

# Environmental Noise Prediction, Noise Mapping and GIS Integration: the case of inner Dublin, Ireland

## Murphy, E., Rice, H.J. and Meskell, C.

Department of Mechanical and Manufacturing Engineering, Parsons Building, Trinity College, Dublin 2, Ireland

Email: murphyen@tcd.ie

#### Abstract

The recent Environmental Noise Directive (END) of the European Union (EU) requires that noise maps and action plans are compiled for agglomerations with a population greater than 250,000 individuals. This paper reports on research conducted to predict and map road transport noise for a study area in central Dublin. Noise emission levels were calculated for  $L_{den}$  and  $L_{night}$  using the Harmonoise prediction method as recommended by the European Union. Emphasis was placed on integrating noise data with a Geographic Information System (GIS). The results demonstrate that using a GIS to integrate noise data with other available spatial data can enhance the accuracy and visualisation of noise maps. In this regard, 3D noise animation was undertaken with a view to increasing public awareness in relation to environmental road transport noise. The results suggest that GIS based noise mapping has the potential to be more effective at informing environmental policy decision-making, particularly in terms of the actions to be taken as a result of excessively high environmental noise levels. The research also demonstrates that noise maps are visually sensitive to different methods of data interpolation. This is something which has not been explored to any great extent in previous noise mapping studies.

#### **1.0 Introduction**

Environmental noise is defined as unwanted or harmful outdoor sound created by human activities. In recent years, environmental noise has become a major consideration in EU environment policy. This is due to a number of factors including the increasing number of individuals living in urban environments, increasing demand for road travel and the rise of Green politics in many EU states. In fact, as a measure of the growing concern in relation to this issue, problems with noise are often rated at the highest level together with global warming in some EU states [1]. Research suggests that that prolonged exposure to high noise levels leads to sleep deprivation, reduced productivity as well as poor cognitive performance in children. Moreover, exposure to noise may have negative impacts on the psycho-physiological systems, can damage hearing and is a serious cause

of annoyance [2]. In urban areas, infrastructure is the most significant source of environmental noise. Clearly, therefore, there is a need for continuous monitoring of noise emissions, particularly where urban traffic flows are greatest.

This paper reports on research conducted to predict environmental road transport noise in inner Dublin. The study area comprises approximately one square kilometre in the centre of the city within the vicinity of Trinity College Dublin. Transport noise emissions were calculated using Predictor 5.0 software. Noise emission values were calculated in decibels for  $L_{den}$  and  $L_{night}$  using the Harmonoise calculation method as recommended by the European Union (EU). Emphasis was placed on integrating noise data with a Geographic Information System (GIS) in order to improve data management, enhance visualisation and ultimately improve the accuracy and efficiency of noise mapping studies.

## 2.0 The Policy Context

In 1993, the Fifth Environmental Action Programme of the European Community (EC) established as a basic objective that individuals should not be exposed to noise levels which may endanger their health and quality of life [3]. The document established a number of targets for noise exposure levels to be reached by the year 2000 while a subsequent proposal reviewing the Fifth Action Programme announced the development of a noise abatement programme to meet those targets.

The EU Green paper on Future Noise Policy [4] followed in 1996 and it was considered to be the first step in the development of a noise abatement programme. The aim of the document was to stimulate public discussion on a future approach in relation to EU environmental noise policy. It also outlined a framework for the assessment and reduction of noise exposure and the future action to be taken in order to reduce noise emissions from various sources.

In 1999 the World Health Organisation (WHO) produced a seminal guideline document relating to environmental noise – *Guidelines for Community Noise* [5]. It addressed such issues as the measurement, health implications, guideline values and management of environmental noise. According to the document, 40% of the population of European Union (EU) countries are exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) during day-time, the level above which prolonged exposure is considered to have adverse health effects; the corresponding figure for night-time is 30%. Taking all exposure to transportation together, the WHO estimated that approximately 50% of EU citizens live in zones of acoustical discomfort. Bearing this in mind, the WHO document sought to "consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in non-industrial areas" [5, iii]. Much of this was to be achieved through environmental noise prediction calculations and environmental noise mapping.

In 2002, the European Parliament and Council adopted the current European Noise Directive (END) [6]. The primary aim of the Directive is to provide a common basis for

addressing the problem of environmental noise across EU member states. The use of common noise assessment methods plays a key role in this regard. Assessment of exposure to environmental noise is to be achieved using 'strategic noise maps' for major roads, railways, airports and agglomerations using the harmonised noise indicators  $L_{den}$  (day-evening-night equivalent sound pressure levels) and  $L_{night}$  (night-time equivalent sound pressure levels). Informing the general public about noise exposure and its effects is a further objective of the END. Member States are expected to produce action plans based upon the results of the noise mapping exercise. It is expected that, where necessary, environmental noise will be prevented and reduced in accordance with the results of the noise mapping analysis and that noise quality will be preserved in areas where is considered to be good.

Taken together, the recent policy documents relating to environmental noise represent a significant increase in the priority of noise abatement in world and EU environmental policy. The current research can be placed firmly within the context of the foregoing policy documents.

## 3.0 Study Area and Objectives

For this research, environmental road transport noise was predicted for approximately a one square kilometre area in central Dublin. The study area is centred on Trinity College Dublin. The area was selected because the College is representative of a quiet area in the central city and thus provides a striking contrast with the surrounding area beyond the college boundary where large volumes of traffic are generated.

The primary objective of the research was to integrate noise prediction calculations with a Geographical Information System (GIS). This was done in order to improve the accuracy of noise maps particularly in terms of data interpolation, as well as offering enhanced visualisation opportunities and a centralised data management facility which is capable of integrating various types of spatial data into noise mapping studies.

#### 4.0 Noise Prediction Calculations

#### 4.1 Data Collection

Noise prediction calculations are highly data intensive and often require data from a number of public and private agencies. In addition, datasets often lack the level of detail required by most noise prediction calculation models. This research was no different. The data included in our noise calculations and the agency that supplied the data are displayed in Table 1.

Traffic Flow information was supplied by Dublin City Council for a six month period from January to June 2005. The traffic data used was derived via the SCATS system and provided detailed 24-hour traffic flow information for the period. Traffic composition data was unavailable. As a result, information relating to the percentage of Heavy Goods Vehicles (HGVs) along the links in the study area was acquired via the Dublin Transportation Office (DTO) traffic simulation model.

Data	Agency	Public/Private	Data Format
Traffic Flows	Dublin City Council	Public	N/A
<b>Road Polylines</b>	Dublin City Council	Public	<b>GIS</b> Polylines
<b>Building Polygons</b>	Dublin City Council	Public	<b>GIS</b> Shapefiles
<b>Building Heights</b>	Mapflow	Private	<b>GIS</b> Shapefiles
Aerial Photography	Ordnance Survey	Public	Raster Dataset
Meteorological Info. <sup>1</sup>	Met Eireann	Public	N/A

#### Table 1. Noise Prediction Calculation Data

#### 4.2 Model Assumptions

For this research, environmental noise was calculated at receiver points located four metres above the ground. Travel speed information was unavailable so it was assumed that the average free flow travel speed was equivalent to the speed limit along the various links i.e. 50 kilometres per hour. Both of these assumptions are in line with the recommendations of the European Commission Working Group for Assessment of Exposure to Noise (WG-AEN) [7].

Because the study area had very little undulation, it was considered to be flat for the purpose of this study. Throughout the study area, 10 metre receiver grid points were used to calculate noise emission levels.

#### 4.3 Noise Indicators

The harmonised noise indicators recommended by the EU –  $L_{den}$  and  $L_{night}$  – were used to gauge average noise levels in the study area. Both  $L_{den}$  and  $L_{night}$  represent the A-weighted long-term average sound level determined over the entire day and night periods respectively for a year (see [6]). An excellent review of alternative noise traffic noise prediction models can be found in [8].  $L_{den}$  is given by the following equation:

$$L_{den} = 101g \frac{1}{24} \left( 12*10^{\frac{L_{day}}{10}} + 4*10^{\frac{L_{evening}+5}{10}} + 8*10^{\frac{L_{night}+10}{10}} \right)$$
(1)

The day period was considered to be from 07.00 to 19.00 while evening and night time periods were considered to be from 19.00 to 23.00 and 23.00 to 07.00 respectively. It is worth noting that these periods may vary slightly between Member States of the EU.

 $L_{den}$  and  $L_{night}$  noise levels were calculated using the commercial noise prediction software package Predictor 5.0. The parameters of the Harmonoise method are built-in to the latest Predictor software package which makes it quite user-friendly.

As stated earlier, a central objective of the study was to integrate noise prediction data with a GIS. This will now be discussed before the noise mapping results are presented.

<sup>&</sup>lt;sup>1</sup> Meteorological data was acquired for the closest weather station to the study area – Dublin Airport. Relative Humidity was considered to be 77%. Mean annual temperature was considered to be 10 degrees Celsius. Mean annual atmospheric pressure was considered to be 1013 (hPa).

#### 5.0 The Role of GIS in Noise Mapping

A GIS is a system which allows one to store, analyse and manipulate different types of spatial data. This is an important consideration in noise mapping research particularly in terms of noise effect studies and in terms of educating public opinion about the impacts of environmental noise. Integrating noise prediction data with a GIS allows for other types of spatial data to be utilised in noise studies. Ultimately, this can provide more accurate noise maps as well as providing more comprehensive data on which to base environmental noise policy decisions. The exact role that can be played by a GIS in environmental noise studies in now discussed.

#### 5.1 A Centralised Data Management Facility

ArcMap is a GIS mapping package within ArcGIS. It offers a centralised data management facility that is compatible with commercial noise software such as Predictor. This is important because it means that all of the data needed for undertaking noise prediction calculations, as well as the data required for noise effect and visualisation studies, can be stored in a centralised database. Data can be imported and exported between Predictor and ArcGIS via Predictor's data exchange system. This is extremely useful because building shapefiles and road polylines have associated attribute tables where building height, traffic flow and average travel speed information can be stored. Grid co-ordinate information and noise emission values can also be stored centrally. It is also possible to store a Digital Terrain Model (DTM) in ArcGIS which can be transferred easily to/from Predictor.

#### 5.2 Enhanced Visualisation

Using ArcScene, a 3D viewing analysis package within ArcGIS, it is possible to undertake 3-dimensional visualisation analysis of noise results for any study area. Figure 1 (a) shows the possibility of integrating aerial photography, building and road geometry information with noise mapping studies while Figure 1 (b) shows a noise raster superimposed over an aerial photograph of the study area. Figure 1 (c) demonstrates the possibility for enhanced visualisation using ArcScene by constructing a 3-dimensional noise map for the study area. ArcScene provides a 3D Analyst extension which allows for the manipulation and representation of spatial data in 3D. In particular, the package allows for the extrusion of building heights into 3-dimensions provided that the heights are contained in the associated attribute table of the building shapefiles. The result is a considerable visual improvement on existing noise mapping studies whereby noise prediction calculations are displayed alongside various other forms of spatial data.



Figure 1. Enhanced Visualisation of Noise Maps Using GIS

## 5.3 3D Animation

ArcScene allows for the possibility of undertaking 3D animations of noise study areas and a number of these animations were performed for the Dublin study area (see animation stills in Figure 2). This has the potential to be a very important visualisation tool in terms of educating and informing the public about the impact of environmental noise in individual localities. It is also worth noting that individuals can interactively navigate the noise environment by using a 'Flythrough' tool in ArcScene. A challenge for future researchers is to integrate sound maps of the study area over interactive navigations in 3-dimensions. Noise animations can be exported from ArcScene as video clips which can then be made freely available to the public via an environmental noise information website. Undoubtedly, such a tool offers considerable potential for increasing public awareness in relation to environmental transport noise.



Figure 2. 3D Animation Using ArcScene

## 5.4 Advanced Data Interpolation Methods

In the noise prediction literature much attention has been given to the importance of accurate input data for noise predication calculations and noise mapping studies. What is less clear, however, is the visual and numerical impact that different data interpolation methods have on the production of noise maps. Given that no standard data interpolation procedure exists at present, this would appear to be an important consideration. For this research, three different types of data interpolation method were used for generating noise rasters in ArcMap – Nearest Neighbour, Inverse Distance Weighting (IDW) and Kriging. For a review of the foregoing interpolation methods see [9].



3 (a) Nearest Neighbour 3 (b) Inverse Distance Weighting Figure 3. Advanced Data Interpolation in ArcMap

Figure 3 shows noise maps produced for different types of data interpolation using the same identical receiver grid spacing. For each noise raster one pixel represents one metre on the ground. Quite clearly, the visual impact varies for each data interpolation method. The nearest neighbour method appears to provide the most graduated method of data interpolation. However, there is no evidence to suggest that this is the most accurate method. Given that noise action plans are likely to be based on strategic noise maps such as those presented in Figure 3, the importance of having a standard data interpolation method incorporated into strategic noise mapping studies is of significant importance.

Mean (dB(A)) <sup>2</sup>	Standard Deviation (dB(A))			
56.11	12.0			
55.35	12.08			
56.38	11.04			
	Mean (dB(A)) <sup>2</sup> 56.11 55.35 56.38			

#### **Table 2. Summary Statistics for Noise Raster Pixel Values**

Each noise raster comprises of thousands of individual pixels and each pixel has an associated decibel value which corresponds to a colour on the noise map. The results presented in Table 2 suggest that both the mean and standard deviation decibel values for the pixels in each noise raster are considerably, although not dramatically, different for each method of data interpolation. Yet again, this highlights the need for a standardised data interpolation method for noise mapping studies while also highlighting the need for further research in this area.

In summary, GIS software has the potential to significantly improve data management in noise studies. Enhanced noise mapping capabilities together with 3D animation in a GIS offers the possibility of not only improving the visualisation of noise maps but of significantly enhancing public awareness of environmental noise, a key objective of the END. Integrating noise data with a GIS also offers the opportunity of using advanced data interpolation techniques which ultimately improve the accuracy of noise maps.

 $<sup>^{2}</sup>$  All of the values in Table 2 relate to calculations for L<sub>don</sub>

#### 6.0 Noise Mapping Results for Inner Dublin

Figures 4 and 5 show the strategic noise mapping results for the Dublin study area. Results for environmental noise emissions from road transport are presented for  $L_{den}$  and  $L_{night}^{3}$ . In each case, noise maps are presented with and without aerial photography information. Graduated colouring was used to present the noise emission data. It was felt that replacing exact noise contours with gradual judgements would, at least to some extent, help to represent the uncertainty of noise measurements more adequately. This is something which has been recommended in previous noise studies [10].

The results for  $L_{den}$  (Figure 4) show that noise emissions along the vast majority of roads in the study area exceed 70 dB (A), the guideline value above which the WHO have recommended day-time noise levels should not exceed [5]. This is somewhat worrying from an environmental policy viewpoint and suggests that noise emissions from transport in this area are adversely affecting individuals' quality of life. The problem appears even more pertinent when one accounts for the fact that car ownership and car use is on the increase in the City Council borough. Looking to the future, it seems likely that noise emission levels for day-time will increase unless noise abatement policies are adopted and implemented in the near future.

The results for  $L_{den}$  also show that noise levels are generally less than 40 dB (A) in the Trinity College campus area. Under the conditions laid down in the END, this area should be preserved as an area of good sound quality. This seems even more important given that the Campus offers a relatively quiet haven in the centre of the city.



Figure 4. L<sub>den</sub> Values for Road Transport - the Dublin Study Area

<sup>&</sup>lt;sup>3</sup> Nearest Neighbour was used as a method of data interpolation for the maps presented in Figures 4 and 5.

The results for  $L_{night}$  (Figure 5) show that noise emissions along most of the roads in the study area are considerably greater than the night-time guideline value of 45 dB(A) recommended by the WHO [5]. This suggests that, in relative terms, the results for  $L_{night}$  are considerably worse than those for  $L_{den}$ . In terms of noise effects, the results for  $L_{night}$  suggests that a large number of individuals may be experiencing a number of adverse health affects, for example sleep disturbance, due to high levels of night-time noise exposure. This is something which will need to be considered when the local authority is devising noise abatement action plans for the area.



Figure 5.  $L_{night}$  Values for Road Transport - the Dublin Study Area

#### 7.0 Conclusion

This paper has reported on research conducted to undertake noise prediction calculations for inner Dublin. Emphasis was laid on integrating noise prediction data with a GIS. It can be concluded that GIS based noise studies have the potential to improve the accuracy and efficiency of noise mapping studies. Noise mapping using a GIS offers a centralised data management facility. It also enhances the visualisation of noise maps through integration with other types of spatial data that could not be utilised easily using commercial noise prediction software packages. Noise animation is also possible which offers considerable potential for increasing public awareness in relation to environmental noise. It has also been demonstrated that, in visual terms, noise maps may vary considerably depending on the data interpolation method used. This highlights the need to introduce a standard data interpolation method for noise mapping studies. Finally, the environmental noise results for inner Dublin suggest that environmental noise emissions from road transport are considerably greater than those values recommended by the WHO for both  $L_{den}$  and  $L_{night}$ .

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