DUBLIN CITY NOISE: MONITORING THE SOUND OF A CITY

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ABSTRACT

Effective management of environmental noise pollution in major cities is a substantial challenge facing many local governments and city authorities. As legislation aimed at protecting citizens from excessive exposure to noise evolves, city managers must employ more advanced methods of understanding and controlling the sources of noise pollution. The European Noise Directive has mandated local authorities in all European cities to evaluate major noise sources and also to share this information with the public. This has led to new approaches to policy generation, which can benefit from the employment of new technologies. Dublin City Council is aiming to become a European leader in the assessment and management of environmental noise. This paper describes a major initiative in Dublin to measure sound levels around the city with a permanent, widespread network of monitoring equipment. Application areas include traffic noise and rail noise monitoring. The data gathered is used in the generation of more effective noise management policy, the refinement of strategic noise maps and also for communicating information to the public on the quality of the acoustic environment at numerous locations around the city. Monitoring stations are deployed at key locations to constantly measure sound levels from major sources of environmental noise. The data collected over the past 4 years has been collated into annual reports, which in turn, informed the generation of the city's latest Noise Action Plan. The information from the monitoring network has also been used to designate the country's first urban Quiet Area, an area of acoustic amenity in the city which will be protected from environmental noise pollution through policy and planning. A dedicated public information website has been launched to provide access to measured data and analysis of the readings in the context of environmental noise management. The analytics software platform is supplemented with educational material intended to make the sound level data more accessible.

1 INTRODUCTION

Over the past decade there has been an increasing realisation of the unwanted effects of noise in urban settings. This has coincided with moves by environmental policy makers to manage exposure to noise pollution. A top-down push from European officials in particular has moved city councils to develop ways of understanding and managing environmental noise levels. Dublin City Council have installed a noise measurement system in order to develop more detailed knowledge of noise levels across the city. The monitoring network combines the latest communication and online technology with reliable sound level measurement standards to balance the needs of acoustic experts and the increasing demand for real time, web based access to smart sensors.

2 URBAN NOISE MONITORING

Populations around the world are continuing to become reliant on large urban developments to sustain economic growth. As a result, more people are moving to cities and large towns. It is estimated that by 2020 over 80% of Europe's population will live in urban areas[1]. This urban growth compounds many of the environmental and transport issues associated with large population centres[2] and requires more sophisticated means of analysing issues and planning sustainable solutions. In the case of a city authority managing pollution this often means a combination of new

regulatory measures and new technology for assessment or control. Environmental noise is a prime example of this process, as the developments over recent years demonstrate. The introduction of the European Noise Directive[3] has raised the priority of environmental noise as a public health issue and has driven the development of more comprehensive national legislation to manage noise as a pollutant[4,5]. In addition to regulatory improvements there has also been considerable improvements in the technology available to environmental practitioners to assess noise emissions in urban settings. Noise mapping software has allowed large scale predictions and visualisations of the influence of transport networks on urban sound levels. This method has been heavily employed in almost all European cities as a means of developing and benchmarking noise control policies. Noise mapping provides regulatory authorities with a practical and scalable method of assessing environmental noise contributions for strategic decision making. In addition to the development of advanced predictive software, there has also been considerable improvements in the technology employed to monitor and report sound levels in urban settings. Noise monitoring networks have been deployed in a number of European cities, either as a supplement to noise mapping or as a more empirical approach to the assessment of environmental pollution.

2.1 Urban Monitoring Networks

There are a number of reasons why city authorities choose to deploy noise monitoring equipment. While noise mapping may provide a solid base for decision making, there are a number of limitations for subsequent steps in the noise assessment and mitigation process. Long term measurements can serve to give a more comprehensive picture of sound levels at key locations of interest. Measurement is particularly useful in scenarios where significant assumptions or simplifications are made in the noise mapping process. Measurement data can be used to validate and refine noise mapping models in areas of uncertainty or points which warrant closer investigation.

One of the primary responsibilities for urban authorities in the Environmental Noise Directive is the communication of information and results that are "*clear, comprehensible and accessible*"[3] through the most appropriate channels. However, no guidance is offered on the definition of what constitutes comprehensible and accessible information, or what qualifies as an appropriate channel. Publishing a strategic noise map along with formulae for decibel calculations and LDEN weightings may still present significant barriers to non-technical audiences[6]. Given the widespread availability of real-time information from multiple sources, there is a common expectation that data should be available to the user online in a dynamic and easily accessible display[7]. The static nature of strategic noise maps do not fully communicate the temporal nature of environmental noise emissions, particularly from transport systems. The EU Harmonica project attempted to address these issues by developing simpler metric for communication noise readings, called a Common Noise Index[8]. This scale uses a linear and graphical indicator to communicate environmental noise quality assessments to non-technical users. The index is suited to long term sound level measurements and is intended to provide a means of communicating information to the public based on the data captured by monitoring networks, removing the technical barriers but based on reliable readings[9]. This project, and subsequent work, highlighted the requirement for a widely accessible and approachable means of displaying information on noise levels.

2.2 Network Features and Requirements

The wider deployment of noise monitoring networks has led to a number of approaches to the capture of environmental noise data. These range from the selective deployment of high end measurement equipment to the use of smartphones for audio capture and tagging. A recent study by Dutch research group TNO compared the various technologies available for urban noise monitoring, grouping systems into four categories based on technical specification. These categories were then compared on five key features which best defined the requirements of an urban noise monitoring network[10]. Figure 1 shows the broad categories chosen and the five key features of a versatile measurement system.

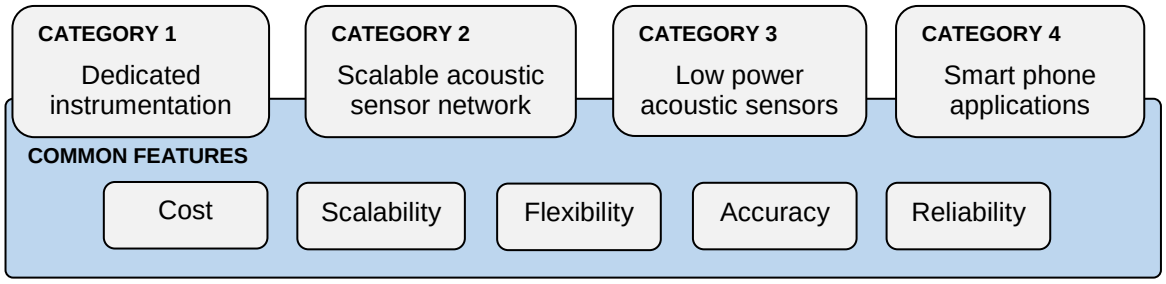

Figure 1: Categories of monitoring equipment and common features

Scalability was defined as the ease at which the network can be expanded to cover further points and provide greater spatial granularity in the measurement results. It is dependent on the network architecture and independent of hardware costs. Flexibility was defined as the ease with which the measurement and reporting set up can be adapted to meet a particular need. The accuracy metric covers the acoustic measurement performance of the equipment, including dynamic range, calibration and stability over time. The reliability feature was then related to the system performance, rather than the long term measurement accuracy, covering system data capture, communications, and robustness of instrumentation. The authors weighted each of these features in order to determine the approach which was most suited to urban noise monitoring. The results of the assessment are reproduced below for illustration[10].

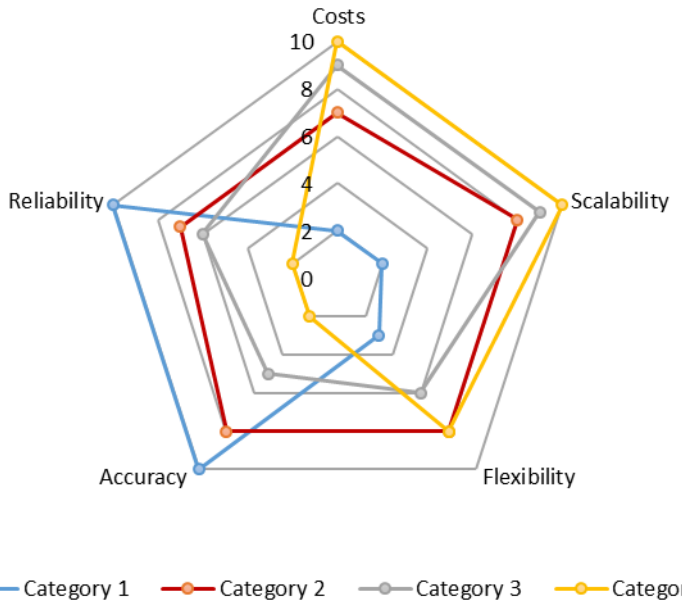

Figure 2: Rating of equipment categories across 5 key feature sets

Figure 2 shows that the Category 2 equipment, characterised by improved scalability and flexibility, provided the best solution for urban noise monitoring. This general category of instrumentation addresses the balance of requirements which must be met when designing, deploying and funding a widespread noise measurement network.

2.3 Monitoring Requirements

The data requirements for urban monitoring are determined by the needs of the city authorities and environmental managers implementing the scheme. In the case of environmental noise assessment and mitigation the primary focus is on long term trends to determine population exposure to sound levels and to gauge the effectiveness of noise reduction strategies. The equipment deployed and the associated reporting tools must be able to gather readings continuously and provide analysis on

the day to day, month to month and year on year patterns which are recorded. This provides the means to assess the influence of seasonal factors as well as local policy on major sources of noise such as transport routes.

In addition to the long term focus, urban monitoring can be used to accurately assess the impact of noise on relatively quiet places or locations of urban amenity. These areas are usually defined in a more subjective manner[11], but provide some relief from environmental noise in a given area. Determining the impact of noise at these locations involves assessing the temporal trends on a more detailed level, generating a requirement for measurement data with finer granularity. Monitoring equipment and the supporting network must provide the flexibility to operate continuously, gathering high resolution readings for detailed analysis, but also provide the ability to assess macro trends across long time frames.

2.4 Smart Cities

The ubiquitous deployment of mobile technology throughout urban centres has driven the demand for real time environmental measurements from widely distributed sources. A proliferation of connected devices has provided opportunities to collect large amounts of data with reasonably small numbers of man hours required to collect and report readings. Noise pollution is no exception, with smart phones in particular providing the potential to collect thousands of geographically dispersed readings each day[12,13].

Smart City projects are being initiated around the world, generally as collaborative efforts by large scale industry partners, city authorities and research institutions. One of the aims of these projects is the establishment of the network architecture and protocols to develop densely deployed sensor networks which monitor environmental parameters and display results through open platforms[14,15]. These sensing platforms routinely include noise as an environmental parameter. Sensors typically consist of low cost units which do not include specifically designed noise measurement hardware or microphones. The readings collected by these networks are of indeterminate accuracy and stability, but cover a wide geographical area with a large number of individual sensors. While the acoustic performance of the equipment may be considerably lower than dedicated measurement networks, these Smart City projects will continue to be deployed on a large scale and will generate large amounts of sound level readings in cities all over the world, which will be openly available to the public.

2.5 Urban Noise Monitoring in Europe

At present there are a small number of well-developed sound level measurement projects active throughout Europe. Each of these has grown from the local or national approach to the implementation of the Environmental Noise Directive where authorities have adopted monitoring as a necessary addition to noise mapping.

One such example of a dedicated sound level monitoring network is deployed in the Paris metropolitan area. The network is managed by the non-profit organisation Bruitparif, which is a dedicated environmental noise observatory. The measurement installations are a mixture of permanent and semi-permanent sites, chosen to monitor noise from road, rail, airports and entertainment activities. Readings are available to the public through a public web platform which provides in depth noise data.

The city of Gdansk have deployed a customised noise monitoring network designed for validation of strategic noise maps[16,17,18]. The system was developed in collaboration with the Technical University of Gdansk and local IT companies, primarily for use by the Environmental Department of the Gdansk Authority who administer the system. The system comprises a number of “simple and cheap” sound level measurement stations which collect and communicate readings on a continuous basis. Technical information on the measurement analysis and partial GIS calculations are available through an online platform.

An EU working group has also established a public information site on Noise in the EU to disseminate information about noise pollution and communicate the information gathered by these various monitoring networks[19]. This project is proposed as a centralised site for detailing urban

noise monitoring projects and noise control initiatives, drawing together the numerous efforts of city authorities to quantify environmental noise levels and make the information accessible to the public.

3 DUBLIN NOISE MONITORING NETWORK

Dublin City Council have deployed a permanent monitoring network to measure and report sound level readings from locations around the city. Similar to efforts in Paris, the goal of the system is to gather accurate sound level data in key locations in order to quantify the long term impacts of major noise sources. In addition to this, the primary aim of the reporting mechanism is to take this large amount of data and deliver clear and accessible information to the public.

3.1 Site Selection

The primary factors in choosing deployment sites were a) location of public amenities such as libraries, b) the presence of a potential noise 'hot spot' indicated by a strategic noise map c) representative locations for major noise sources and d) an area designated as an Urban Quiet Area. Sites were selected so that, in so far as is possible, no single dominant sound source, such as major roads, road junctions, industrial sources etc. would have a disproportionate influence on the sound levels being measured. The sites and the rationale for choosing them are summarised in Table 1 and the map of their locations is presented in Figure 3 (data for numbered sites is presented in the following sections). In total over 40 measurement stations are deployed in the Greater Dublin area, with the subset used for analysis displayed below.

Site	Rationale for choosing site
Drumcondra	Library - opposite public park (Griffith) and close to a national route (N1)
Ballyfermot	Close to a busy route into the city with a high volume of slower moving traffic
Ballymun	Library, next to a school and recreational ground, close to a busy artery
Dublin City Council Rowing Club	Recreational area of natural beauty, adjacent to National Park and close to busy artery
Walkinstown	Close to busy route in residential area
Woodstock Gardens	Retirement village in highly residential area, with high volumes of slow traffic
Navan Rd	Next to National Park on busy national route into city (N3)
Irishtown Stadium	Recreational sports ground close to busy freight route (port traffic)
Chancery Pk	Adjacent to the Luas (Tram) Line
Blessington St Basin	Designated an 'Urban Quiet Area', one of 8 in Dublin in 2013

Table 1: Noise Monitoring Sites in Dublin

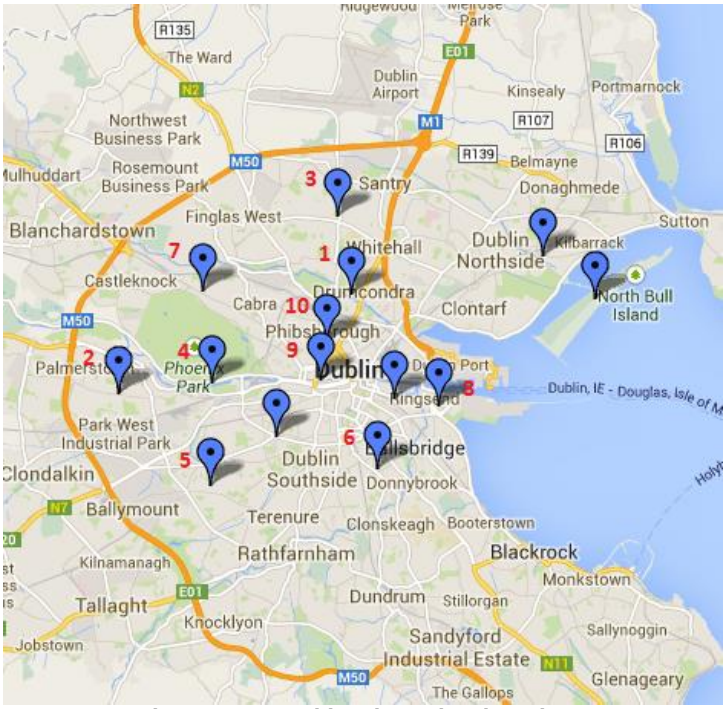

Figure 3: Sound level monitor locations

3.2 Equipment and Measurement Parameters

A Sonitus Systems EM2010 was installed at each measurement site (see Figure 4). This unit is a ruggedised environmental noise monitor designed for long term automated operation. Sound levels and statistics are recorded at user programmed intervals and automatically reported via a GSM link. Each unit is fitted with a Class 2 environmental microphone and noise measurements are compliant with IEC 61672[20]. In this deployment the following A and C weighted statistics were calculated and recorded: L_{EQ}, L_{05}, L_{10}, L_{50}, L_{90}, and L_{95}. L_{EQ} values were measured for 5 minute periods on an ongoing basis. Results are synchronised with an online database every 15 minutes.

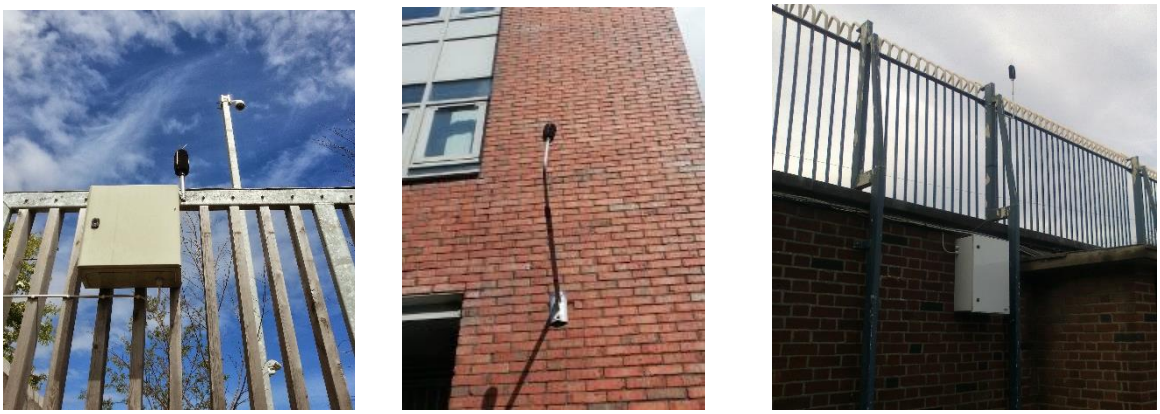

Figure 4: Noise Monitoring Installations

3.3 Architecture and Operation

Each sound level measurement station is designed to operate independently of the network, logging results to on-board storage and then communicating readings automatically to a centralised database. This data push system ensures the scalability of the network as additional units can be added without any further configuration. The centralised management system monitors the performance of each unit, checking data for unusual trends and ensuring that all units are operating continuously. In addition to the administration of the network, the platform also performs automated analysis on the sound level readings to generate information for display through a public website. A block diagram of the monitoring network operation is presented in Figure 5.

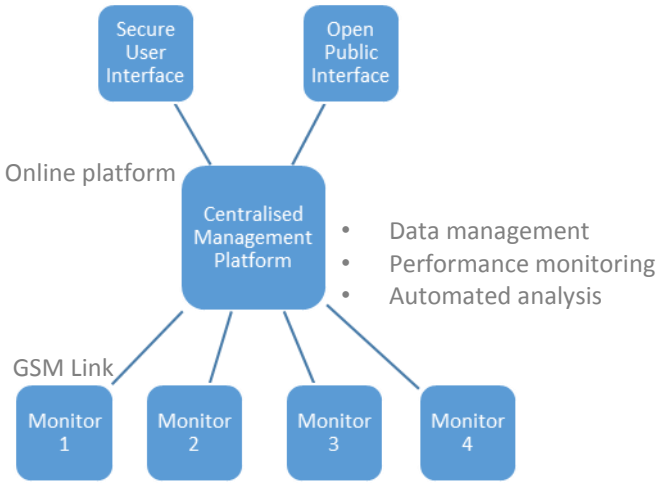

Figure 5: Network operation overview

3.4 Performance Results

Ten deployment sites were chosen for detailed analysis in this paper. These sites are ten of the longest established measurement locations, with some installations present for up to five years. The analysis period chosen covered the twelve months from April 2013 to March 2014. The deployment has proved extremely reliable with all units achieving a high level of data capture; based on a 5 minute measurement period a unit should record 105,210 readings per annum. All but one of the units have achieved in excess of 95% of this number, with most units recording data more than 97% of the time. Missing data points are few and have been attributed to brief power outages and down time for calibration checks. The percentages for each unit are presented in Table 2 below.

Site Name	Site Number	% 24 hour data	% Day time data (7:00-22:59)	% Night time data (23:00-06:59)
Drumcondra	Site 1	98.8	99.1	98.3
Ballyfermot	Site 2	98.4	98.8	97.6
Ballymun	Site 3	97.4	97.6	97.0
Dublin City Council Rowing Club	Site 4	95.8	96.1	95.3
Walkinstown	Site 5	98.5	98.8	97.9
Woodstock Gardens	Site 6	97.7	97.9	97.3
Navan Rd	Site 7	96.4	96.8	95.4
Irishtown Stadium	Site 8	93.9	94.2	93.3
Chancery Park	Site 9	98.8	99.1	98.3
Blessington St Basin	Site 10	96.7	97.0	96.1

Table 2: Reliability of Monitors

4 PUBLIC INFORMATION PLATFORM

Public participation and information sharing is a central point in the Dublin Noise Action Plan. Increasing public awareness of environmental noise is considered to be a key step in the effective implementation of noise mitigation policy. Dublin City Council has an ongoing policy of sharing datasets through appropriate online channels. Accordingly, an open, web-based platform was developed to share the information derived from the continuous sound level readings. The design and content of the website were refined through continuous user feedback and detailed research into information presentation for non-technical users[21]. This approach was centred on the definitions within the Environmental Noise Directive, aiming to deliver information which is clear, comprehensible and accessible.

4.1 Turning Data into Information

The public information site is hosted at www.dublincitynoise.ie. The website is structured to allow visitors to access information in increasing levels of detail, obtaining an overview of the monitoring network and drilling down into statistics and results at graduated levels. Each layer of information is supported with explanatory material to frame the values and a non-technical educational section is also provided to explain key concepts. Examples of information presentation are shown in Figure 6.

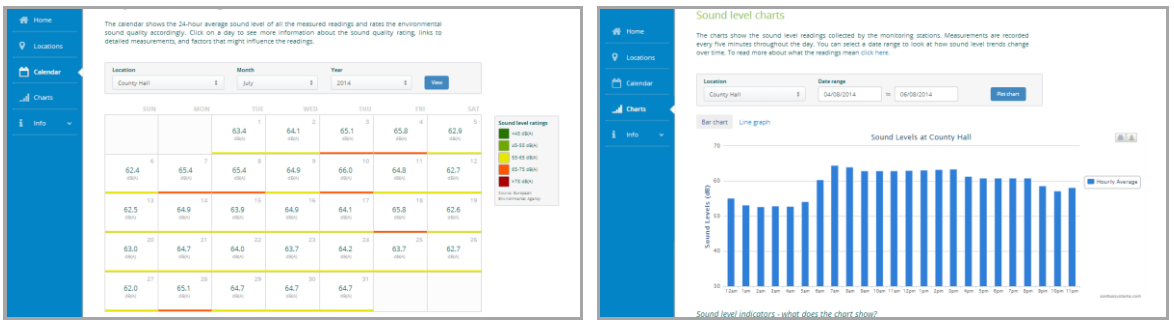

Figure 6: Online user interface

The analytical software which derives the information displayed on the site is automated and updates the website as new data is received from monitoring stations. Users can access a map of the network, view a monthly overview of environmental noise ratings at each site and drill down to hourly averages and individual readings. Each section of the website provides further insight into the temporal variations of environmental noise across months, days, and hours. The information section also provides an overview of the measurement concepts involved in recording sound level readings, presented in a non-technical manner. In contrast to the Harmonica and Noise in EU websites, no new sound level indicators were used, instead using decibel readings presented in context, to meet user expectations and avoid the need for introducing technical material or new, specifically designed concepts.

Information generated by the platform is automatically shared through social media channels. The open data is also shared with the European Environmental Agency NoiseWatch[22] platform to disseminate the results to a wider audience.

5 DATA REPORTING

The data gathered by the monitoring network is used internally by the City Council to gauge the changes in environmental noise levels year on year, as new policies are developed and implemented. Continuous monitoring of sound levels allows direct comparison of annual and seasonal variations at measurement sites. The reporting capability of the monitoring system allows the Council to verify noise mapping calculations, refine actions plans and assess acoustic quality at locations of interest. During 2013, eight areas within Dublin were designated as urban Quiet Areas,

which are to be protected from excessive environmental noise in the future. The first of these sites was Blessington Street Basin, a small park and reservoir where sound levels had been monitored for a number of years in order to accurately assess the influence of local noise sources. Seven similar sites which matched the criteria of the Basin were then selected for protection[23].

An analysis of the readings from the time frame outlined in section 3.4 shows that the sound levels at the site were relatively low compared to other urban locations. Table 3 shows the proportion of the time that sound levels were exceeded at each measurement site. This analysis can be used to gauge the relative quietness of each location.

L_{EQ} dB(A)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
>35	100	99	100	100	100	100	99	99	100	100
>40	99	99	100	100	97	94	99	97	100	99
>45	93	98	100	97	86	67	98	84	100	90
>50	74	89	98	86	68	30	87	53	99	60
>55	47	62	88	52	33	6	44	17	91	19
>60	10	14	69	10	6	1	5	6	61	4
>65	1	1	24	1	2	0	0	3	5	1
>70	0	0	0	0	0	0	0	2	0	0
>75	0	0	0	0	0	0	0	1	0	0
>80	0	0	0	0	0	0	0	0	0	0

Table 3: Proportion of time sound levels are exceeded (24 hours)

The figures indicate that Site 10, Blessington Street Basin, is considerably quieter than many other sites, with sound levels consistently lower over the 12 month period, only exceeding 55dB(A) 19% of the time. These empirical results have allowed the City Council to reinforce considerations such as the location of the site in the city centre, public usage and visual amenity and designate the site as a Quiet Area for environmental protection.

L_{EQ} dB(A)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
>35	100	100	100	100	99	99	100	100	100	100
>40	100	100	100	100	91	84	100	92	100	98
>45	98	95	100	92	62	40	97	58	100	72
>50	78	70	94	61	24	11	69	28	98	24
>55	32	19	65	18	8	2	18	8	73	4
>60	5	1	15	1	3	0	1	4	16	1
>65	1	0	1	0	1	0	0	3	1	0
>70	0	0	0	0	0	0	0	2	0	0
>75	0	0	0	0	0	0	0	1	0	0
>80	0	0	0	0	0	0	0	0	0	0

Table 4: Proportion of time sound levels are exceeded during the night

The Dublin Noise Action Plan proposes a number of thresholds for assessing the need for action at a given site. A nighttime noise level of <50dB(A) is proposed as desirably low and a level of >55dB(A) as undesirably high. These guideline values help to determine whether a site requires protective action, mitigation measures or no action at all. Table 4 displays the proportion of time that measured values for L_{NIGHT} exceeded various thresholds. Nighttime values at Site 6 were the lowest across the measurement network. Levels exceeded 55dB(A) only 2% of the time. This

retirement village, although not a public amenity, is subject to desirably low levels and can now be protected from future increases in traffic noise levels. The measurement network provides objective results available to the City Council on the effectiveness of their noise management measures.

6 DISCUSSION

The network has proven to be very reliable with all units achieving 94% data capture and upwards. There are short outages for calibration checks and maintenance which are unavoidable. Consequently the data set is extensive and there are no significant periods of downtime, leading to a high level of confidence in the measurements. While only 10 units have been chosen for analysis in this paper the performance is representative of the entire network.

The primary shortfall of the predictive noise mapping technique is the large amount of data inputs that are needed. In a dense urban area these are often estimated, using average speed limits and traffic volumes. This tends to give predictions that are uniform across numerous similar areas where accurate data is not available. The analysis shows that in reality there is significant variance between areas which might otherwise have been classified as similar locations. Using the long term measurement network provides both a means for refining the noise mapping model and more accurately assessing the noise exposure levels in the area.

Dublin City Council have used this extensive data over a number of years for generating annual reports aimed at examining the long term trends at measurement sites of interest. The findings of these reports have been used to designate Quiet Areas for protection from environmental noise. While sound levels across the network are reasonably high, in particular for the L_{NIGHT} readings, the monitoring network has allowed the City Council to identify the loudest and quietest locations where noise management efforts will be of greatest benefit.

The public information platform serves as the primary means of communicating information to the public. Readings are available in real time and automated analysis allows users to view quality ratings and general trends in the sound level measurements at each site. The readings are supported with non-technical material explaining the acoustic and environmental considerations involved in sound level measurement. The readings are automatically shared through social media channels and similar information platforms operated by other European groups. The public website is central to the City Councils effort to avoid the simple sharing of data silos and provide accessible and understandable information to the general public.

7 CONCLUSION

Cities throughout Europe and around the world are developing more specific and refined policies for managing noise as a pollutant. Noise monitoring programs are becoming increasingly common as authorities balance the strategic nature of noise mapping with the detailed empirical results of measurement campaigns. Technology trends for urban monitoring are leading towards dense deployments of networked devices sharing a range of environmental parameters with citizens. These smart networks will contain a range of technologies of varying quality and accuracy. The technology selection by environmental managers will involve balancing project requirements of scalability, accuracy and cost with user expectations of ubiquitous data.

Dublin City Council have deployed a network of noise measurement stations to accurately assess sound levels at important sites and communicate results to the public. The deployment has delivered both time and cost savings for the Council compared to manual surveys and has delivered large amounts reliable data on actual sound levels throughout the city. The high data capture rate throughout the network has allowed for year on year comparisons and assessment of noise trends. While the readings indicate that a high proportion of sites experience undesirably high nighttime noise levels, the measurement campaign has clearly identified sites which should be protected from increases in environmental noise. Achieving desirably low environmental noise levels throughout the city may prove to be a challenge, but the detailed information from the measurement network has enabled the authorities to evaluate long term trends and focus efforts where they are expected to have the greatest benefit. The effectiveness of policy measures will continue to be evaluated

each year and public engagement will be measured on an ongoing basis. The noise measurement network will be integrated with future intelligent sensor deployments by the City Council, in order to ensure that noise is at the fore of environmental policy and reporting.

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