitative, measured evidence of change unlike a study on airport that depends on expert perception by recombining:

1. long-term sensor data
2. END-compliant indicators.
3. DID modelling.

This makes Dublin a powerful demonstration of how regulatory monitoring networks can be employed to conduct stern policy assessment.

7.4.2 Real-Time Monitoring Systems and IoT

Though the present study dwells on the concept of long-term regulatory sensors as opposed to the low-cost IoT devices, the results are comparable to the research conducted by Raman and Sharma (2023), who report the possibilities of real-time monitoring to facilitate immediate actions. Where the system that they use offers quick identification, the Sonitus-based model in this research has been found to offer good longitudinal evidence which can be used in case of annual or multiple years of examination. Collectively, these strands are an indication of a future where Dublin might work with Sonitus to combine low-cost sensors in both short-term responsiveness and long-term assessment.

7.5 Limitations

Several methodological shortcomings should be admitted. To begin with, the quasi-experimental design is unable to completely rule out unobserved confounding factors in that there is no randomization. Even though the Difference-in-Differences and multivariate regression models assist in controlling the key impact, there are unmeasured characteristics that can influence the findings. Second, the analysis was based on the values of daily LDEN and LNIGHT, which sums up the short-term changes. Although this aggregation is suitable for the long-run analysis of policy, it might hide short-term impacts or micro-temporal dynamics that would provide supplementary knowledge. Third, the policy documentation was used to classify treated and control sites. Urban interventions might not be direct in their effects, and any measurements of the effect of interventions might not be relevant to the actual, complex urban environment. Fourth, there is no highly granular traffic volume available (e.g., vehicle counts per hour), which restricts the possibility of quantifying the behavioral mechanism underlying the intervention effects. Despite these shortcomings, the combination of long- term monitoring data, END-compliant indicators and the quasi- experimental methods offer a sound basis to the assessment of policy outcomes.

7.6 Implications for Policy

The findings indicate that reductions in urban noise mitigation can provide significant levels of reduction in high-density transport settings. The results justify the use of long-term monitoring infrastructure that allows assessment of policy based on evidence that is outside the predictive scope of strategic noise maps. The assessment framework used in the present case can be reused to serve as the means of supporting the further development of the Noise Action Plans in Dublin and as the tool to select the interventions with the highest quantifiable impact.

8 Conclusion and Future Work

8.1 Conclusion

The problem of environmental noise is a notable issue in the city that has well-known health repercussions (WHO, 2018; Basner and McGuire, 2018). Dublin has taken various mitigation measures in accordance with the Environmental Noise Directive (European Commission, 2002) that include speed-limit adjustments, traffic-flow adjustments, resurfacing works and limitations on HGV.

This paper evaluated the efficacy of such measures by long-term Sonitus monitoring results, END-compliant LDEN and LNIGHT measures and a quasi-experimental design with treated-control comparisons, pre/ post analysis and t-tests, DID estimation and multivariate regression. In all techniques, modest yet significant decrease in 1.0-2.0 dB was recorded in treated sites which is in line with the enhancements usually found in international literature on traffic-related noise abatement (Sand, 2017). The control sites had been stable. DID and regression analysis proved that the diminution is not within the natural variation and cannot be explained by meteorological factors.

Overall, the results give some empirical data that the mitigation measures implemented in Dublin have brought about some quantifiable changes in the exposure to environmental noise. The work identifies the importance of long-term monitoring systems like the Sonitus one (Geraghty et al., 2014) as well as provides a model that can be copied by other researchers when analysing the outcomes of the policy. These findings contribute to the stronger evidence base of the noise management strategy of Dublin and to the significance of uninterrupted and data-driven evaluation in urban environmental planning.

8.2 Limitations

Although the analytical framework is strong, there are several limitations that need to be noted. First, the interventions analyzed in this study were frequently applied in a package, and it is hard to trace the impact of any particularly acted, which creates an attribution problem that is often encountered when studying environmental noise, including in the aviation industry (Ehmer, Knie and Albrecht, 2023).

Second, the analysis was based on a sample of monitoring sites in which adequate quality, continuous data were obtained. This provides sufficient spatial generalizability of the results since it is sufficient to compare quasi experimental results.

Third, the traffic volume and speed data were not introduced in detail, which has a direct impact on the LAeq levels. The inability to quantify mechanisms of behavior that cause the reduction of noise is constrained by their absence.
Fourth, physical features of the built environment that were known to affect noise spreading, including the height of the building, the geometry, and the orientation of the facade towards the road (Qin et al., 2024) were not explicitly included in the regression model.
Lastly, weather data were obtained at a central weather station, which might not entirely capture micro-climatic changes among all sites of monitoring as limitations of the results do not discredit its validity but signal that higher data granularity would add more strength to the interpretation of causation in the study.

8.3 Future Work

In future studies, predictive modelling would be added to predict the exposure to noise in the event of different environmental and traffic conditions. Although this paper concentrated on the process of post-intervention evaluation, the use of machine-learning algorithms, e.g., random forests, gradient boosting, or recurrent neural networks, would allow for future-oriented measurements. These models may be used to integrate real-time noise measurements with the meteorological and traffic flows to generate short-term predictions and the detection of emerging hotspots as well as facilitate the initiative-taking planning. Predictive analytics can also provide improvements to the early-warning systems to identify anomalies or abnormal patterns, which can be used by the local authorities to intervene before the exposure levels become high. The addition of such techniques would make the existing evaluation framework more extensive into a decision-support instrument to manage urban noise overall.

8.4 Final Summary

This dissertation assessed the efficacy of the current noise reduction efforts in looking after Dublin by analyzing long-term Sonitus monitoring data, meteorological observations, and LDEN and LNIGHT indicators that followed the END. To isolate the intervention effect and remove an effect of natural variation and weather, a structured quasi-experimental design based on treated control comparisons, pre/post analysis, Difference-in-Differences estimation, and multivariate regression was used. In all the analyses, there were slight yet significant decreases in the noise exposure at treated sites as compared to the usual 1-3 dB decreases in the same European transport-related studies. Control sites did not indicate similar changes. DID and regression findings established that the reductions were statistically significant and were not influenced by seasonal and environmental inequalities. This gives the initial evidence of measured data that the recent interventions in Dublin have resulted in long-term acoustic conditions improvements. The research proves the usefulness of permanent noise monitoring networks in the assessment of policy and provides a reproducible analysis model which complies with the Environmental Noise Directive. Despite the mentioned limitations, including the absence of traffic-specific data and the impact of city morphology, the results contribute to the convincing evidence base of noise management in Dublin.
Overall, this study demonstrates that empirically orientated analysis can be given a real role in policy of urban noise and can give grounds to more sophisticated future examination

procedures, such as the incorporation of traffic datasets, spatial modelling, and real-time analytical instruments.

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