A PRACTICAL FRAMEWORK FOR STRATEGIC NOISE MAPPING

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Ireland

April 2008

A thesis submitted to the University of Dublin in partial fulfillment of the requirements for the degree of Ph.D.

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Declaration

I declare that I am the author of this thesis and that all work described herein is my own, unless otherwise referenced. Furthermore, this work has not been submitted in whole or part, to any other university or college for any degree or qualification.

I authorise the library of Trinity College, Dublin to lend or copy this thesis upon request.

Eoin King

Eoin King, April 2008

Summary

Environmental noise is a major form of pollution and it is estimated that at least one quarter of the population of the EU suffer a reduced quality of life due to exposure to noise. To address the problem the European Union issued Directive 2002/49/EC with the aim of developing a uniform approach towards the assessment and subsequent management of environmental noise. The directive requires Member States to ensure strategic noise maps are produced for designated areas and presented in terms of universal noise indicators. These maps must also be presented to the public in a clear, comprehensible and accessible manner. Given that public involvement is central to the directive it is thus important that noise maps are accurate, or perhaps more particularly, it is important that predicted results will satisfy independent public analysis.

The work described in this thesis develops a framework for the production of accurate strategic noise maps in a practical manner. Baseline noise maps were initially created using standard commercial software as a benchmark and compared with results obtained through independently developed "in-house" software. The developed calculation model strikes a balance between the complexity of noise propagation calculations and computational efficiency. Refinements could then be made to the baseline maps by integrating on-site noise measurements while also incorporating certain aspects of an uncertainty analysis. Additionally the model was assembled in such a way to allow for the effective evaluation of proposed action plans without exhausting computational resources. Finally novel methods of presenting final noise maps were also explored with a view to developing a routine suitable for public dissemination.

The overall result of this work provides a template on how noise maps may be

created and ultimately presented for public dissemination purposes. The purpose of this work was not to develop a noise mapping tool to compete with today's commercial software packages, which still fall short of capability of implementing the directive as it was intended, but rather to investigate the possibility of developing a simple alternative, that would enable the practical development of strategic noise maps.

List of associated publications

- "Refining noise maps for public dissemination", Proceedings of Euronoise 2006, Tampere, Finland.
- "Relating short-term measurements to the L_{den} indicator", Proceedings of Inter-noise 2007, Istanbul, Turkey.
- "The development of an independent noise prediction model", Proceedings of the 19^{th} International Congress on Acoustics, Madrid, Spain, 2007.
- "The development of a practical framework for strategic noise mapping", Paper in preparation.

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But of course when you are caught up in research it's not simply a job, it's more a state of mind. It's something that takes complete control over your life and it's something you can never escape from (not that I ever wanted to). With this is mind I have to thank all the people who supported me as I endeavored to control the "immensity of sound".

My folks (Ma and Da) you've seen me through a lot. How can I ever thank you enough. Some day I'll have that house built for you - with your help the foundations have been laid. Thanks also to my big sisters, Caitriona and Niamh. (I also have to thank Grace and Ciara. Ciara in particular helped me understand the fundamentals of enhanced noise propagation modelling).

Within the department itself it seemed more like a family than an office. I made some good friends over the years and I want to thank you all for everything - especially my lunch buddies Steve-o and Bjorn and my international travel companion Franz.

And finally Sheila. Simply put the reason I am who I am today, without you I would just be like your middle name.

"Noise.

A stench in the air. Undomesticated music.

The chief product and authenticating sign of civilisation."

Ambrose Bierce

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Within the European Union it is estimated that the costs caused by noise pollution lie between 0.2% and 2% of the gross domestic product. As such, a best case scenario means annual financial losses of more than 12 billion Euro [1]. Examples of elements that contribute to the economic damage include a reduction in house prices, lost labour days and reduced possibilities of land use [2]. In addition to the financial aspect, more than 25% of the population of the EU experience a reduced quality of life due to exposure to environmental noise and is some cases it may result in certain health deficiencies. It is evident that a uniform approach to the management and control of the problem is necessary. To achieve this the EU issued a directive, Directive 2002/49/EC, hereafter referred to as the Environmental Noise Directive, the END, with the aim of establishing a common European-wide standard to deal with environmental noise. This calls for the production of environmental noise maps for designated areas and the ensuing development of noise action plans.

On a European scale, the undertaking of detailed noise studies in response to the END is probably the highest profile activity the acoustics and noise control authorities have carried out to date. It is reasonable to assume that these results will lead to articles within the media, bringing conclusions and possible comparisons between cities and states, to the public domain. In order to ensure the industry's credibility is upheld, good results and a robust recommendation for action should be a desirable aim [3]. It is therefore imperative that noise maps accurately present the situation with regards to noise and as such satisfy any public scrutiny as the involvement of public is a central premise of the END.

1.1 Effects of environmental noise

If a tree falls in a forest with no-one to hear it does it make a noise? No, as noise is generally defined as unwanted sound, normally because it is unpleasant, annoying or it is interfering with the perception of wanted sound. Environmental noise is defined by the E.U. as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic and sites of industrial activity" [4]. Environmental noise effects many people in many different ways, from the simple reduced enjoyment of a balcony to genuine health deficiencies.

It is interesting to note that the likelihood of an individual experiencing reduced health due to noise exposure is strongly dependent on his/her sensitivity to noise and because the range of effects is so large that individual personal experiences are never a reliable measure for the effects of noise on a community [2]. This is because different people react to different noises in different ways. This was evident in a study carried out as early as 1928, by Hyde and Scalapino, which showed that for the same sonic energy, changes in arterial tension differed among subjects when listening to a Tchaikovsky symphony or the March of the Toreadors in Carmen. Thus it may be assumed that sound measurements will never be able to completely explain the nuisance or effects of noise on humans.

According to the International Programme on Chemical Safety (WHO 1994), an adverse effect of noise is defined as a "change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases in susceptibility of an organism to the harmful effects of other environmental influence". This definition includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs [5].

Auditory effects include ringing in the ear, temporary hearing loss and permanent hearing loss. Non-auditory effects include stress, hypertension and ischaemic heart disease. Hypertension and ischaemic heart disease occur in the case of long term exposure to noise levels above 65dB and may be responsible for a few percent of the heart attacks in the EU including the related mortality [2].

The World Health Organisation defines human health as "a state of complete physical, mental and social well-being, not merely the absence of disease and infirmity" [6]. Therefore other non-physical effects of noise must also be considered as impacting on human health. It is widely recognised that the most common adverse effect arising from exposure to environmental noise is annoyance. A number of adverse effects are listed below:

- *Noise induced hearing impairment*

  Hearing loss may be either temporary or permanent. Exposure to high levels of noise over a relatively short period of time may result in temporary hearing loss, temporary threshold shift (TTS), which may last for a few hours. Tinnitus or ringing in the ears may also occur. Permanent hearing loss is quantified by specifying the permanent threshold shift (PTS) as a function of frequency. Hearing impairment is a broader term specifying the loss in the ability to understand speech. Typically, hearing impairment is defined as a rise in the threshold of hearing. This means that the ear cannot respond to sounds at a low pressure level. On a worldwide scale, noise induced hearing impairment is the most widespread irreversible occupational hazard, with an estimated 120 million people suffering from hearing problems worldwide [7]. Environmental noise does not normally cause hearing loss, except when exposure is exceptionally high and over a long period, typically occurring near airports [8].

- *Cardiovascular and physiological effects*

  Acute noise exposure activates the autonomic and hormonal systems, leading to temporary changes such as increased blood pressure, increased heart rate and vasoconstriction. After prolonged exposure, susceptible individuals in the general population may develop permanent effects, such as hypertension and ischaemic heart disease [7]. The overall conclusion is that cardiovascular effects are associated with long-term exposure to noise levels above 65dB, and may be responsible for some of the heart attacks in Europe [2]. However these associations are somewhat weak but such small risks are very important as quite a large number of Europeans are exposed to these levels, the number of which will rise in the absence of some positive action.

- *Annoyance*

"It was a thing beyond all imaginings... the deafening side drum tatoo of tyred wheels, the creaking and groaning and chirping and rattling of vehicles, light and heavy... it was not any such paltry thing as noise. It was an immensity of sound".

H.B. Creswell [9]

Annoyance, widely regarded as the most common adverse effect of exposure to environmental noise, is the scientific expression for the non-specific disturbance by noise, as reported in a structured field survey [2]. Evidence of annoyance would include the reduced enjoyment of use of a garden or closing windows in order to avoid sleep disturbance, etc. Many different factors will effect the extent of annoyance on any individual, for example, intermittent noise is more annoying than continuous noise and narrow band signals are more annoying than wider band signals [10]. In addition it has been found that long-term annoyance is slightly, but statistically significantly, higher in the summer than in the winter [11]. Also, in a study carried out in Jordan, it was found that marital status and gender significantly affected the annoyance level caused by traffic noise, with single individuals reported to be more annoyed than married individuals and single females were found to be more annoyed than single males [12].

- *Sleep disturbance*

Environmental noise may also affect people's ability to gain the appropriate amount of sleep required for the maintenance of good health. Sleep disturbance is seen as a health effect on its own, but may also cause after effects like mood changes, fatigue and other impaired functions. In fact it is estimated that more than 30% of the population of the EU are exposed to noise which is disturbing to sleep.

Another study which demonstrated how the nature of the noise itself as opposed to the decibel level affects us was carried out in Japan. In this particular experiment subjects were exposed, while sleeping, to road traffic noise and a recording of frogs croaking with 49.6dB(A) and 49.5dB(A) L_{Aeq} respectively. It was found that the percentage of stage 2 of sleeping increased while the REM stage decreased during exposure to traffic noise, which meant that the quality of sleep was degraded, while no significant effect was noted during exposure to the frogs croaking [13].

- *Cognitive development*

Possibly the most worrying aspect is the effect environmental noise may have on children. A study carried out by researchers at Cornwall University concluded that children living in loud areas displayed symptoms of stress related anxiety, nervousness and even diminished motivation.

In another study, 326 German schoolchildren were followed up prospectively as the old Munich airport was replaced by a new international facility. Children attending the schools near the old airport improved their reading scores and cognitive-memory performance when the airport shut down, while children going to school near the new airport experienced a decrease in scores. Another study which was conducted cross-nationally in the Netherlands, Spain and the UK found a linear exposure-effect association between exposure to aircraft noise and impaired reading comprehension and recognition memory in children [14]. This was also evident in another study carried out in the United States as long ago as 1972 where it was found that children living near noisy highways in Los Angeles had lower than average reading scores [15]. Thus it is very much apparent that exposure to environmental noise impairs cognitive development in children.

1.2 The noise policy of the European Union

It is possible to determine the level of noise in a particular area by using a variety of methods and measurement periods. It is also possible to present results in many different fashions. For example the United Kingdom use an hourly L_{10} indicator, which is the value of noise in dB(A) which is exceeded for 10% of the time, while in France the indicator $L_{Aeq,LT}$ is used, which represents the average long term level of the noise. This means that different noise studies may not be directly compared or combined resulting in the inability to develop a common approach to the management of environmental noise. This issue is one of the main reasons behind the development of the END, as it seeks to develop a common European-wide strategy regarding the management, control and evaluation of environmental noise. The Directive states it's aim as the definition of a common approach intended to avoid prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise [4].

The Directive does not however set a common defined noise limit as it would not be feasible to do so at the moment given the large difference in scale and comprehensiveness of implementing noise studies throughout different Member States [2]. However each Member State should set their own limits which should be published with the noise map. The fundamental principles of the END are as follows with a summary presented in Figure 1.1 [16]:-

- *Monitoring the environmental problem.*

  Member states were required to develop strategic noise maps by June 30^{th} 2007, for all agglomerations of over 250,000 inhabitants, all major roads with over 6 million passages a year, major railways with more the 60,000 train passages a year and major airports with over 50,000 take-off or landing movements a year. A second phase of maps, due in 2012, will require maps to be made of agglomerations having between 100,000 and 250,000 inhabitants, roads with between 3 and 6 million vehicle passages a year and railways with between 30,000 and 60,000 train passages a year. Strategic noise maps must also take account of high volume outdoor industrial and machinery noise levels.

A strategic noise map presents data on an existing, previous or predicted noise situation in terms of a noise indicator, the exceeding of a limit value and an estimation of the number of dwellings, schools and hospitals in a given area that are exposed to specific values of a noise indicator. Particular attention should be given to road traffic, rail traffic, airports and industrial activities. Maps must be made for an assessment height of 4m and must be expressed in terms of the universal noise indicators L_{den} and L_{night}.

- *Informing and consulting the public*

The competent authorities are required to ensure that the general public are kept well informed, are consulted in relation to any proposed action plans and given an opportunity to participate in the preparation and review of such action plans. The results of this participation will be taken into account when considering action plans and the public should be informed in respect of all decisions taken. This will lead to a well-informed and educated public forming the basis for a more consistent and effective approach to the management of environmental noise.

- *Development of action plans*

Article 8 of the Directive states that by no later than July 18^{th} 2008, Member States must ensure that the competent authorities have drawn up action plans to reduce noise where necessary and enforce protection of quiet areas. The action plans must also include a record of public consultation together with what action is intended for the next five years, including measures to protect quiet areas.

- *Development of a long term EU strategy*

The primary objective of the END is to reduce the number of people exposed to unacceptable noise levels throughout Europe in the long term. Establishing a common approach to noise control will lead to the development of a framework for the EU to reduce noise levels.

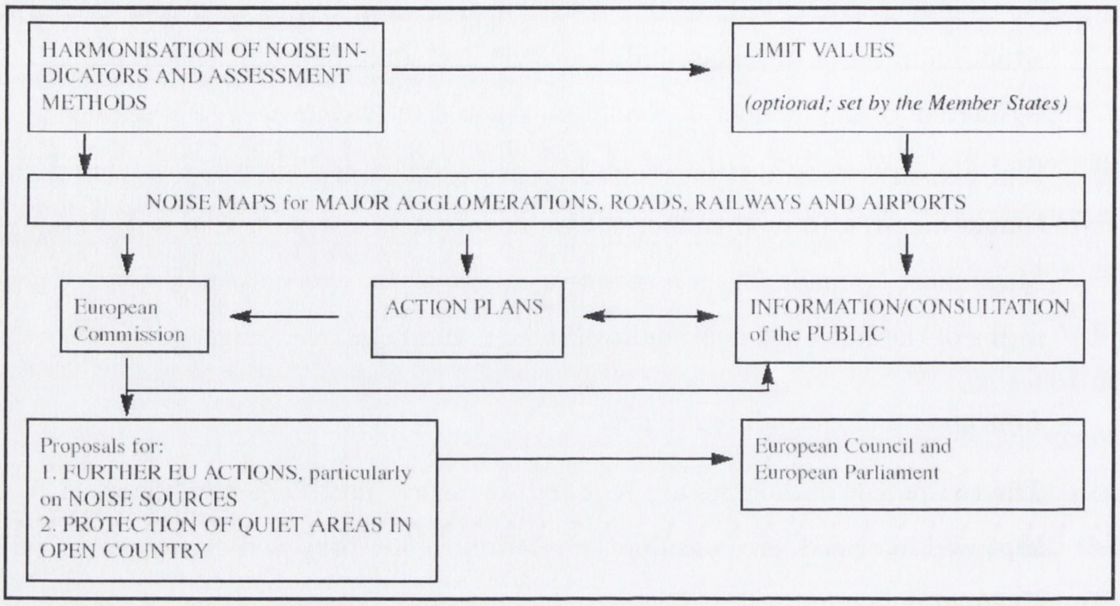

Figure 1.1: Overview of EU Directive on Environmental Noise

1.2.1 Noise indicators

The END defines two specific indicators which must be used when presenting environmental noise maps, L_{den} and L_{night}. L_{den}, the day-evening-night noise indicator, represents the noise indicator for overall annoyance expressed in dB(A). It may be calculated from [4]:

$$L_{den} = 10log\frac{1}{24}\left(12.10^{\frac{L_{day}}{10}} + 4.10^{\frac{L_{evening}+5}{10}} + 8.10^{\frac{L_{night}+10}{10}}\right) \tag{1.1}$$

in which L_{day} is the A-weighted long-term equivalent sound level determined over the day period of one year, between the hours of 07.00 and 19.00, $L_{evening}$ is the A-weighted long-term equivalent sound level determined over the evening periods of one year, between the hours of 19.00 and 23.00, and L_{night} is the A-weighted long-term equivalent sound level determined over the night periods of one year, between the hours of 23.00 and 07.00. The weighting factors in the above equation are designed to account for the increase in annoyance at different periods throughout the day, hence the addition of 10 to the value for L_{night} and 5 to the value of $L_{evening}$. L_{night} shall also act as the noise indicator for sleep disturbance. The periods listed above are the default values set out in the directive and may be altered slightly by each member state, provided the overall length of time periods still add to 24. The day-evening-night indicator is closely related to the day-night level, L_{dn}, which is widely used in the US and in some Member States for the characterisation of aircraft noise [2].

The indicators L_{den} and L_{night} are to be used to determine the average response of a population that is subject to long-term noise exposure so are ideal indicators to be used for planning purposes. However, as they represent long term average levels, they are not the appropriate tools to be used to assess short term situations, which are often the source of noise complaints to authorities. The END also states that in some cases it may be advantageous to use special noise indicators and related limit values. Some examples of when these might be appropriate include when the noise source under consideration operates for only a small proportion of time, the noise contains strong tonal components or the noise has an impulsive character. The possibility of introducing these *custom-made* noise indicators should not be ignored in order to ensure the development of the most appropriate action plans.

1.2.2 Interim computational methods.

Annex 2 of the directive lists recommended interim methods which may be used by Member States with no national computation methods or where Member States wish to change computational methods. The recommended methods are :

- *Road Traffic Noise:* the French national computation method "NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB)", referred to in "Arrêté du 5 mai 1995 relatif au bruit des infrastructures routiéres, Journal Officiel du 10 mai 1995, Article 6" and in the French standard "XPS 31- 133".

- *Rail Traffic Noise:* The Netherlands computational method published in Reken-en Meetvoorschrift Railverkeerslawaii 96, most commonly referred to as RMR.

- *Aircraft Noise:* ECAC.CEAC Doc. 29 Report on Standard Method of Computing Noise Contours around Civil Airports 1997.

- *Industrial Noise:* ISO 9613-2: Acoustics: Abatement of sound propagation outdoors, Part 2: General Method of calculation.

The Commission provides guidelines concerning the use of these interim computational method in [17] as each method must be adapted to the definitions of L_{den} and L_{night}.

In addition, Article 10.1 of the directive states that the Commission will submit a report to the European Parliament and the Council containing a review of existing Community measures relating to sources of environmental noise. This report is now available and provides such a review [18].

1.2.3 A universal assessment method

Harmonoise

"Harmonised, Accurate and Reliable Methods for the European Directive On the Assessment and Management of Environmental Noise"

The END notes the lack of a harmonised and reliable method for noise prediction and the need for a new method which would be suitable for use by all Member States. In the short term, Member States may use the recommended interim calculation methods but in the long term a more robust, universal procedure is required. This led to the initiation of the Harmonoise project. The main objective of this project was to develop a common European noise prediction method, which would meet all aspects of the Directive and is expected to become the obligatory prediction method for all Member States. The project did not aim to develop noise prediction software but rather a detailed description of noise prediction methods which may then be implemented into a software package independently.

Harmonoise delivers two prediction models, an engineering model intended for everyday use and a reference model, the *Golden Standard*, that serves to calibrate the engineering model and also as a high accuracy model for complex propagation problems that cannot be solved in a satisfying way by the engineering model. Both models use the same source model, as a central concept of the Harmonoise method is that the source and propagation models are completely separated.

The model is quite detailed and is designed so that it may be implemented in all areas of Europe. It must account for different meteorological conditions, from the rainy plains of Ireland, to snow covered roads in Finland and the sun drenched cities in southern Spain, different road surface types, different rail types etc. It results in the definition a detailed model for the calculation of road traffic and rail noise, much more detailed then any model which may have been used previously.

Imagine

"Improved Method for the Assessment of the Generic Impact of Noise in the Environment"

The Imagine project started in December 2003 and is seen as the natural successor to the Harmonoise project. While the Harmonoise project concentrated on rail and road traffic sources, the Imagine project introduced noise from aircraft. The goal of the Imagine project was to standardise the Harmonoise methods and provide guidelines on how to use these methods to produce noise maps and develop associated action plans. Essentially, Imagine will prepare the Harmonoise methods for use by Member States.

1.3 The noise situation in Ireland

Statutory Instrument No.140 of 2006, which entered into force on April 3^{rd} 2006 outlines the requirements that Ireland has to achieve in order to comply with the first round of mapping outlined in the END. It requires the city of Dublin to be mapped along with major roadways, major railways and the only major airport. Authorities must also develop action plans for each area, and make results and action plans available to the public, through dissemination by any appropriate means, including the use of available information technologies.

A detailed study of the Directive highlights an important issue relating to its application in Ireland. A directive, as an instrument of European Law, is a detailed document which by it's terms sets out the aims and objectives of the European Union in a particular area, for example, environmental noise mapping. A directive is then transposed into national law by each Member State. The Member State has the freedom to define how the directive will be implemented within a timeframe set by the European Union. Notably, this is where the discretion of the individual Member State ends. Each directive sets out, in detail, its aims and objectives. These detailed aims and objectives are to be considered by each Member State as the low water mark, in that their transposition of the directive can only create a higher standard of regulation and must not fall short of the requirements laid down by the European Union. The ECJ has held [19] that all directives are in fact directly effective in their entirety. Therefore even where a State fails to provide in its transposition for the full effect of a directive any citizen of the European Union effected by the inadequacies of the transposition can claim the full rights/obligations provided for by the directive in its original or intended format.

In Ireland, directives are usually implemented by way of a statutory instrument. The Statutory Instrument [20] that is the subject of this thesis may fall under this category due to its apparent inaccurate transposition of the Directive. Various noise mapping bodies are charged with the responsibility of producing noise maps and the Environmental Protection Agency, EPA, is defined as the authority overseeing the implementation of the legislation.

The END was to initially give only minimum requirements, outlines and general objectives for the production of noise maps, action plans, limit values and informing the public. It is up to each Member State to apply and develop their own methods and approaches in more detail.

	km of Road 2007	*Agglomerations 2007*
Sweden	930	3
Denmark	1,043	1
Spain	9,494	19
Italy	9,589	13
Germany	16,000	31
UK	12,000	28

TABLE 1.1: Identified targets in other EU countries

Figure 1.2 [21] is based on annual average daily traffic flow, AADT, figures from as far back as 2001. There is approximately 700 km of road that need to be mapped

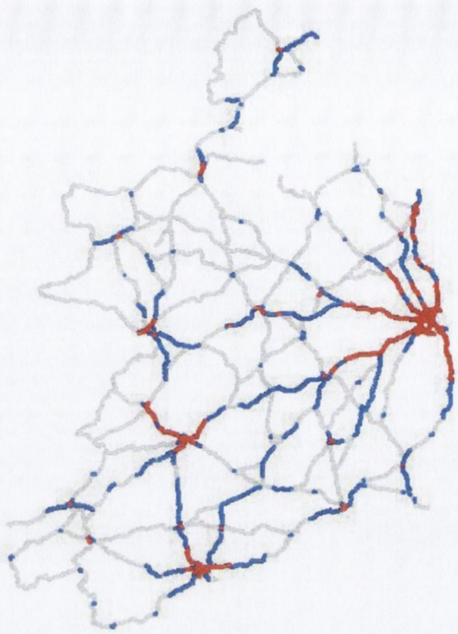

FIGURE 1.2: Identified Irish roads that should be mapped

for the first round of noise mapping, coloured in red, and approximately 3000 km that need to be mapped for the second round in 2012, coloured in blue. These totals may be compared with several other EU countries, presented in Table 1.1 [22] [23] [24] [25].

1.3.1 The ETI Capability Development Project

"Environment Transport Interface Capability Development Project"

In response to the END, a project called the ETI Capability Development Project was initiated in Ireland. The project was primarily funded by the Environmental Protection Agency, under the capability development scheme with co-funding from Dublin City Council and the National Roads Authority. The project was divided into three different work packages, namely:

- Work Package 1: Impact of traffic on air quality
- Work Package 2: Environmental noise from transport
- Work Package 3: Valuation of environmental costs of transport

The research described in this paper is primarily associated with satisfying the goals of work package 2 which was also split up into the following sub packages:

WP 2.1: Baseline noise maps

The objective of this work package was to apply tools and methods currently being used in the creation of noise maps of two different areas in Ireland and to determine the suitability of using these tools for future noise studies. A large part of this work formed the basis of a Masters Thesis [21]. Contrasting sites were chosen - Shannon/Ennis N18 and the Westland Row area, adjacent to Trinity College, Dublin. It was found that the ArcGIS/Predictor version 4 software, was an inappropriate tool to efficiently perform this task.

WP 2.2: Enhancements to noise maps

The objective of this work package was to explore the viability of applying additional noise mapping methods beyond the current practice. As initial studies of the standard software proved them to be deficient and cumbersome, a considerable effort was expended to establish an independent software platform which integrated with the ordinance survey databases and the ArcGIS presentation generalised mapping tool.

The Directive also calls for public involvement throughout the mapping process, so emphasis was put on the development of a purpose built website which not only presented strategic noise maps but also the less exact issue of quality of the noise environment. The emphasis is not on communicating precise technical data, but rather informing non-technical people about difficult concepts associated with environmental noise such as measurement/modelling uncertainty, noise scales (e.g. the weighted dB scale is not intuitive) and noise quality (intermittency and frequency content etc.)

WP 2.3: Networked monitoring instrumentation

In the area of environmental noise mapping it is evident that a number of experimental measurements are performed. In some noise studies, measurements are used to supplement predictive mapping whilst in others, measurements form the complete basis of the noise mapping process. In the latter case both capital and running costs associated with such mobile and semi-mobile stations are key factors and a need for flexible low cost measurement techniques has emerged.

Under WP 2.3, a pc type low power system has been designed and built with facilities for pcmcia data acquisition and gsm/rf data relay. A Linux operating system was developed for this architecture. The unit is equipped with 4 channels and initial results have proved promising at several test locations throughout the system. The instrumentation is still being completed, but will prove to be a valuable asset in the validation of predicted noise maps. Initial test units have been installed at various locations on the national roads network and within the agglomeration of Dublin. Initial tests have yielded positive results.

WP 2.4: Advanced noise propagation techniques

This work package was established so that the research programme could react to philosophical changes which were likely to occur in this field in the life of the project. For example, a topic which must be addressed is how to deal with uncertainty in modelling, it's correlation with measurements and how best to disseminate this aspect of the mapping to the public. This has lead to the development of confidence level maps, which identify areas of high confidence in results. Another issue worth examining is the concern that the mapping strategies being pursued across Europe would prove too complicated and require large computational power to implement. A delicate balance between computational simplification and accuracy of results had to be achieved.

1.4 Research Objectives

There exist today a number of software packages which may be used to create noise maps. However these tools were developed prior to the issue of the END and as such do not comply in full with it's obligations. In addition, it is apparent that if commercial software is used for the development of strategic noise maps, users will be quite restricted as to how they wish to treat the data. Restrictions may be in place to regulate how maps are presented and in some cases the software will limit the size of area that may be mapped and the computational resources that may be used due to licensing agreements and shortcomings in the design of the software. To this end it was decided that the development of in-house software which would be completely versatile and computationally efficient would prove quite beneficial, particularly in the development of refinements to the noise map which would include features not available elsewhere.

This software was developed to meet the key objectives of the END. It was designed to be user-friendly, time efficient, accurate, versatile and offer a real alternative to today's commercial tools for those authorities required to develop strategic noise maps. The goal was not to produce a marketable product, it was rather to investigate the possibility of providing an alternative to today's expensive software packages which could be used by responsible authorities in the production of noise maps and developing relevant action plans.

The primary objective of this research was then to carry out a noise study in full, using the in-house software, and produce results which would satisfy the END's key deliverables. A number of developments were also explored to further develop the noise study. This involved undertaking various duties beyond the actual production of noise maps, including the assessment of different action plans. Levels of uncertainty in predicted results were determined after an analysis of the treatment of input data. Results obtained from the in-house software were directly compared to a standard commercial tool and both models were then compared with actual on-site measurements. Finally the entire study was merged together and presented in an easily accessible and comprehensive fashion which would be suitable for public dissemination.

Chapter 2

Calculation Procedures

Today there exist many different methods which may be used to determine the noise level at a specific point and results obtained may be expressed in various manners. This problem has been widely recognised as it means different noise surveys may not be compared or combined. In general the chosen calculation method will define an approach based on theory and empirical formulae and set out procedures for determining the level of noise produced at the source and the attenuation of the noise as it propagates away from the source. Several of the most common calculation methods are summarised below, specifically with relation to the calculation of road traffic noise.

ISO 9613 [26]

The ISO (International Organisation for Standardisation) is a worldwide federation of National Standard bodies. It is officially a non-governmental organisation, however the ISO lies somewhere between the public and private sectors as many of it's members are linked to their respective countries government while other members are uniquely in the private sector.

There exist a number of ISO standards that deal with the prediction of environmental noise. ISO 1996 provides authorities with material for the description of noise in community environments, while ISO 9613-2 develops an engineering method for calculating the attenuation of sound during outdoor propagation at a distance from a variety of sources. This method is based on the decomposition of a line source into a series of equivalent point sources. The contribution of each source is combined to give the overall equivalent noise level at the position of the receiver.

XP S 31-133 [27] [28]

This method is quite similar to the ISO standard in that it divides the road into separate point sources and as such relies on point to point calculations. A flow of cars along a road is modelled as a number of source lines which are then broken up into point sources. It is the French national computational method and refers to the "Guide de Bruit" as a default emission model for road traffic noise calculations. Following the Directive the European Union recommend several standards to be used by countries with no national standard or by those who wished to change computation methods, with this method being chosen as the method to use for the calculation of the propagation of road traffic noise.

Calculation of Road Traffic Noise (CRTN) [29]

This method was released in 1988 and replaced the previous method which was developed in 1975. The revision was carried out by the Transport and Road Research Laboratory and the Department of Transport in the United Kingdom. This publication includes a method which may be used to determine the noise source emission levels of road traffic due to the nature of it's composition along with a method to determine how the noise is attenuated as it propagates away from the source.

It differs from ISO 9613-2 and XP S 31-133 as it treats roads as line sources and not a collection of point sources. Also predicted noise levels are expressed in terms of the L_{10} index, which is the noise level exceeded for 10% of the time, and is therefore quite different to the L_{den} and L_{eq} indicators. As such, a conversion factor is required to change results obtained from the CRTN model to satisfy the directive. This conversion was developed from a regression relationship established between L_{eq} and L_{10}. The CRTN method is probably the most widely used standard for noise prediction in Ireland today, and was included in Statutory Instrument No. 140 of 2006.

The Harmonoise method [30]

The objective of the Harmonoise project was to provide new prediction methods for environmental noise from roads and railways to meet the requirements of the Directive. Again it treats road sources as separate point sources and relies on point to point calculations. The method for calculating the source noise emission is completely independent from the propagation model. This standard has been developed to a far greater degree than other standards described, including a number of different meteorological classes, different vehicle sub classes etc. Consequently a great deal more input data are required to run the model thoroughly, leading to fears that the model is overcomplicated and as such not practical to use for mapping large scale scenarios.

2.1 The emission model

Road traffic noise is the most dominant source of environmental noise throughout Europe. It is mainly a combination of noise resulting from the propulsion system of a vehicle and noise due to the interaction between the tyres of the vehicle and the road surface. The level of noise a vehicle produces is very much dependent on the speed it is travelling at. For low speeds engine noise will dominate while at higher speeds the road/tyre noise will dominate. This means there is a crossover speed, the recognised value of which has differed in the past [31]. In 1979, Penn wrote "Engine noise generally predominates for all vehicles until speeds around 60 miles per hour are reached, when for light vehicles noise between tyre and roads is likely to take over" [32]. While in 2000 Kinsler stated "Tyre noise predominates at all but the lower speeds" [5].

A number of calculation procedures exist, corresponding to the above mentioned standards, to determine the noise resulting from a flow of traffic, each having similar input variables including; the average speed of the traffic, the hourly flow of traffic and the percentage of heavy vehicles in the flow. Some of these methods are now explored.

2.1.1 Calculating road traffic noise - French Method

The French method requires the sound power level per metre length, $L_{A,w/m}$, as an input level. The associated noise emission model, Guide de Bruit 1980, defines a noise emission level, E, which is used to determine $L_{A,w/m}$.

This is used to calculate the basic sound power level, $L_{A,w,i}$, of a point source i, for each octave band, j, and may be calculated from:

$$L_{A,w,i} = L_{A,w/m} + C + 10log_{10}(l_i) + R_j \tag{2.1}$$

where $L_{A,w/m}$ is the sound power level per metre along the road for each octave band, C is the correction for the type of road surface in dB(A), l_i is the length of the line section of the source in metres and R_j is the spectral value, corresponding to a correction for A-weighting and calculated from table 2.1, for each octave band in dB.

j	Octave Band [Hz]	Value of R_j [dB(A)]
1	125	-14.5
2	250	-10.2
3	500	-7.2
4	1000	-3.9
5	2000	-6.4
6	4000	-11.4

TABLE 2.1: Value of R_j for each octave band

$L_{A,w/m}$ may be calculated from:

$$L_{A,w/m} = 10log_{10}\left(10^{(E_{lv}+10log(Q_{lv}))/10} + 10^{(E_{hv}+10log(Q_{hv}))/10}\right) + 20 \tag{2.2}$$

where E_{lv} and E_{hv} are the sound emission levels for light and heavy vehicles respectively, and are determined from nomograms supplied with NMPB-Routes-96, see appendix A, and Q_{lv} and Q_{hv} are the volumes of light and heavy traffic flow during the reference interval $[hr^{-1}]$.

The noise emission E, is determined from the nomogram figure for any specific case and represents the sound level for a single light or heavy vehicle travelling at the given speed over the given road type

As presented in the nomogram, several types of traffic flows are accounted for [18]:

- *Fluid continuous flow*

  Vehicles move with a nearly constant velocity on the road section. Traffic flow is considered fluid if the flow is stable for periods of at least 10 minutes.

  Usually this type of traffic flow is representative of traffic on a motorway or a major urban road, outside of rush hours.

- *Pulsed continuous flow*

  A pulsed flow has a significant proportion of vehicles in a transitory state, either accelerating or decelerating. It is however possible to determine an average overall velocity for a pulsed continuous flow of vehicles which is stable and repetitive for a sufficiently long period of time. This type of traffic flow would represent city centre roads, or roads at pedestrian crossings etc.

- *Pulsed accelerated\decelerated flow*

  A significant proportion of vehicle is accelerating\decelerating, meaning the notion of speed has a meaning only in discrete points as it is not stable during displacement. Typical of traffic after\on approach to a crossing, traffic lights, etc.

The use of the nomogram is adequate for determining the noise levels when only one or two roads are under consideration. However in order to create a noise map, encompassing many different roads with different characteristics, an alternative is required. The nomogram is essentially a chart representing a numerical relationship between the noise level and the conditions under which the vehicle is travelling. An alternative to this chart has been developed which is more practical to implement in software [18]. The emission level may be calculated from:

$$E = E_o + alog(\frac{v}{v_o}) \qquad (2.3)$$

where v_o is set at 20 km/hr and values for E_o and a may be determined from tables.

Fluid Continuous Flow			
Slope	Speed (v)	E_o	a
Flat	v < 44	29.4	0
	v > 44	22.0	21.6
Down	v < 44	29.4	0
	v > 44	22.0	21.6
Up	v < 43	37.0	-10.0
	43 ≤ v <44	32.1	4.8
	v > 80	22.0	21.6

TABLE 2.2: Values for E_o and a for light vehicles travelling in a continuous fluid flow

The relevant values for the condition of continuous fluid flow of light vehicles are displayed in Table 2.2, with the full tables also presented in Appendix A.

With the calculated value for E, the sound power level per metre may be calculated as before.

2.1.2 Calculating road traffic noise - CRTN

The UK's CRTN method supplies a method to determine the noise levels at the source resulting from traffic flows. The hourly and 18-hour L_{10} noise levels may be calculated from:

$$L_{10,1hr} = 42.2 + 10log_{10}q \tag{2.4}$$

$$L_{10,18hr} = 29.1 + 10log_{10}Q \tag{2.5}$$

where q and Q are the are the hourly and 18-hour flows of all light and heavy vehicle respectively. The above equations must be modified to account for various aspects of the traffic flow. Additional corrections may be required when calculating noise levels in situations where the traffic flow is low, i.e. less than 200 vehicles per hour. Depending on the mean traffic speed, V, and the percentage of heavy vehicles, p, the following correction should also be applied:

$$Correction_{(Flow)} = 33log_{10}\Big(V + 40 + \frac{500}{V}\Big) + 10log_{10}\Big(1 + \frac{5p}{V}\Big) - 68.8 \tag{2.6}$$

The value of p is given by

$$p = \frac{100f}{q} \qquad or \qquad p = \frac{100F}{Q} \tag{2.7}$$

depending on whether the correction applies to $L_{10,1hr}$ or $L_{10,18hr}$. In the above equation f represents the hourly flow of heavy vehicles while F represents the 18-hour flow. A heavy vehicle has an unladen weight exceeding 1525kg while motorcycles and mopeds should be included as light vehicles.

There also exists a correction for gradient, G, of the road, where G is expressed as a percentage

$$Correction_{(Gradient)} = 0.3G \tag{2.8}$$

The gradient may also reduce the mean speed depending on the gradient level and the amount of heavy vehicles in the flow.

An additional correction must also be included for the type of road surface. The corresponding correction is dependent on a number of factors, such as the texture of the road surface or if the surface is impervious or not. When the mean speed is less than 75 km/hr and the road has a given texture depth, TD, the correction for a concrete surface is:

$$Correction_{(Surface)} = 10log_{10}(90TD + 30) - 20 \tag{2.9}$$

and for a bituminous surface:

$$Correction_{(Surface)} = 10log_{10}(20TD + 60) - 20 \tag{2.10}$$

This correction equates to a correction of 0.79dB for a road with a mean texture depth of 3mm. In the case of an impervious road surface, 1dB(A) should be subtracted from the basic noise level if V is less than 75km/hr. While if the road surface is pervious macadam, 3.5dB(A) should be subtracted from the basic noise level at all speeds. It should be noted that this correction was not included in the NMPB method as the NMPB method was developed over a number of different road surfaces and as such yields average noise levels over an average surface.

This will result in a noise level in terms of the L_{10} indicator and as such does not comply with the Directive. To address this, the Transport Research Laboratory, TRL, released a paper describing a mathematical procedure that may be used to convert values of $L_{10,1hr}$ and $L_{10,18hr}$ to L_{den} depending on whether the available traffic parameters relate to a single hour or to the specified 18-hour period [33]. The 18-hour Method is of particular interest as it predicts a 24-hour indicator, L_{den}, based on an 18 hour indicator. It is assumed that the 6 hours that are unaccounted for will influence the L_{den} level to the same degree for each road. A number of measurements were taken across the UK and the relationship between L_{10} and L_{den} was determined following a regression analysis. Two separate road classifications were developed for Motorways and Non-Motorways and each require a different conversion formula:

For Motorways:

$$L_{den} = 0.90xL_{A10,18hr} + 9.69 \tag{2.11}$$

For Non-Motorway roads:

$$L_{den} = 0.90xL_{A10,18hr} + 4.20 \tag{2.12}$$

Roads are classified in a different manner following the assumption that different road types will follow different diurnal patterns. The difference in the diurnal pattern will have an impact upon the predicted result as the L_{den} value, which is based on a 24-hour period, is predicted from an 18-hour noise level. Thus if the pattern of the noise levels over the remaining 6 hours differs between Motorways and Non-Motorways, the L_{den} value will be affected.

2.1.3 Calculating road traffic noise - Harmonoise

Initially vehicles are divided into separate categories as shown in figure 2.1 [30]. There are three main categories, light, medium and heavy, with two other categories to account for off road vehicles and two-wheelers. Each vehicle category is represented by a combination of sources resulting from tyre/road noise and propulsion noise. The sound power level for a single moving vehicle, $L_{W,m,i}$ in dB(A), is calculated per 1/3 octave band, corresponding to the input data for one single vehicle at an instantaneous time. The equations to be used in calculations are presented in Appendix B.

Combining sources

The sound power output $L_{W,m,i}$ for a single moving vehicle is then used to calculate the total sound power for each vehicle category of a source line with unit length from:

$$L'_{W,m,i} = L_{W,m,i} + 10log(\frac{Q_m v_o}{1000Q_o v_{eq,m}}) \tag{2.13}$$

Main category (type)	No.	Sub-categories: Example of vehicle types	Notes
Light vehicles	1a	Cars (incl MPV:s up to 7 seats)	2 axles, max 4 wheels
	1b	Vans, SUV, pickup trucks, RV, car+trailer or car+caravan(1), MPV:s with 8-9 seats	2-4 axles(1), max 2 wheels per axle
	1c	Electric vehicles, hybrid vehicles driven in electric mode(2)	Driven in combustion engine mode: See note
Medium heavy vehicles	2a	Buses	2 axles (6 wheels)
	2b	Light trucks and heavy vans	2 axles (6 wheels)(3)
	2c	Medium heavy trucks	2 axles (6 wheels)(3)
	2d	Trolley buses	2 axles
	2e	Vehicles designed for extra low noise driving	2 axles(5)
Heavy vehicles	3a	Buses	3-4 axles
	3b	Heavy trucks(4)	3 axles
	3c	Heavy trucks(4)	4-5 axles
	3d	Heavy trucks(4)	≥6 axles
	3e	Trolley buses	3-4 axles
	3f	Vehicles designed for extra low noise driving	3-4 axles(5)
Other heavy vehicles	4a	Construction trucks (partly off-road use)(4)	
	4b	Agr. tractors, machines, dumper trucks, tanks	
Two-wheelers	5a	Mopeds, scooters	Include also 3-wheel motorcycles
	5b	Motorcycles	

FIGURE 2.1: Summary of vehicle categories to be used in Harmonoise

where v_o is the reference vehicle speed, 1km/hr, $v_{eq,m}$ is the equivalent vehicle speed for each vehicle category, Q_0 is the reference traffic flow, 1 h^{-1} and Q_m is the traffic flow for each vehicle category.

The total sound power of a source line with unit length is obtained by summation over the different vehicle categories:

$$L'_{W,i} = 10log_{10} \sum_{m} 10^{0.1L'_{W,m,i}} \quad (2.14)$$

2.2 The propagation model

For the purpose of developing an independent model it was decided to implement the French national computational procedure [27] in the development of the software, as this is the EU recommended method and is also advised in the relevant Irish Statutory Instrument. This method describes a detailed procedure to calculate noise levels from road traffic and the attenuation of this noise.

The method allows for meteorological effects by calculating the noise level for two separate conditions, homogeneous conditions and conditions favourable to propagation. These two levels may then be combined by using the factor p, which represents the level of occurrence of favourable conditions, taking a value of between 0 and 1.

$$L_{Ai,LT} = 10log(p_i 10^{L_{Ai,F}/10} + (1 - p_i)10^{L_{Ai,H}}) \qquad (2.15)$$

If detailed meteorological data are not available, some default values for p have been set as 0.5, 0.75 and 1 for the day, evening and night periods respectively [18].

2.2.1 Segmentation of the source of noise

Although most engineering methods treat a road as a number of point sources, it is important to note that a vehicle is not a point source, but rather the sound field radiated by a real vehicle can be approximated by the sound field radiated from a finite set of incoherent point sources [34]. A single moving point source will change into a line source by integration over a long time period, and subsequently these line sources may then be divided into a number of incoherent, stationary point sources [35]. The line source may be divided into points by a number of methods: equiangular decomposition, decomposition by a uniform step or variable decomposition (a combination of both). However the length of step between two consecutive point sources should not exceed half the orthogonal distance between the point source and the nearest receiver. To account for this decomposition the level of sound power for a point source, per octave band, is then corrected, as described in 2.1.1 above, with the term $10log_{10}(l_i)$, where l_i is determined as shown in figure 2.2. This ensures a uniform representation of the source.

2.2.2 Attenuation of sound

Sound propagating outdoors generally decreases in level the further it travels from the source due to a variety of reasons; geometrical divergence of the sound, meteorological effects, presence of geographical barriers etc. It is possible to calculate how much the sound attenuates irrespective of the original sound level. The total attenuation term

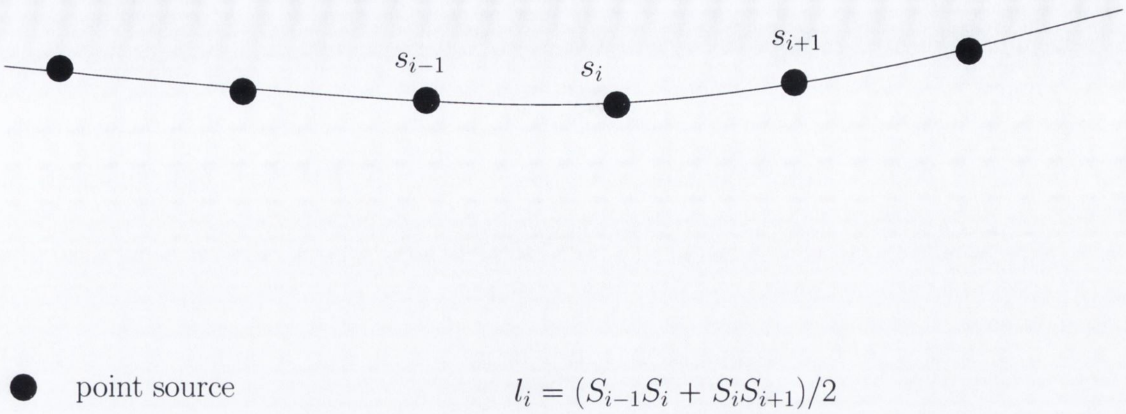

FIGURE 2.2: Segmentation of source

for each octave band, $A_{total,i}$, may be calculated as a sum of all different attenuation mechanisms. For homogeneous conditions this is expressed as:

$$A_{total,i,H} = A_{div} + A_{atm} + A_{gr,H} + A_{bar,H} \tag{2.16}$$

where

A_{div} is the attenuation due to geometrical divergence.

A_{atm} is the attenuation due to atmospheric absorption.

$A_{gr,H}$ is the attenuation that arises due to ground effect in homogeneous conditions.

$A_{bar,H}$ is the attenuation due to the presence of a barrier in homogeneous conditions.

while the noise level at a particular point of interest, $L_{A,i,H}$, may be calculated from :

$$L_{A,i,H} = L_{A,w,i} - A_{total,i,H} \tag{2.17}$$

where $L_{A,w,i}$ is the original sound power level produced by point source for each octave band, in homogeneous conditions. $L_{A,i,F}$, representing the sound level at the same point in conditions favourable to propagation, is calculated in a similar manner and the total sound level can then be determined from the equation previously presented in section 2.2.

2.2.3 Geometrical divergence

As a sound wave travels from a point source, it's energy is conserved but the energy of the wave must be spread out over a greater area. In XP S 31-133, geometrical divergence, A_{div} is accounted for by the formula:

$$A_{div} = 10log(4\pi d^2) \tag{2.18}$$

where d is the distance between the source and receiver, in meters. This signifies a sound level which decreases by 6dB per doubling of distance, or a 20dB reduction for each tenfold increase of distance. This is approximately equivalent to the ISO equation for geometric divergence:

$$A_{div} = 20log(\frac{d}{d_0}) + 11 \tag{2.19}$$

Geometric divergence is the only type of attenuation not related to the frequency of the sound. All other attenuation mechanisms are, and as such each type of attenuation is calculated over different octave bands. The frequencies considered are 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz.

2.2.4 Atmospheric absorption

As sound propagates through the atmosphere it's energy is gradually converted into heat. This leads to a decrease in the sound level at a receiver point located some distance from the source, although at distances close to the source the attenuation due to atmospheric absorption is negligible and only becomes obvious at great distances. XPS 31-133 references the method described in ISO 9613-1 to calculate the level of atmospheric absorption. This standard specifies an analytical method for the calculation of this attenuation and describes it in terms of an attenuation coefficient, which is dependent on four variables; the frequency of the sound, the atmospheric temperature, the humidity and the pressure of the air. Tables are provided in ISO 9613-1 for the attenuation coefficient given certain values of humidity, pressure, temperature and the frequency of the sound.

These variables are used to determine the value for atmospheric attenuation coefficient α. Supplied with ISO 9613-1 is a table which lists all the values for α for

- Frequency of the sound between 50Hz and 10kHz
- Humidity of the air as a percentage between 10% and 100%.
- Temperatures between -20^oC and 50^oC
- Pressure of 101,325kPa - one atmosphere

Once α is derived the attenuation of sound due to atmospheric absorption propagating through a distance d may be derived from:

$$A_{atm} = \frac{\alpha d}{1000} \tag{2.20}$$

2.2.5 Ground effect

The attenuation due to ground effect is principally dependent on the nature of the ground over which propagation occurs, i.e. whether it is acoustically absorbent or not, and the prevailing atmospheric conditions, as some conditions may cause curvature in the propagating sound waves. The following method describes the methods for calculating the attenuation due to ground effect both for homogeneous conditions and conditions favourable to propagation.

Characterisation of acoustic ground surfaces

The acoustic absorbent properties of a particular ground surface is directly related to it's porosity. Compact grounds are generally reflective and porous ground types are generally absorbent. The acoustical properties of different ground surfaces are expressed through the use of a ground factor G, which is assigned a value of between 0 and 1, for which two types of ground surfaces are defined. A value of 0 corresponds to a reflective ground surface, a hard surface, while a value of 1 represents an absorbent ground surface, a soft surface. The coefficient of G may take a value of between 0 and 1 to represent the proportion of absorbent ground surface between source and receiver, some examples of ground surfaces are displayed in table 2.3

Surface	*ExampleofSurface*	*Value*
Hard	Concrete, water, etc	G = 0
Soft	Grass, vegetation, etc	G = 1
Mixed	Both hard and soft ground	Between 0 and 1

TABLE 2.3: Assortment of ground types with associated value for G

Calculating A_{gr}: Favourable Conditions

In favourable meteorological conditions, the sound rays are curved towards the ground. Consequently, the ground effect is primarily influenced by the nature of the ground close to the source and close to the receiver. Indeed, taking into account the curvature of the rays, the propagation path is predominantly sufficiently high above the terrain in the middle of the propagation path and as such has only a minimal influence on the overall ground effect. However, over large distances, the propagation path can rebound on the terrain between source and receiver and must thus be accounted for. Calculations for ground effect are performed separately for the three different defined regions, the source region, the receiver region and the middle region.

Each zone will be influenced by the ground factor coefficient, G. The corresponding coefficient for each zone will be G_s, G_r and G_m. In the present case, only two coefficients are considered: the coefficient for the source region, G_s and G_{path}, corresponding to the average characteristics of the terrain over which propagation occurs, encompassing both the middle and receiver regions ($G_m = G_r = G_{path}$).

Depending on the source (road or rail), the ground located in the vicinity of the source is considered systematically:

- For a road source, the road is assumed to be of reflective nature G = 0, taking into account the carriageway of the road is much larger than the height of the source.
- For a rail source, the ground is assumed to be absorbent in nature.

To calculate the ground effect in the middle zone and the receiver zone, the value for G_{path} is equal to the fraction of absorbent ground over which propagation occurs. Consider the example shown in figure 2.3. In this case,

$$d = d_1 + d_2 + d_3 + d_4 \tag{2.21}$$

$$G_{path} = (0.d_1 + 0.d_2 + 1.d_3 + 1.d_4)/d = \frac{d_3 + d_4}{d} \tag{2.22}$$

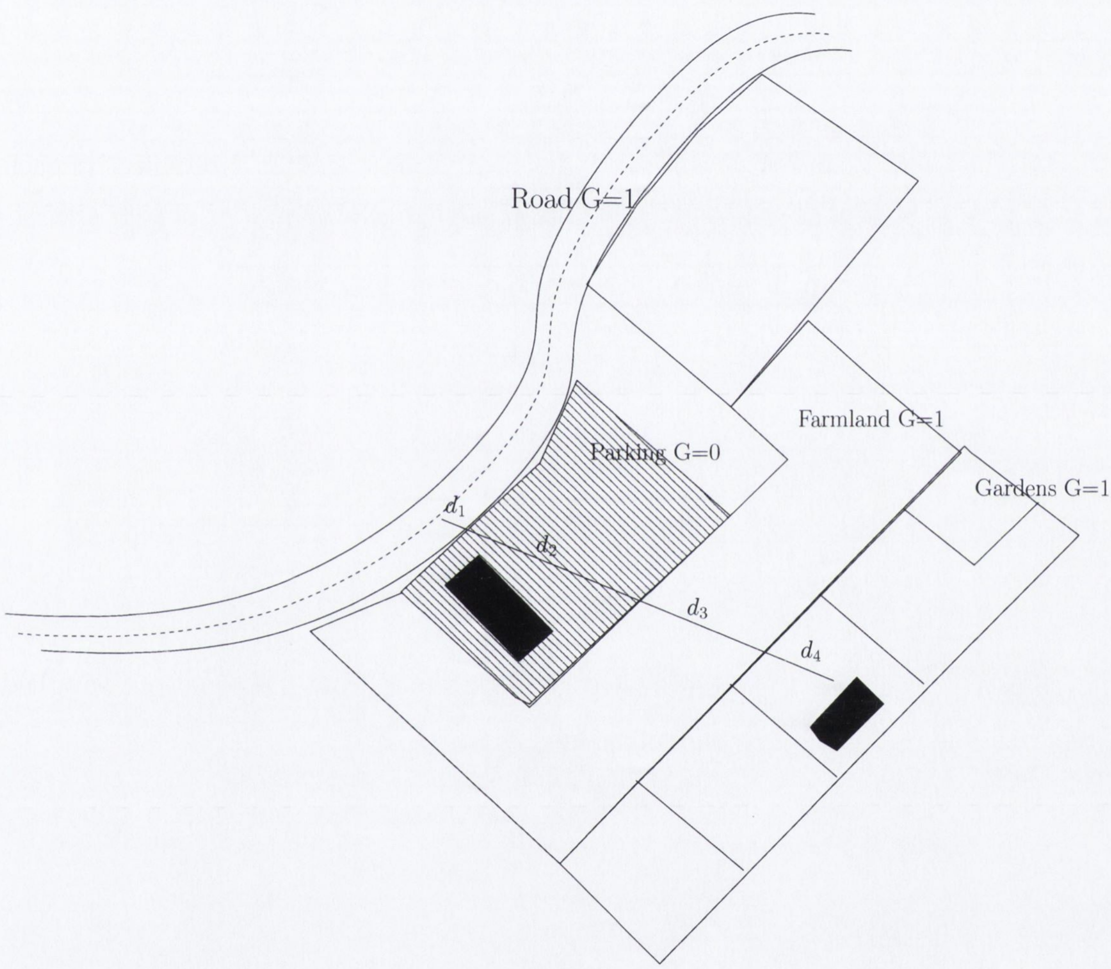

FIGURE 2.3: Determining G_{path} for a propagation path

In cases where the source and the receiver are close, i.e. $d_p \leq 30(z_s + z_r)$, the distinction between ground types near the source and receiver is not necessary. In certain conditions however, if the receiver is very near the edge of the road, one should consider a receiver of different ground type characteristics to the source. To account for this, the ground factor G_{path} is corrected in the following manner:

If $d_p > 30(z_s + z_r)$:

$$G'_{path} = G_{path} \tag{2.23}$$

If $d_p \leq 30(z_s + z_r)$:

$$G'_{path} = G_{path}\frac{d_p}{30(z_s - z_r)} + G_s(1 - \frac{d_p}{30(z_s - z_r)}) \tag{2.24}$$

The overall attenuation due to ground effect, in favourable conditions, is then calculated from

$$A_{gr} = A_{s,F} + A_{m,F} + A_{r,F} \tag{2.25}$$

where $A_{s,F}$, $A_{m,F}$ and $A_{r,F}$ represent the attenuation due to ground effect in each defined zone as calculated from the table displayed below.

Frequency [Hz]	$A_{s,F}$ or $A_{r,F}$ [dB]	$A_{m,F}$ [dB]
125	-1.5 + G.a'(z)	-3q(1-G)
250	-1.5 + G.b'(z)	-3q(1-G)
500	-1.5 + G.c'(z)	-3q(1-G)
1000	-1.5 + G.d'(z)	-3q(1-G)
2000	-1.5(1 - G)	-3q(1-G)
4000	-1.5(1 - G)	-3q(1-G)

TABLE 2.4: Formulae for calculating A_{gr}

where a'(z), b'(z), c'(z) and d'(z) may be determined from the equations supplied with the standard, and q may be determined from:

if	q
$d_p \leq 30(z_s + z_r)$	q = 0
$d_p > 30(z_s + z_r)$	q = 1 - $30(z_s + z_r)/d_p$

TABLE 2.5: Calculating a value for q

Note that the calculation of the attenuation due to ground effect in this manner is an assumption of the general case and as such does not consider the effects due to diffraction over discontinuous ground.

Calculating A_{gr}: Homogeneous Conditions

In the case of homogeneous atmospheric conditions, it is assumed that sound rays are rectilinear, thus no curvature occurs, so it is not necessary to identify the three different zones. In this case only the term G_{path} is considered to represent the propagation path which is calculated identically to the case of favourable conditions. The attenuation due to ground effect for homogeneous conditions is then calculated from:

- if $G_{path} \neq 0$:

$$A_{gr,H} = -10log\Big(4\frac{k^2}{d_p^2}(z_r^2 - \sqrt{\frac{2C_f}{k}}z_s)(z_r^2 - \sqrt{\frac{2C_f}{k}}z_r + \frac{C_f}{k})\Big) \geq -3(1 - G'_{path}) \quad (2.26)$$

where

$$k = \frac{2\pi f_c}{c} \quad (2.27)$$

f_c is the central frequency under examination, in Hz, and c is the speed of sound in air, ms^{-1}. C_f and w, which is a function of frequency and G_{path}, may be determined from:

$$C_f = d_p\frac{1 + 3wd_pe^{-\sqrt{wd_p}}}{1 + wd_p} \quad (2.28)$$

$$w = 0.0185\frac{f_c^{2.5}G_{path}^{2.6}}{f_c^{1.5}G_{path}^{2.6} + 1.3 \cdot 10^3 f_c^{0.75}G_{path}^{1.3} + 1.16 \cdot 10^6} \quad (2.29)$$

Note if $A_{gr,H}$ is less than -3(1-G'_{path}), $A_{gr,H}$ is taken to equal -3(1-G'_{path}).

- if $G_{path} = 0$:

$$A_{gr,H} = -3dB \quad (2.30)$$

2.2.6 Diffraction

If a barrier is situated between a source and receiver a correction must be applied to account for any subsequent attenuation. Generally sound will reach the receiver by diffraction over the top of the barrier or by direct transmission through the barrier. When calculating the attenuation due to diffraction over a barrier, A_{bar}, it is convenient to initially investigate if the level of diffraction is sufficient enough to impede the noise propagation. This is achieved by investigating the difference in sound path length, δ, i.e. the difference in path length that sound would travel from source to receiver with and without the presence of the barrier and identifying if this difference is significant enough to cause attenuation.

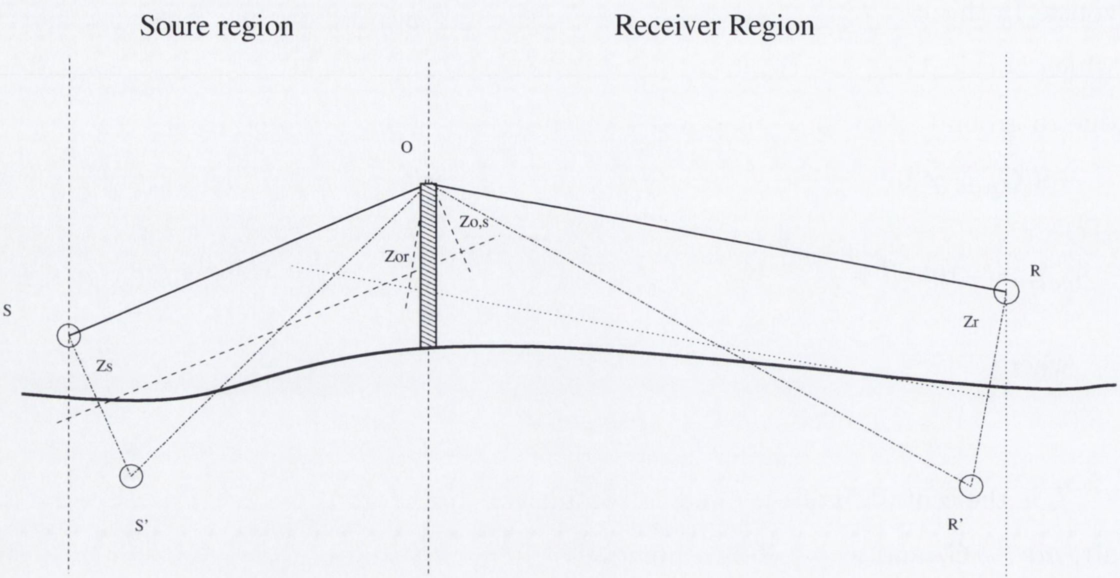

FIGURE 2.4: Calculating A_{bar}

When calculating attenuation coefficients, the attenuation due to the presence of a barrier will also effect the attenuation arising from ground effects and as such, results obtained for A_{bar} will directly impact on the value for A_{gr}. If the noise path passes sufficiently high over the top of the obstacle it is not required to carry out calculations for A_{bar}, it is assumed that the source and receiver are in direct sight of each other. In this case the ground effect is calculated as normal while A_{bar} is equal to 0 dB(A). However if the opposite is true and the barrier impedes the noise path, the following procedure must be adopted and A_{gr} is set to a value of 0 dB(A) as the ground effect is taken into account directly in the general formulae used to calculate A_{bar}.

Calculating A_{bar}

Figure 2.4 illustrates the general method for calculating the attenuation due to diffraction. This method is based on the method of decomposing the propagation path into two sections, the source region and the receiver region, as indicated in the diagram. To quantify the level of attenuation the following procedure should be adopted.

Step I

The first step to is to determine:

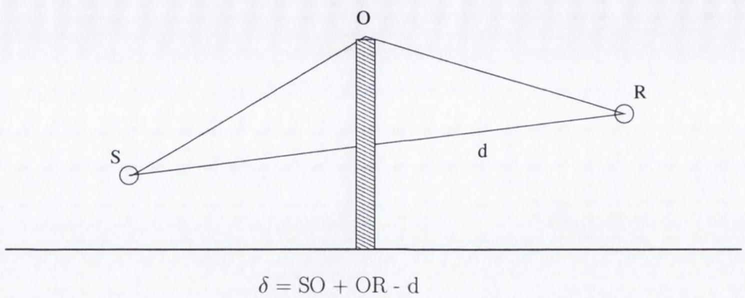

FIGURE 2.5: Simple Diffraction - R below O

- The ground type in the source region and receiver region

- The source image, S'

- The receiver image, R'

Step II

The difference in pathlength, δ, must be calculated for both homogeneous and favourable conditions. Homogeneous conditions are first examined. The pathlength difference is calculated in the vertical plane containing both the source and receiver as displayed in each of the figures below, 2.5 to 2.8, where O, O_1 and O_2 are the points of diffraction. This is an approximation of Fermat's principal and is acceptable when dealing with a line source. Fermat's principle, or the principle of least time, is the idea that the path taken between two points by a ray of light is the path that can be traversed in the least time. This principle is sometimes taken as the definition of a ray of light. Fermat's principle can be used to describe the properties of light rays reflected off mirrors, refracted through different media, or undergoing total internal reflection. It can be deduced from Huygens's principle, and can be used to derive Snell's law of refraction and the law of reflection.

It should be noted that the calculation of δ is not as straightforward in the case of conditions favourable to propagation. The curvature of the sound rays must be simulated by introducing the quantity ΔH which may be calculated from

$$\Delta H = \frac{d_1 d_2}{2\gamma} \tag{2.31}$$

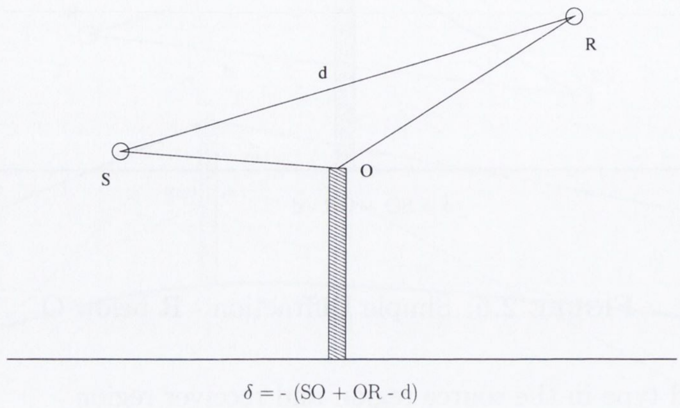

FIGURE 2.6: Simple Diffraction - R above O

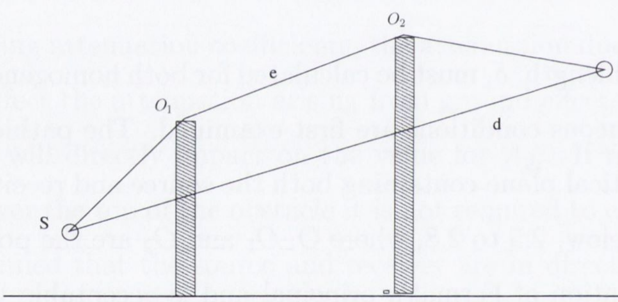

FIGURE 2.7: Double Diffraction - 2 separate barriers

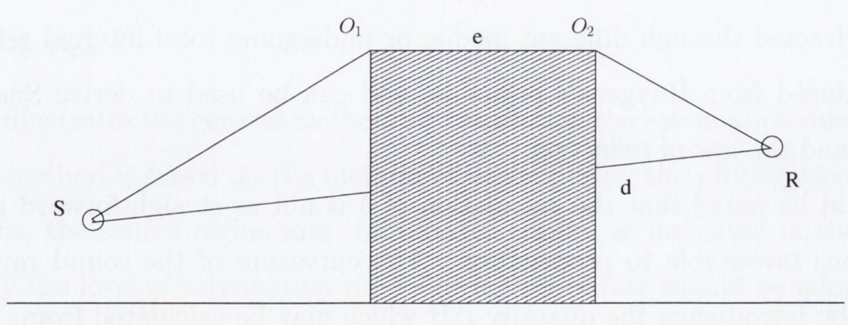

FIGURE 2.8: Double Diffraction - solid barrier

where γ represents the acoustic ray curvature, in metres. γ is approximately equal to 8d, where d is the direct distance of propagation, with a minimum value of 1000m, if γ is less than 1000m, then γ is assigned the default value of 1000m.

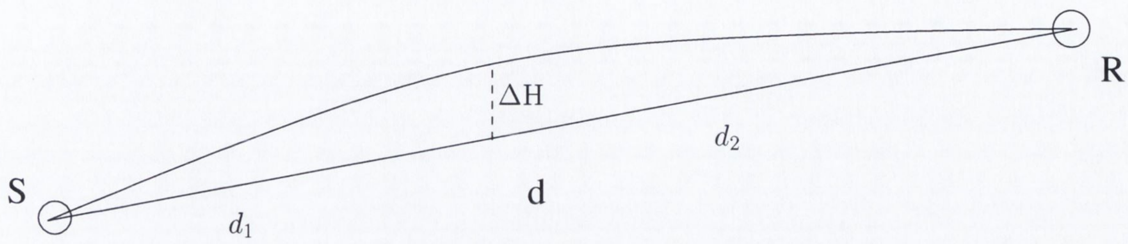

FIGURE 2.9: Determining Δ H

In conditions favourable to propagation, δ is calculated from the formulae presented in the figures below, 2.10 to 2.12. If S and R are in direct sight, the value for δ will be negative. It is possible that the noise path will be obstructed in homogeneous conditions but not in favourable conditions, as is presented in figure 2.11 as the acoustic rays circumvent the diffracting edge.

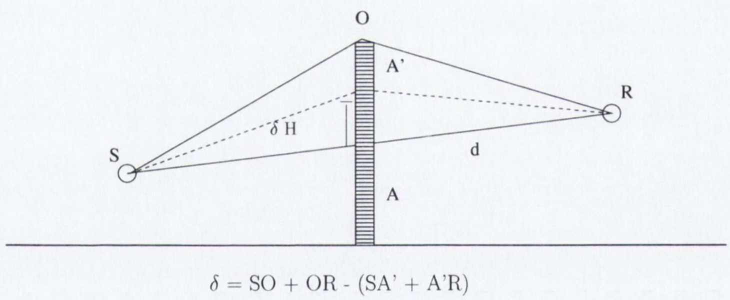

FIGURE 2.10: Favourable conditions scenario 1

For multiple diffraction in favourable conditions, the following principles must be followed:

a) determine the point A from the quantity ΔH calculated from the diffracting edge

b) eliminate any edges leading to negative diffraction

c) determine the sound path resulting in the shortest distance from source to receiver and passing by each point of diffraction. An example is presented in figure 2.13

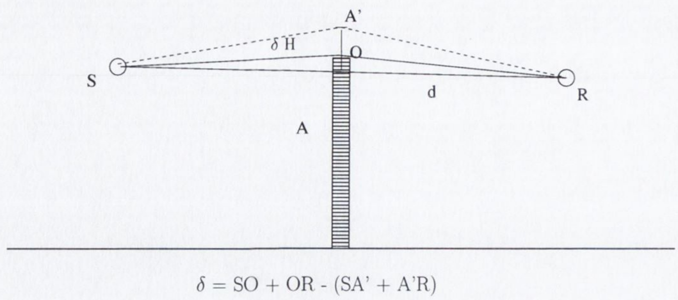

FIGURE 2.11: Favourable conditions scenario 2

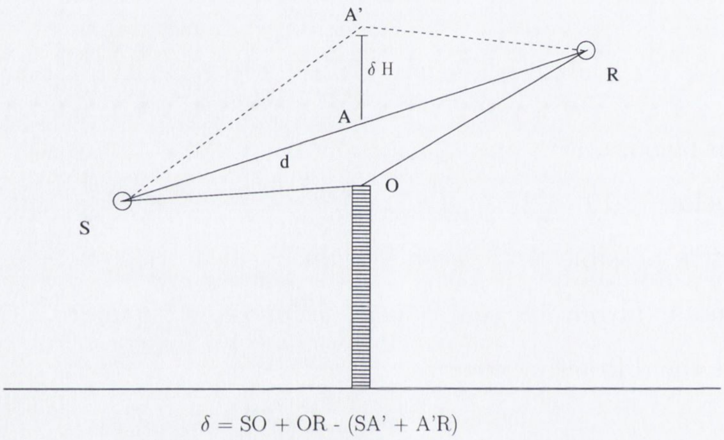

FIGURE 2.12: Favourable conditions scenario 3

In order to determine if there is really an effect of diffraction, the pathlength difference is compared to the quantity λ / 20 at a frequency of 500Hz, about 0.034m.

If the difference in pathlength is less than 0.034m, it is not required to calculate A_{bar}, the source and receiver is considered to be in line of sight and A_{bar} is zero for each octave band. However in the opposite case one must apply the following formulae for each octave band. In doing so A_{gr} is now zero as the effect of ground attenuation is included in the calculations for A_{bar}. This rule is applicable for all cases, homogenous or favourable conditions, multiple or single diffraction.

Step III

For pure diffraction, with the absence of ground effect, the attenuation is given as:

-if $(40/\lambda)C''\delta \geq -2$:

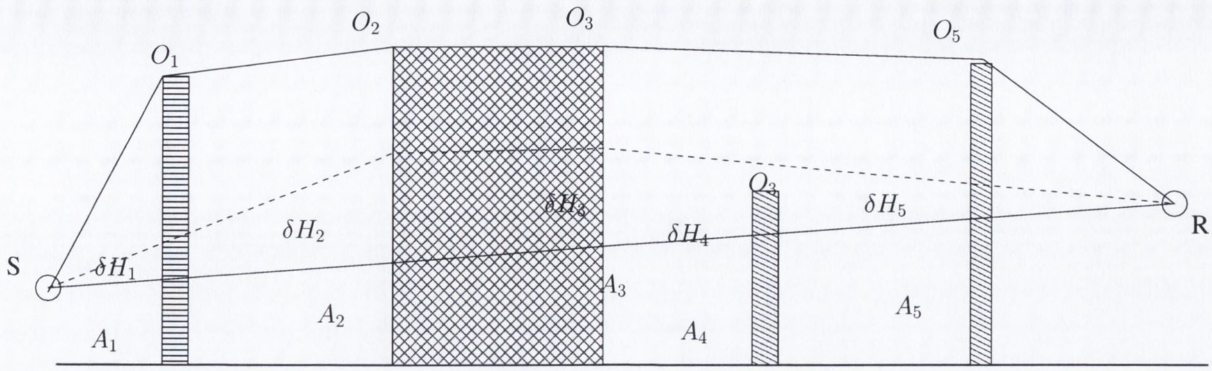

FIGURE 2.13: Calculating pathlength difference with multiple Diffraction

$$A_{bar} = 10log(3 + (40/\lambda)C''\delta) \tag{2.32}$$

-if $(40/\lambda)$C"δ < -2:

$$A_{bar} = 0dB \tag{2.33}$$

where:

λ is the wavelength of sound of the nominal central frequency for each considered octave band

δ is the difference in pathlength between the diffracted path and direct path

C" is the coefficient accounting for multiple diffraction:

$$C'' = \frac{1 + (5\lambda/e)^2}{1/3 + (5\lambda/e)^2} \tag{2.34}$$

The above formula is to be applied in the case of single diffraction, for multiple diffraction C" is calculated as the total difference between the two extreme diffracting edges, see figures 2.7 and 2.8 above

The final calculated values for A_{bar} must lie between 0dB and 25dB. This means that if A_{bar} exceeds 25dB, it then assumes the value of 25dB, and likewise if A_{bar} is negative, it is equal to 0dB. This is an important consideration when it comes to implementing this type of attenuation in a computer model.

Step IV

The attenuation $A_{gr(S,O)}$ must also be considered and is calculated from:

$$A_{gr(S,O)} = -20log\Big(1 + \Big(10^{-A_{gr(S,O)}/20} - 1\Big)\Big)10^{-(A_{bar(S',R)} - A_{bar(S,R)})/20} \tag{2.35}$$

where $A_{gr(S,O)}$ is the effect of the attenuation due to the ground between the source S and the point of diffraction O, for the road surfaces and when the edge of diffraction is not too high, one can assume this term has the value of -3dB, in order to account for reflection on the surface: $A_{gr(S,O)}$ = -3dB in homogeneous and favourable conditions. In other cases $A_{gr(S,O)}$ may be calculated separately.

Step V

Finally the attenuation due to diffraction is then calculated by examining the effects in the source region and receiver region,

$$A_{bar} = A_{bar(S,R)} + A_{gr(S,O)} + A_{gr(O,R)} \tag{2.36}$$

Simplified treatment of housing

In a densely populated area with multiple houses it would be quite time consuming to calculate the attenuation due to each individually building and barrier. ISO 9613 offers a suitable alternative, developing a simplified approach to determine the effect of diffraction. It states that this effect may largely be compensated by propagation between houses and reflections from other houses in the vicinity.

An approximate value for the attenuation in a built up region, A_{house} may be estimated from two separate contributions, $A_{house,1}$ and $A_{house,2}$ from the equation:

$$A_{house} = A_{house,1} + A_{house,2} \tag{2.37}$$

where $A_{house,1}$ is dependent on the density of the buildings along the propagation path, B, and the length of the propagation path through the built up region, d_b.

$$A_{house,1} = 0.1Bd_b \tag{2.38}$$

$A_{house,2}$ may be included if there are a well defined row of buildings near a road provided this term is less than the insertion loss of a barrier at the same position with the mean height of the buildings, and may be calculated from the following formula where p, representing the percentage of the length of the facade relative to the total length of the road, is $\leq 90\%$.

$$A_{house,2} = -10log_{10}\left(1 - \left(\frac{p}{100}\right)\right) \tag{2.39}$$

As before, the value for $A_{house,1}$ will also interact with A_{gr} which must be adapted accordingly.

2.2.7 Reflections

XP S 31-133 also sets out a method for calculating the effect of reflections in an area. Vertical reflections for objects are treated according to the image source.

One considers an obstacle to be vertical if it is inclined at an angle of less than 15^o. To examine obstacles inclined at a greater angle, it is necessary to apply this method in three dimensions.

The obstacles whose dimensions are small with respect to the wavelength of the sound should be neglected for the calculation of reflection. The reflections on the ground are not treated here: they are incorporated directly in calculations for ground effect and diffraction.

If L_w is the level of power of the source S at α_r the coefficient of absorption, on the surface of the obstacle, the level of power of the source image S is equal to:

$$L'_w = L_w + 10log(1 - \alpha_r) \tag{2.40}$$

Chapter 3

Development of baseline noise maps

In order to satisfy Work Package 2.1 of the ETI Project, it was necessary to create some baseline noise maps which would then form the platform from which further improvements could be developed. This was initially achieved by utilising readily available commercial software. ArcGIS was used as a G.I.S. package while Bruel and Kjaer's Predictor was used for all noise predictions.

A noise map is a graphical representation of the situation with regards to noise in a particular area with different colours representing different noise levels in dB(A). According to the END a noise map should present data on an existing, a previous or a predicted noise situation in terms of a noise indicator, the exceeding of a limit value and an estimation of the number of dwellings, schools and hospitals in a given area that are exposed to specific values of a noise indicator. Special emphasis should be placed on road traffic, rail traffic, airports and industrial activity sites. In general a noise map determines the noise level from a variety of sources present and calculates the resulting noise propagation over a defined area.

For a preliminary study, the area surrounding Trinity College, in the heart of Dublin, Ireland was examined. To produce the baseline maps for this test location a certain amount of input data was required; traffic composition, traffic speed, the position of geographical features, meteorological conditions etc. Initially this information was obtained from Dublin City Council. The primary aim of this exercise was to develop a noise map in the same manner as would be developed by the responsible authorities and thus encounter many of the problems that would generally be faced throughout the production process.

In order to create even a simple noise map, it is necessary to gather a very large amount of data, which was deemed impractical in some cases. This meant a certain amount of assumptions and averages would have to be made in order to produce a noise map, leading to some degree of uncertainty in results.

In addition to a map showing contours of noise in an area, a certain amount of information is required to accompany each noise map in order to satisfy the EU directive. Some of the additional information required includes: a concise description of the area under examination, the name of the authority responsible for the map, information on any noise control programmes that have been carried out in the area and the computation or measurement methods that have been used must be sent to the Commission. The levels of the most exposed facade of a dwelling and how many people are living in a dwelling with a quiet facade are also requested, each posing a difficult task for authorities to determine throughout the process. A quiet facade is defined as a facade of a dwelling at which the L_{den} value is more than 20 dB lower than at the facade having the highest L_{den} value.

3.1 Software in use

The accuracy of final results will depend greatly on the accuracy of input data and how this data is handled at each stage of the process. It is essential to have accurate map data in the calculation of reliable noise maps as incorrectly positioned roads or barriers may significantly reduce the accuracy of the calculated result. As such a G.I.S. application is used to gather the necessary data. An appropriate use of G.I.S. makes it possible to optimise the quality and effectiveness of noise studies. G.I.S. (Geographical Information System) is a system of computer software, hardware and data used to manipulate, analyse and present data that is relevant to a spatial location. G.I.S. combines layers of information relative to an area in order to provide a detailed description of that area. The co-ordinate system for each layer is carefully designed so that as each layer is combined, they align perfectly together. This process is called geo-referencing. Noise effects may be determined by combining certain layers and results may then be compared with where people live or where certain activities take place, providing a useful tool when determining population exposure levels and other requirements of the END.

The G.I.S. application used in the course of this project is ArcGIS which is developed by ESRI. ArcGIS is used primarily in the presentation of the noise maps and data collection while all the relevant calculations are performed elsewhere. This means that data must be exported from ArcGIS to another package. In order to achieve this some knowledge of the ArcGIS file structure in necessary.

Bruel and Kjaer's $Predictor^{TM}$ (Predictor) is a noise prediction software package developed by the Dutch software developers DGMR. It imports data contained in shapefiles which are initially created in the GIS package, in order to display the roads, buildings, barriers, etc present in the area. Alternatively this data may be manually inserted into a project by the user, which is quite a time consuming process and impractical for creating noise maps of large areas. Once the topographical data is imported the user must input data with regards to traffic levels, road properties, meteorological conditions etc. The software will then calculate the noise levels at various grid points according to whatever engineering method is defined. A number of methods are supported including CRTN, ISO 9613, NMPB and Harmonoise. Predictor is widely used in Ireland today and as such is the commercial predictive software of choice for this particular project.

3.2 Producing baseline maps

To produce the noise map for the test location, certain data had to be adapted to suit whichever engineering method was to be used, as different methods require different forms of data, particularly when inputting traffic details. Several noise maps for a portion of the test area were created with Predictor following three different calculation methods; an initial version of the Harmonoise Standard, CRTN and XP S 31-133. These were then compared directly with one another to investigate variation in levels.

3.2.1 Data input

Limited data were available so several assumptions had to be made. Traffic flow data had to represent a full year and was adapted accordingly. Where possible solutions as suggested by the Good Practice Guide (GPG) were followed [3]:

- *Roads Shapefile*

  The spatial position of each road is required in the form of a shapefile. This was then imported directly into ArcGIS and transferred to Predictor. The characteristics influencing noise generation for each road were also required and were stored in the shapefile's associated database.

- *Buildings Shapefile*

  The presence of buildings and barriers will influence the direct propagation of sound. If obstacles are positioned inaccurately it may significantly reduce the accuracy of the noise map and undermine any associated action plans. The height of each barrier and building is required along with its spatial position. If the height of a building is incorrect or unknown it may have an impact on final results. In the data received from Dublin City Council, the height of each building was supplied.

- *Topographical Data*

  The presence of hills and valleys will influence the propagation of noise, as the ground profile may result in the existence of some earth barriers. In addition to this, a gradient in the road will also influence the level of noise produced at the source. However, as this data was unavailable, it was assumed that Dublin is predominantly flat. The error associated with this assumption was presumed to be negligible as the test area was in an urban environment and was predominantly flat.

- *Traffic Flow*

  Traffic data was also obtained from Dublin City Council. This data was averaged over the first 6 months 2005 and was assumed to be representative of the entire calendar year. It was presented as hourly traffic counts and was thus easy to adapt to obtain counts for the day, evening and night time periods.

- *Traffic Composition*

As the percentage of traffic composition was unknown, the suggestions outlined in the Good Practice Guide were followed. Sample traffic counts were conducted throughout the day period on a selected number of roads and similar types of roads were assigned those compositions. As the CRTN method and XPS 31-133 do not have a vehicle classification system including medium vehicles, for the purpose of comparison with the Harmonoise model, medium vehicles were regarded as a mixture of light and heavy vehicles.

Displayed in the table below is the average traffic composition on a typical Dublin city centre road:

TABLE 3.1: Average Traffic Composition

Road	*% Light*	*% Medium*	*% Heavy*
Typical Road	75	15	10

- *Traffic Speed*

As regards speed data, the simplest solution was to use the sign-posted speed limit, which was 50km/hr in all areas of the test location. This is one possible suggested by the Good Practice Guide [3]. Free flow traffic speeds were also investigated leading to a different result for the average speed. Other alternatives were also explored, including measuring traffic speed by means of radar techniques and actually physically driving through the area and noting the average speed. The table below shows different results obtained. More details of this work is presented in Appendix C.

It is evident that different values will be arrived at depending on which method is used. It is also quite clear the actual driving speeds are quite lower than signposted speeds, which would be the easiest and cheapest solution if traffic

TABLE 3.2: Average Traffic Speed

Method	*Average Speed [km/hr]*
Signposted Speed Limit	50
Average Free Flow Speed	36
Average Radar Speed	32
Average Driving Speed*	14

data is unknown. It is important to identify how these varying values for average traffic speed will influence final results.

The average traffic speed, determined with the radar gun was significantly lower than the signposted speed limit but greater than the average speed recorded when driving. It should be noted that the recorded driving speed would have been influenced by traffic congestion, accelerating, decelerating and waiting at traffic lights, while the speeds determined by radar were recorded while the traffic was flowing. Based on these figures a uniform speed of 30km/hr was assigned to all roads in the area.

FIGURE 3.1: Determining Traffic Speed by Radar

- *Road Surface*

The road surface type of each road was also unknown. The default value of dense asphalt was selected. The type of road surface will have an influence on final results as some road surfaces result in louder noise levels generated at the source. However the roads in the test case were all of uniform type.

- *Road Gradient*

  The gradient of the road may affect the level of noise produced at the source. Vehicles work harder as they travel uphill, which is important at the low speeds in an urban environment when engine noise dominates. However, it was assumed for this exercise that Dublin is completely flat. This will slightly under predict noise levels produced by vehicles driving uphill while over predict noise levels produced by vehicles travelling in the opposite direction. Taking this into account with the relatively flat test area, it is reasonable to assume that this approximation will result in a negligible error at the source.

- *Meteorological Conditions*

  Prevailing meteorological conditions proved to be another factor that had to be accounted for. However it is suggested in the Good Practice Guide that "within a dense urban setting, due to the closeness if buildings and the varying widths of roads etc, meteorological conditions, when compared to other variables, do not have a dominant effect on sound pressure levels. In most situations they can be ignored". Thus the effect of meteorological conditions was assumed to be negligible, however the average meteorological conditions were noted for reference.

3.2.2 Resulting noise level

Once all the input data were collected and imported into Predictor, the noise calculations could begin. It was decided to run calculations for each standard. Each simulation took a different length of time to compute due to the varying complexity of calculations for each standard. A summary of each calculation is shown below in table 3.3.

Upon completion of all calculations, the results were then exported from the mapping software to ArcGIS in order to display results in an effective manner. A number of issues arise in the determination of resulting noise levels:

Calculation Method	*Num. Sources*	*Num. Receivers*	*Elapsed Time*
Harmonoise	405	6175	323 minutes
CRTN	135	6175	55 minutes
XPS 31-133	540	6175	50 minutes

TABLE 3.3: Comparing calculation time for each computational model

- *Position of Receivers*

To comply with the directive, receiver points must be set to a height 4.00 $\pm$ 0.2m above the ground. In order for a direct comparison of noise maps and measurements, measurements should be made at a microphone height of 4m. This will make it difficult for members of the public to independently verify calculated noise maps.

- *Noise Indicator*

Maps were expressed in terms of L_{den}, however it was also possible to plot maps according to L_{day}, $L_{evening}$ and L_{night}. L_{den} is a long term equivalent sound level so the L_{eq} levels calculated in XP S 31-133 are suitable to determine L_{den}, however the CRTN L_{10} indicator is not suitable to adapt to L_{den} and some degree of manipulation is required as previously outlined in section 2.1.2.

- *Interpolation Method*

Results were imported into ArcGIS and it's mapping tool was used to generate a contour map of the noise levels. A number of interpolation methods were available; inverse distance weighted, spline and kriging. It has been demonstrated in [36] that noise maps may vary considerably depending on the type of interpolation used at this stage. A need for a standard data interpolation method for noise mapping studies has thus been identified. In this case the inverse distance weighted technique was used for all maps.

3.2.3 Further aspects of the Directive

Once noise contours have been plotted in ArcGIS and a noise map has been presented, it is important to note that the noise study is not yet complete as regards satisfying the END. The Directive also calls for more information to be recorded:

- The estimated number of people living in areas exposed to certain noise levels at the most exposed facade, calculated separately for road, rail, air traffic and industrial sources, for both L_{den} and L_{night}.

- The existence of quiet facades must be noted.

- The estimated number of dwellings, schools and hospitals exposed to different noise levels.

- The exceeding of a limit value, the value of which is left to the discretion of the Member State.

- Any dwelling with special insulation.

- For roads, railways and airports, the total area, in km^2, exposed to values of L_{den} higher than 55, 65 and 75 dB.

In addition a report must be submitted with the noise map providing a concise description of agglomerations, along with a summary of any noise control measures that have taken place in the past. This report should also assess the need for implementing further control measures and should set both long-term and medium-term goals for the reduction of the amount of people exposed to excessive environmental noise levels.

3.3 Initial results

It was important to create the baseline noise maps in order to identify potential pitfalls in the process. It is apparent that the collection of necessary raw data is an issue of extreme importance and should be addressed with care. In addition the data manipulation required to export from ArcGIS to Predictor was identified as an unnecessary and time consuming step. It was also evident that a clear interpretation of results was not possible, as it is unclear as to how exactly Predictor implements each standard.

A selection of calculation procedures appropriate for use in Ireland were also examined in order to have a clear understanding of how results will vary depending on the chosen standard. The next section displays a number of initial baseline noise maps, calculated with Predictor and displayed in ArcGIS, following three different calculation procedures; the CRTN method, the Harmonoise method and the recommended interim method, XPS 31-133.

3.3.1 Alternative standards

Figures 3.1 to 3.3 show the noise maps created from each corresponding prediction method. The fact that each map was created using three different procedures means that a direct comparison between maps may not be appropriate. This problem is at the core of the END and has been addressed by the development of a proposed universal calculation procedure. However by displaying maps using the same indicator L_{den}, this problem is overcome to some degree. It is evident that the three noise maps vary to some extent, with the Harmonoise model calculating more extreme attenuation behind buildings and barriers.

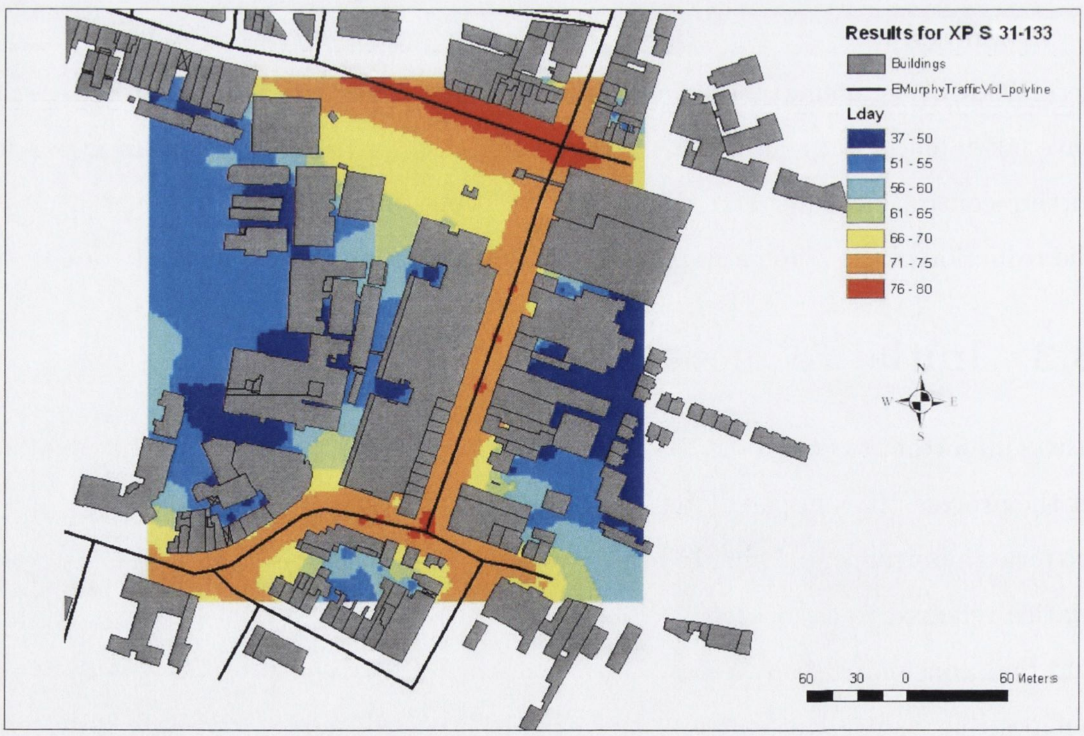

Figure 3.2: Noise map calculated following XPS 31 - 133

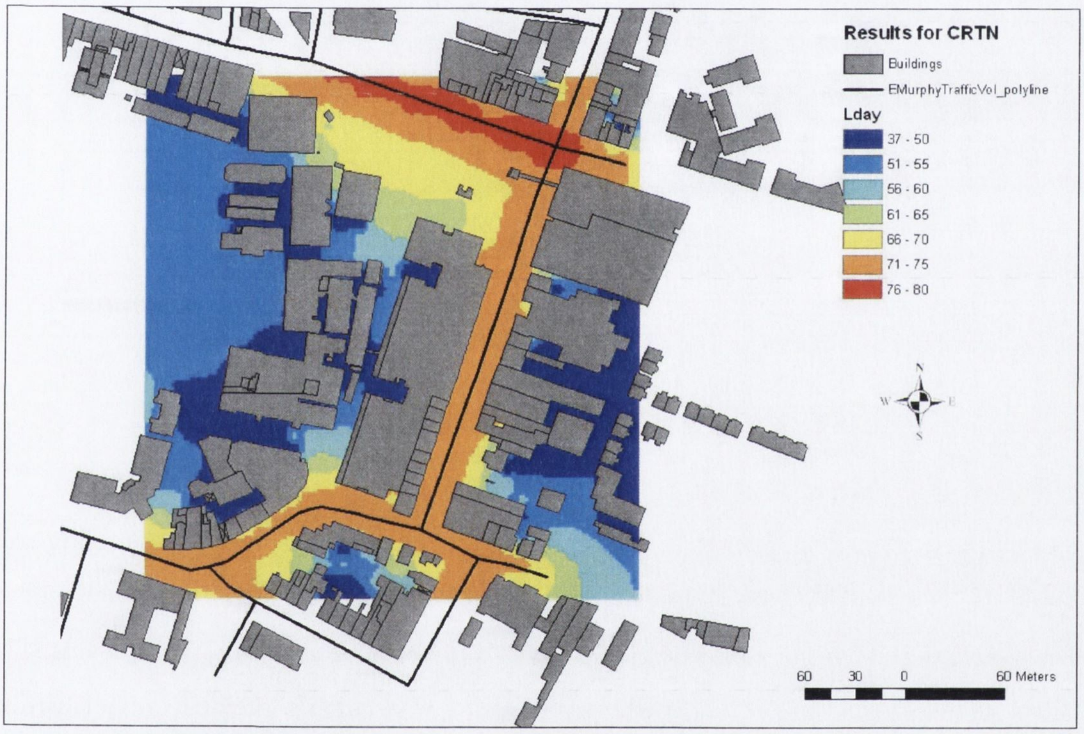

FIGURE 3.3: Noise map calculated following CRTN

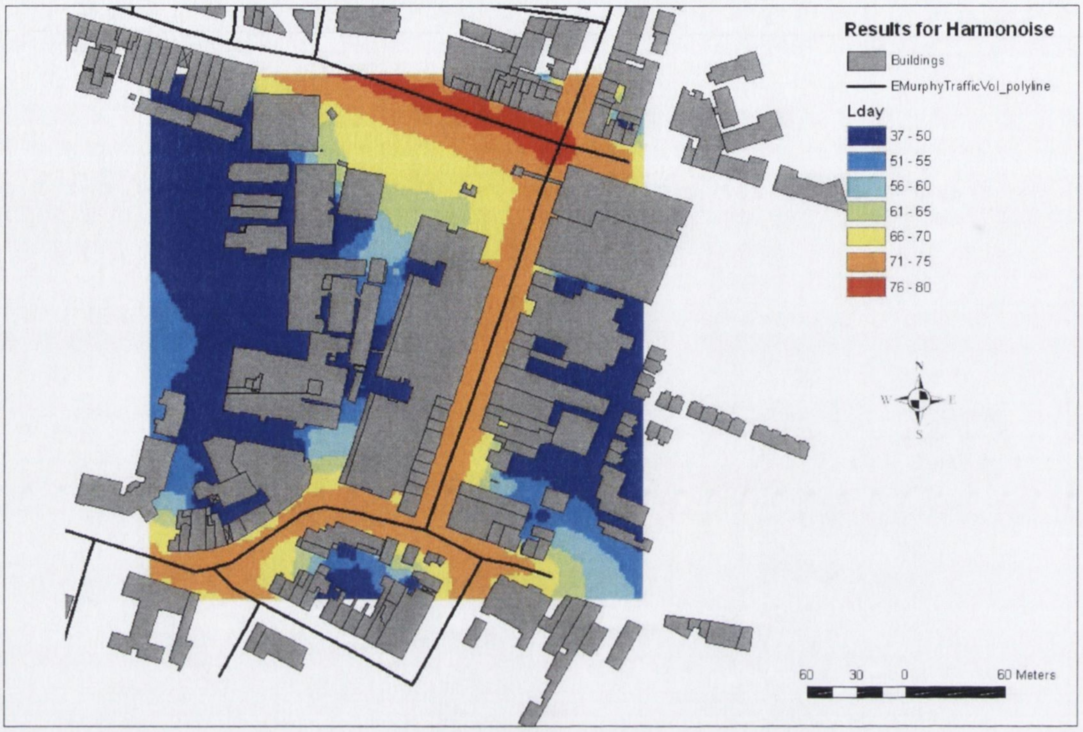

FIGURE 3.4: Noise map calculated following Harmonoise

The purpose of the Directive was to define a common approach to managing noise problems. It is evident that there was some need for this as it is clear that each method used above do not agree with each other, particularly in areas of low noise levels. This will be of particular importance when the effects of resulting actions impact directly on members of the public. If an action plan recommends the implementation of a controversial strategy, the results of the corresponding noise map will be publicly scrutinised. Therefore it is vital that maps are displayed as clear as possible with an in-depth analysis of results.

The development of the Harmonoise standard will provide a uniform standard, but it may be an overcomplicated and unpractical solution. It may be seen from results that the Harmonoise noise model calculates much more extreme attenuation. In fact it calculate levels of below 40dB in certain locations behind clusters of building, which may not be reflected in measurements as the ambient noise will influence these low levels. Interestingly the CRTN model and XPS model compare relatively well. The

Table 3.4: Comparison Statistics - results displayed in dB(A)

Statistic	*XP S 31 -133*	*CRTN*	*Harmonoise*
Min Level	43.00	41.04	22.05
Max Level	78.00	77.00	77.00
Mean Level	60.60	58.99	55.56
Standard Deviation	9.64	10.59	14.18]
Computational time	40 mins	55 mins	5hrs 23mins

XPS model calculates a slightly louder source which influences the overall sound levels.

However, upon a close examination of results it is noted that the complex Harmonoise model took longer to compute and while it may have calculated a more accurate map given the input data, it required more input data, some of which was not available and produced results that did not differ a great deal from the two less complex models.

Overall it is evident that the calculated noise maps from each model are, on the whole, quite similar. The loudest road is easily identifiable and quite areas are also very much apparent, albeit, the models disagree with the extent to how quite these areas actually are. While the Harmonoise model is assumed to give results to a higher accuracy, it is hard to justify the significant increase in computational time. Furthermore, it must be assumed that errors are present in each model considering the assumptions applied to the input data in section 3.2.1. Thus a balance between accurate calculation of the scenario and efficient computational loading is a desirable aim.

3.3.2 Alternative software

It was expected that each standard would give alternative results, however it should be noted that the results obtained will also depend on how accurately each standard has been implemented by the software developer, as a alternative interpretation will result in different results. A study of a number of software packages produced a comparison between five different software packages (identified as Software A, B, C, D, and E) with results obtained by manually calculating noise levels following the

CRTN standard revealed the extent of variation between several packages [37]. Most results were within 1dB(A) of the calculated result, however the result did demonstrate the variations from the predicted methodologies by the various packages as displayed in table 3.5.

Table 3.5: Range of discrepancy between various software and hand calculated results

Software	Difference [dB(A)]
A	-1.4 to +0.5
B	-0.8 to +1.0
C	-2.5 to +1.3
D	-1.8 to +0.6
E	-3.0 to +0.8

Results obtained from the various packages were also compared over a 1 km^2 area of a city. Again a significant variation in results was noted, in one location a difference of 11dB(A) was observed. It may be concluded that the use of different software with the same input data can have significant difference on the resulting noise map.

This also highlights the problem associated with the black box approach. As the manner in which standards are implemented in commercial software packages may not be explored, it is not possible to determine why the variation in results exist. This may also be a problem for future standards as it has been identified that the current description of the Harmonoise standard does contain some unclear phrases, inconsistencies and loose ends. It is not a robust document for software implementation yet [38].

3.3.3 Initial conclusions

Following the development of these baseline noise maps it was possible to identify a number of issues which will impact future noise studies. The level of data required to make an accurate map was determined along with the steps that have to be taken to develop a noise map. It was evident that a large amount of input data will not be available and as such have a direct effect on the accuracy of the final noise map. Additionally a number of less obvious issues were uncovered and a number of these could be addressed in order to improve the overall mapping process. Most notably:

- Different calculation methods will yield different results. This was most noticeable in the new Harmonoise method. It is expected that this method is most accurate but considering the absence of quality input data, the benefits of such a method are questionable.

- Different software packages following the same calculation method may yield different results. This may be of some concern if different studies of the same area yield different results, or if maps created by different software packages have to be combined to form a complete noise map.

- The emission model is by far the chief source of error and uncertainty. Errors at the source of the noise will have an impact over the entire map.

Chapter 4

An enhanced mapping tool

Throughout the course of this project a number of tools were developed to aid the mapping process. Each tool was used to supplement the analysis and presentation of relevant noise maps and each played an integral role in the noise study. Chief developments include: the creation of independent noise prediction software, the production of purpose built noise monitoring instrumentation and the design and maintenance of a custom-built website. During the development of the monitoring instrumentation groups from different work packages of the ETI Capability Development Project worked closely together. Each tool then combined together to form the basis of an advanced noise mapping model, capable of delivering an overall solution to the challenges of the END.

It is imperative that maps are developed and presented in a fashion that will be accessible to the general public. The development of an independent noise prediction model is the first step to meeting this objective. The next step involves a detailed measurement campaign and presenting results in dynamic fashion, adapting to various different acoustic scenarios. This type of interactive map will enable maps to be displayed in a unique fashion; displaying error, displaying the different effects of various action plans, presenting how noise varies throughout the year, at different times of the day, for different meteorological conditions etc.

Although it is not required by the END to produce a map in such a fashion, it will serve public knowledge and assist the involvement of the general public when deciding what action plans to adopt in the near future. The Working Group for the Assessment of Exposure to Noise recognises the need for accurate maps that will stand up to scrutiny when it states "The END noise maps and subsequent action plans are probably the highest profile activity that the acoustics and noise control community has carried out in the public's eye. Based on previous experience, the generation of these results will probably lead to articles within the media. Articles may compare adjacent towns or cities. In order that the industry's credibility is upheld, good results and robust recommendations for action plans should be a desirable aim"[3].

4.1 "Predict-a-*Flash*"

It was quickly recognised from the onset of this research that if commercial software is used in the development of strategic noise maps, users will be quite restricted as to how data is handled, how maps are presented and in some cases the size of area that may be mapped and the computational resources that may be used due to licensing restrictions and shortcomings in the design of the software. As a result it was decided that the development of *in-house* software which would be completely versatile and computationally efficient was imperative, particularly in the development of refinements to the noise map which would include features not available elsewhere.

"Predict-a-*Flash*" was originally developed in Matlab, with the primary goal to investigate whether one could produce accurate results using the standard commercial tool (Predictor) as a benchmark. This involved implementing the chosen calculation method in a computer model and comparing predicted noise levels for the test site to those of Predictor. When this was accomplished the goal turned to computational efficiency, i.e. to produce results in a time efficient manner and to investigate the possibility of developing a simple, stand-alone executable program, which would offer a real alternative to today's commercial software.

The propagation model used by the software was developed following the French national computational model XPS 31-133, as outlined in chapter 2, which is the recommended interim method to be used by Member States [4] and one of the methods adopted by the Irish Governing Body [20]. The source model follows procedures outlined in the associated French model NMPB-Routes-96. The division of calculations into two separate models, the source model and the propagation model, is also recommended in the new Harmonoise model, which will prove useful when redesigning the software to accommodate the Harmonoise standard.

In 2002 Wolfel were commissioned to produce a report concerning the adaption and revision of the interim computational methods for strategic noise mapping [18]. This purpose of this report was to provide Member States guidelines on how best to implement the interim standards. A number of adjustments are suggested and some of these recommendations are included within Predict-a-*Flash*'s core calculation engine.

4.2 User-interface platform

The developed model links data from ArcGIS, Microsoft Access and Microsoft Excel. Using Microsoft Access it was possible to develop a custom built platform which allows easy viewing and editing of data and is designed in a user-friendly, self explanatory manner, meaning no expertise is required. A screen shot of this platform is shown in figure 4.1. The platform itself can be launched internally from the ArcGIS toolbar.

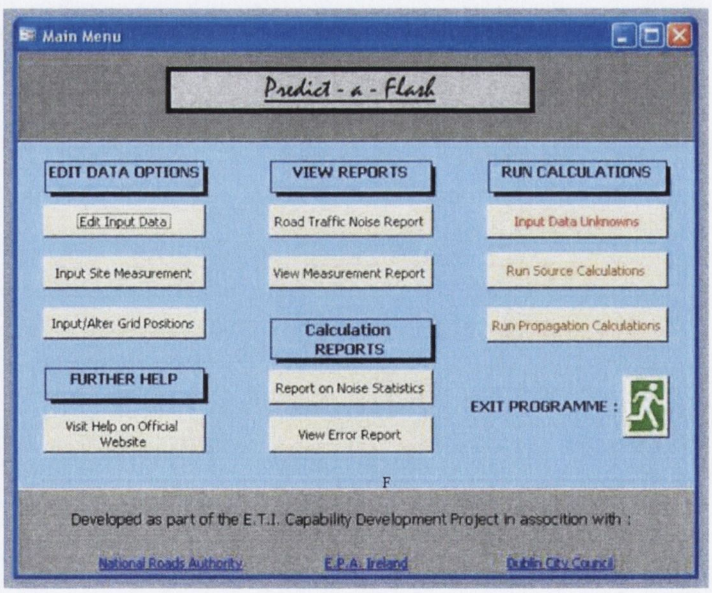

FIGURE 4.1: Screen-shot of Predict-a-*Flash*'s front-end platform

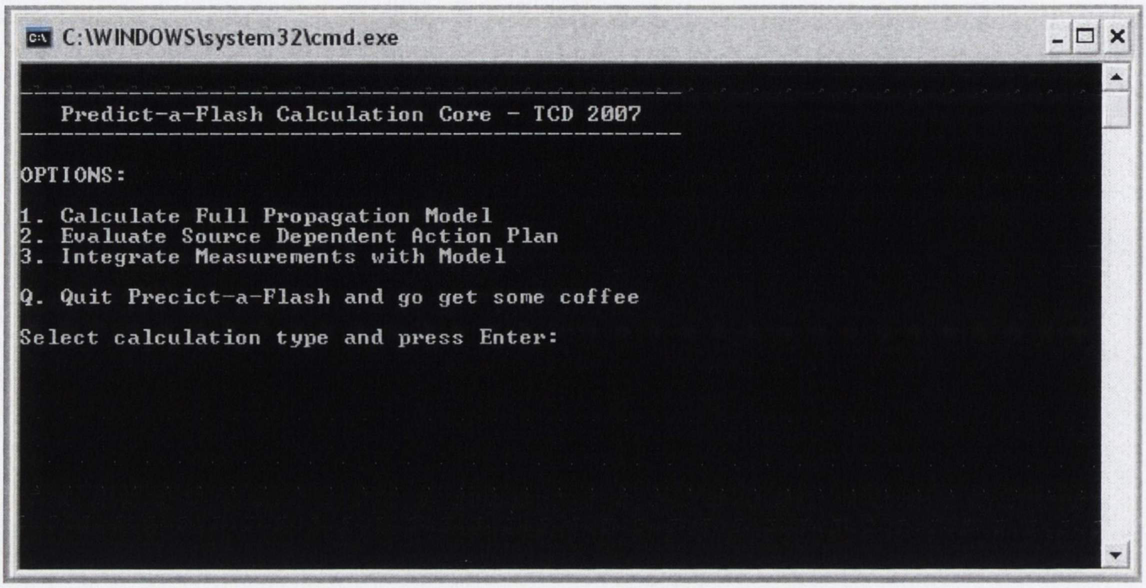

FIGURE 4.2: Screen-shot of Predict-a-*Flash*'s calculation core

4.2.1 Analysis of computational procedure

The overall model is a combination of two separate packages, the source model, which is developed in Microsoft Excel, and the propagation model, which may be compiled as a stand-alone executable file. The attenuation of noise is based on the point to point propagation of sound and calculations are developed according to the chosen standard. The manner in which the model handles data and performs calculations is now explored.

It is initially assumed all data is collected and presented in a G.I.S. package, in this case ArcGIS. As such all relevant data can be exported as separate shapefiles, eg. as roads, buildings, surface regions, etc, from ArcGIS. Each shapefile will contain information relating to the characteristics of traffic flow for each road, as well as factors which will influence the propagation of noise, e.g. the height of buildings, ground surface properties etc.

The general work-flow structure of the model is presented in figure 4.3.

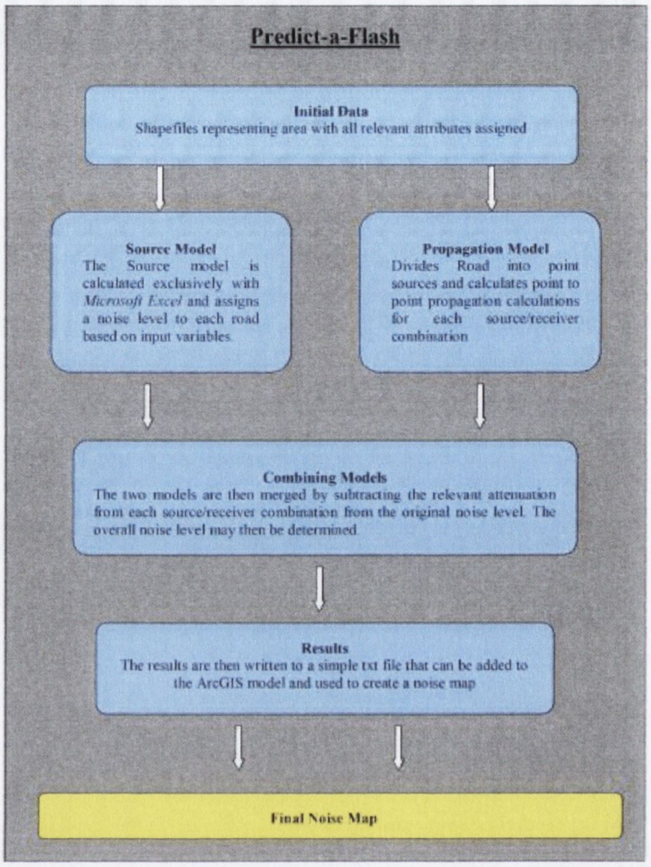

FIGURE 4.3: Predict-a-*Flash* work-flow

Importing data

A shapefile is a vector data storage format for storing the location, shape and attributes of geographic features. A shapefile is stored in a set of related files. According to the white paper released by ESRI in 1998, a shapefile consists of a main file, an index file and a database file [39]. The main file (.shp) is a direct access file in which each record describes a shape with a list of vertices. The database file (.dbf) contains information with regards to the attributes associated with each shape, while the index file (.shx) contains data pointing to the structure in the main file. The database file takes the format of a standard DBF file used by many table based Windows applications; hence it is easily linked with Microsoft Access and Microsoft Excel.

Initially the shapefile containing all the details of roads present in the area is examined. The traffic flow properties are all stored in the database file (.dbf) which can be opened with Excel. Traffic counts must be present in this file in order to calculate noise levels corresponding to each road

The Shapefile C Library, available online at *http://shapelib.maptools.org*, provides the ability to write simple C program for the reading and writing of ESRI shapefiles and the associated attribute file. This library is freely available and was used to convert the positional data of roads and buildings shapefiles to a list of corresponding vertices in a simple text file. This text file, coupled with source results obtained from Excel, completes the input data required to predict noise levels.

Calculating the source model in Excel - *See also Section 2.1.2*

The .dbf file associated with the roads shapefile may be read directly by Microsoft Excel. It is then possible to link the attributes contained in the .dbf file to a predefined spreadsheet template, which contains all the necessary functions required to calculate the noise level at the source.

In order to link the road attributes to the predefined template the traffic data should be divided into traffic flow for each period (day, evening and night), and for each vehicle category, (light and heavy), as presented in the sample table below.

TABLE 4.1: Sample input data format for Predict-a-*Flash*

Road Name	D_L	D_H	v_{day}	E_L	E_H	v_{eve}	N_L	N_H	v_{night}
Westland Row	503	144	45	505	116	40	245	78	50
Pearse Street	493	141	45	368	86	40	156	57	50

where D_L and D_H represent the number of light and heavy vehicles on the road throughout the day period and v_{day} is the average speed of the vehicles throughout the day period. E and N represent the Evening and Night periods respectively.

Calculations are performed using a macro designed in Visual Basic, the core programming language for Excel. Making use of multiple macros which may be assigned to separate buttons and Excel's ability to switch between worksheets, makes the development of simple, user-friendly platform possible. The program then outputs the noise levels associated with each road or road section, at each frequency for each period, see figure 4.4, which is stored in a text file that forms part of the input data required for noise propagation calculations.

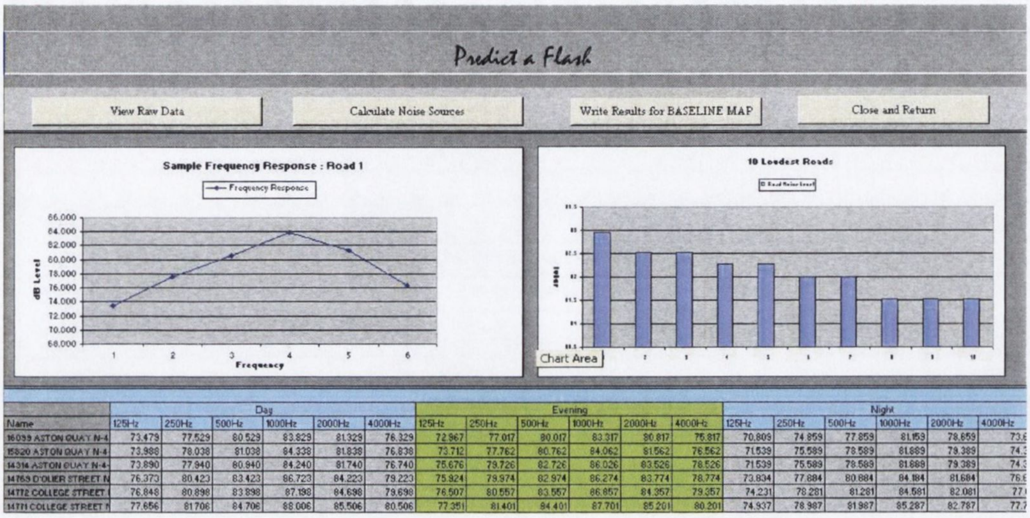

FIGURE 4.4: Screenshot of Predict-a-*Flash* in Excel

Source segmentation - *See also Section 2.2.1*

Line sources were segmented using the equidistant decomposition method. The length of each section was set to a maximum of 5m. The issue of source segmentation is addressed more thoroughly in the Harmonoise project. It recommends a method of segmentation using a combination of maximum viewing angle with a maximum segment length criteria. The goal was to have an "unambiguous method of source segmentation without generating an unnecessarily large number of propagation paths" [40]. However by relying on a combination of the viewing angle and segment length, segments must be recalculated for every receiver point as each will have a different viewing angle. Thus the simple equidistant approach was decided upon for the initial version of the developed model.

The appropriate spacing between point sources had to be determined. If points are too close together it will lead to an unnecessary increase in computational time, while if they are too far apart, the collection of point source will not accurately represent the road, and will lead to fluctuating noise levels along the road, upsetting the continuity of the noise map, see figure 4.5.

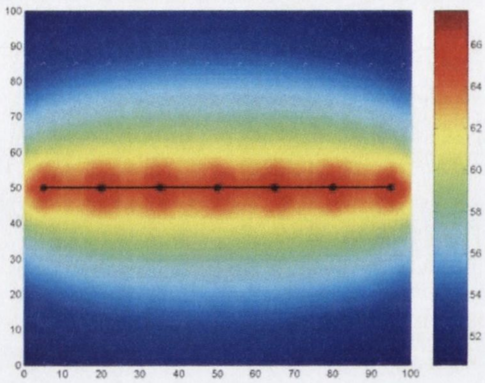

FIGURE 4.5: Poor representation of road source

It is recommended that the distance between two consecutive point sources should not exceed half the distance from point to receiver and as a general rule the step should not exceed 20m, thus if this rule was applied to each receiver point, the road would have to be subdivided for each specific point source. As such, it was decided to adopt a uniform 5m step when dividing the road, accepting that in areas very close to the road the division will not be half the distance from point to receiver.

Displayed in figures 4.6 to 4.8 are simple noise maps surrounding a road represented by a set of incoherent point sources at different spacings. There is also two receiver situated at the positions (50,40) at a distance of 10m from the road, represented in the figure by a circle (o), and (40, 49) at a distance of 1m from the road, represented in the figure by a star (*). The predicted noise levels at each of these receivers are displayed in table 4.2

Upon a simple analysis of this stretch of road it was concluded that the error associated with this division was acceptable, considering receivers will be at a height of 4m in accordance with the directive, while receivers were to be placed at a regular grid of 10m spacing.

Development of receiver grid

Initially a regular grid of equal spacing was developed over the test area. Again, it was found that the interpolation between these points had a major effect as to the quality

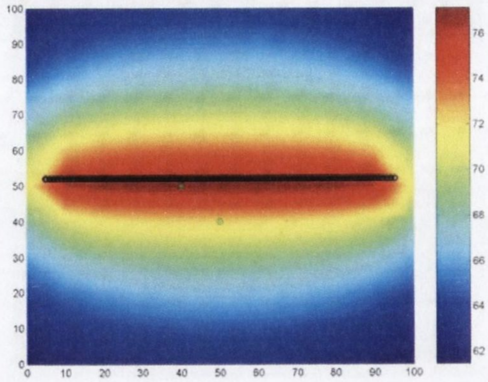

FIGURE 4.6: Representing road with 1m spacing between point sources

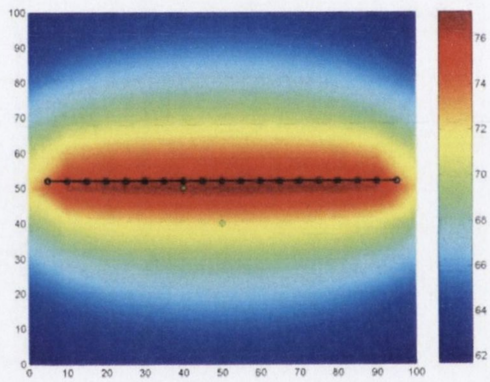

FIGURE 4.7: Representing road with 5m spacing between point sources

of the appearance of the final noise map, particulary in regions close to the road, in a similar manner to figure 4.8 .

In order to determine the noise levels at the most exposed facade it is suggested in the Good Practice Guide that a spacing of 3 metres between receiver points is appropriate. However it allows for situations where the software is not able to produce these specific grid points, then normally spaced grid points may be used to approximate the noise levels at the facade.

The GPG also recommends that the grid spacing for agglomerations should not exceed 10 metres. A wider spacing in large open areas may be acceptable but should not exceed 30 metres.

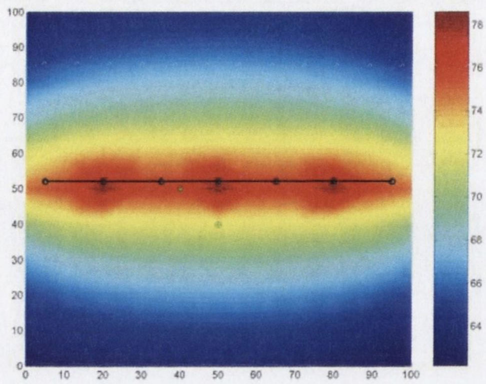

FIGURE 4.8: Representing road with 15m spacing between point sources

TABLE 4.2: Predicted noise levels at separate receiver points

Spacing	Near Point (*) [dB(A)]	Far Point (o) [dB(A)]
1m	77.14	72.05
5m	77.19	72.09
10m	76.61	72.13
15m	76.32	72.22

It may be desirable to use a grid spacing of less than 10 metres in some urban areas, particularly when buildings face each other across narrow roads. This will be of particular importance when determining the noise levels at the facades of buildings. Interpolation is not recommended in this case as the interpolation will not account for the various acoustical factors that may exist in such areas.

The propagation model - ***See also Section 2.2***

The manner in which the extent of the attenuation of noise, as it propagates from source to receiver, is calculated in the software is now presented. Figure 4.9 shows how each attenuation mechanism relates to the theory outlined in chapter 2 of this thesis.

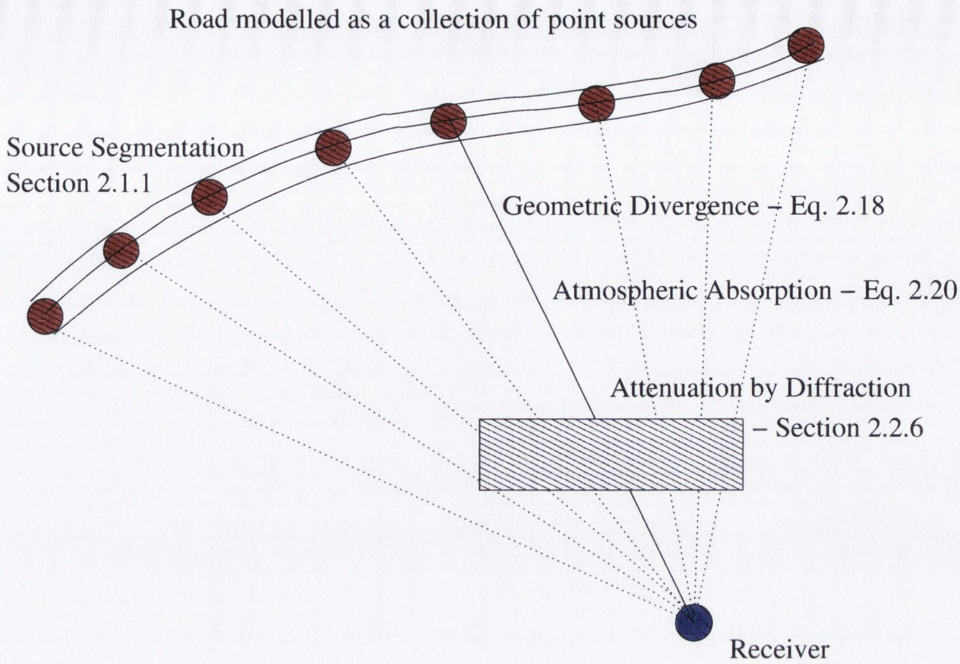

Figure 4.9: Relating the propagation model to the theory previously presented

Geometrical divergence - *See also Section 2.2.3*

ISO 9613, XPS 31-133 and Harmonoise all have an equivalent formula to describe geometric divergence, which approximates a sound level that diminishes by 6dB per doubling of distance. A strict implementation of this results in a rise in attenuation as the distance over which the sound propagates increase as shown in figure 4.10

Barrier attenuation - *See also Section 2.2.6*

The presence of buildings in an area poses the biggest obstacle to compute accurate results in a time efficient manner. Receiver points which are affected by the barrier must be determined for each barrier and relevant attenuation coefficients must be calculated. In the case of the developed model it was decided that simplicity was the best starting point and improvements would be developed as required.

Initially it was determined if the building was situated between the source and receiver and as such if there was a chance it would affect the propagation of noise. If it was found that it would not influence the propagation it was ignored. Those buildings that would affect the propagation were then assessed, by assuming each building was

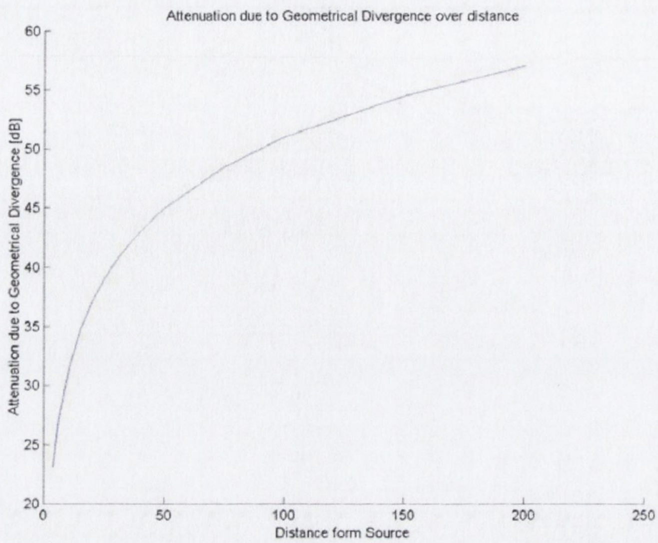

FIGURE 4.10: Attenuation due to geometric divergence

a simple barrier with a diffracting edge located at the centroid of the building. Only diffraction over the top of the building was considered. This calculation was repeated for every building that was deemed to be possibly affecting the propagation and the two most influential buildings, i.e. the two most effective barriers, were accounted for in calculating the attenuation due to the presence of barriers in the area, to a maximum value of 25dB.

Reflections

Reflections are not accounted for in the initial version of the software. It is noted that reflections will influence the noise levels close to buildings, so they should be accounted for, especially in urban cases, when displaying noise maps. Take for example the situation in figure 4.11.

The length of the reflected path will be equal to

$$r_{total} = s + r \tag{4.1}$$

The pressure at the receiver point resulting from the source will be a summation of the noise resulting from the direct path and the noise resulting from the reflected path.

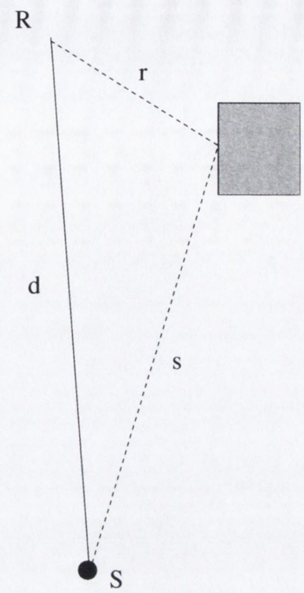

FIGURE 4.11: Calculating effect of reflections

$$p = \frac{A}{d} + \frac{A}{r_{total}} \tag{4.2}$$

$$p^2 \approx \frac{A^2}{d^2} + \frac{A^2}{r_{total}^2} \tag{4.3}$$

by ignoring the product term. Continuing

$$20log_{10}p = 20log_{10}\sqrt{\frac{A^2}{d^2} + \frac{A^2}{r_{total}^2}} \tag{4.4}$$

$$20log_{10}p = 20log_{10}\frac{A}{d}\sqrt{1 + \frac{d^2}{r_{total}^2}} \tag{4.5}$$

This equation may then be expressed as

$$20log_{10}p = 20log_{10}\frac{A}{d} + 20log_{10}\left(\sqrt{1 + \frac{d^2}{r_{total}^2}}\right) \tag{4.6}$$

which may be rewritten as

$$20log_{10}p = 20log_{10}\frac{A}{d} + 20log_{1}\left(\sqrt{2}\right) \tag{4.7}$$

if r_{total} is approximately equal to d, i.e. the building is right beside the road resulting in the worst case scenario for a reflection. The first term in the above equation accounts for the original noise source while the second term accounts for the reflected noise. As r_{total} approaches d, this value will reach a max of 3dB, and conversely over large distances, ie $r_{total} \gg$ d, this term will go to zero, hence if the reflecting surface is far away, it's influence is negligible.

Model simplifications

The initial version of Predict-a-*Flash* does not include a ground surface attenuation either. It is assumed that all ground is uniform and does not affect propagation. This could be included by identifying reflective and absorbent ground regions from a separate shapefile and applying the relevant attenuation coefficients. For the test case no alternative ground regions were identified so a universal ground surface was applied.

In addition, only homogeneous conditions are considered. It is assumed that the attenuation in homogeneous conditions will be sufficiently accurate to long-term average noise levels. The author recognises that the provision for meteorological correction, as contained in XP S 31 -133, is an important factor in noise propagation calculations. However, meteorological effects will have many different results over a very wide scale, so the mere inclusion of conditions favourable to propagation is not nearly sufficient in calculations. Thus it is flagged as a potential source of error. However, this will save valuable computational time without having a heavy impact on final predicted results.

4.2.2 Comparative results

Using Predictor as a bench-mark initial results proved promising. Figure 4.12 is a noise map showing results as calculated by Predictor following XP S 31-133, while figure 4.12 shows a noise map as calculated by the developed model.

It is clear that both maps display very similar noise levels. A summary of some general statistics is presented in table 4.3.

It is noted that the attenuation calculated by the developed model appears to be

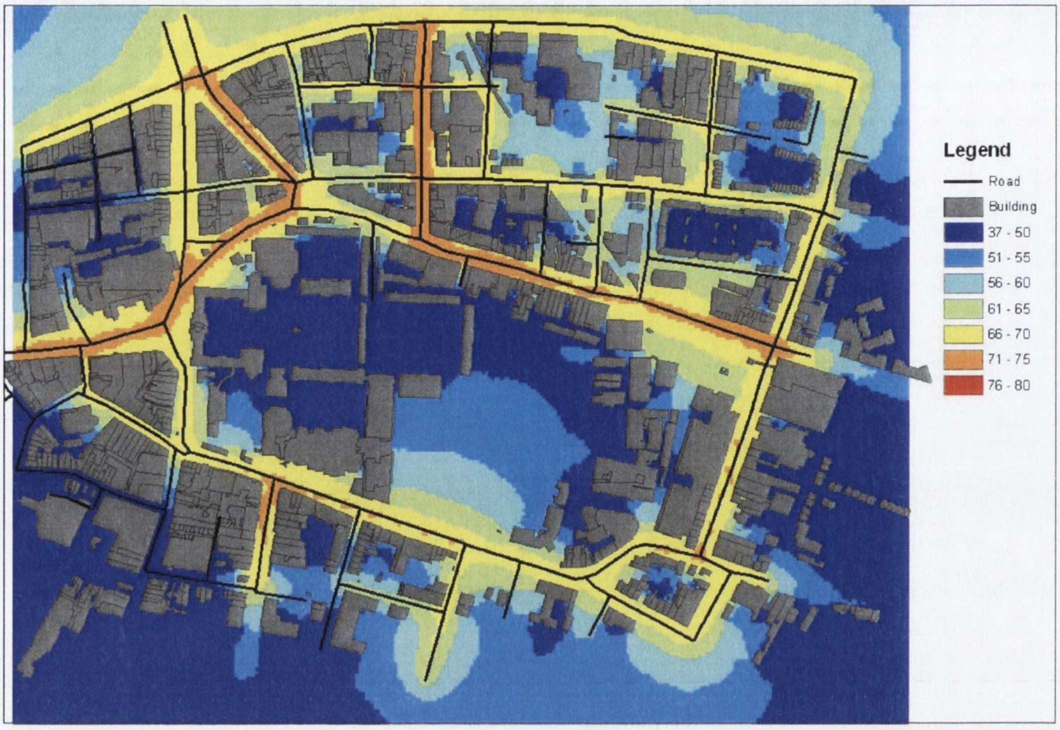

FIGURE 4.12: Noise map obtained from commercial software

more severe in places. However it is apparent that in general the two maps agree, with loud areas and quiet areas easily identifiable in both maps.

While the results appear to be the same, the developed model sets itself apart from Predictor in an analysis of computational performance. The developed model took 26 minutes to run when compiled with Intel's icc compiler, compared to Predictor's 5 hours 40 minutes. It was also impossible to compare the same area for a finer grid as, due to licensing restrictions with the commercial software, it was not possible to map this area with a 5m grid. It is worth noting at this point that calculating a noise map for the same area following the initial version of the Harmonoise standard with Predictor took approximately 5 days.

Calculations are performed in a time efficient manner as they are performed in a customised manner. Certain simplifications have been introduced to speed up the process without compromising the integrity of results.

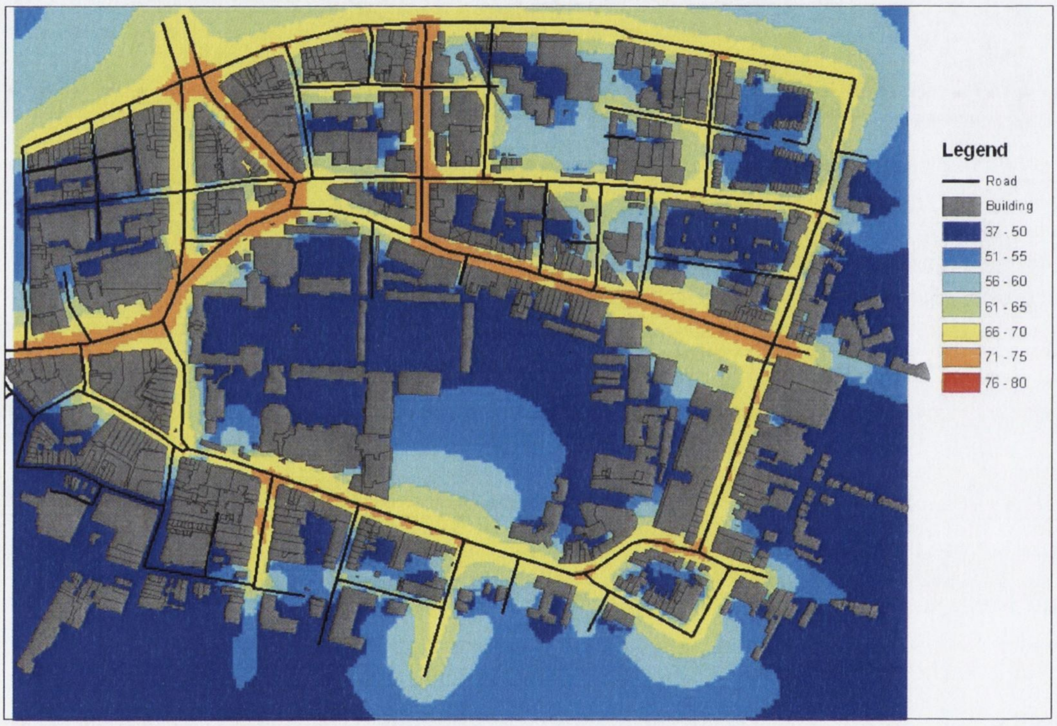

Figure 4.13: Noise map obtained from Predict-a-*Flash*

Statistic	Commercial Software	Predict-a-*Flash*
Min Level	34 [dBA]	38 [dBA]
Max Level	75 [dBA]	76 [dBA]
Mean Level	55 [dBA]	55[dBA]
Standard Deviation	10 [dBA]	10 [dBA]

TABLE 4.3: Comparison of summary statistics, Predict-a-*Flash* vs. Commercial software

Having established that "Predict-a-*Flash*" implements the calculation procedures in an efficient manner, and produced results comparable to the standard tool, it means the model can be developed further. More complex calculations may be introduced if required, for example refections and ground surface characteristics should be accommodated for in future models. Additionally varying meteorological conditions may also be examined. Nevertheless, as an initial tool, it is possible to take the mapping stage further by the inclusions of any modifications necessary, thus providing a useful tool to implement any possible refinements not available elsewhere.

4.2.3 Reflections

As previously stated the initial version of the developed model does not include calculations for reflections. The effect of omitting reflections was then evaluated using the commercial software. Figure 4.14 shows the noise map calculated with the commercial software ignoring the effect of reflections. It is apparent that the effect of reflections is negligible close to the source while the maximum difference of about 3dB is more noticeable away from the source. Table 4.4 provides a summary of relevant statistics.

Statistic	Reflections	No Reflections
Min Level	34 [dBA]	31 [dBA]
Max Level	75 [dBA]	74 [dBA]
Mean Level	55 [dBA]	53[dBA]
Standard Deviation	10 [dBA]	11 [dBA]

TABLE 4.4: Comparison of summary statistics, Reflections included vs. Reflections not included

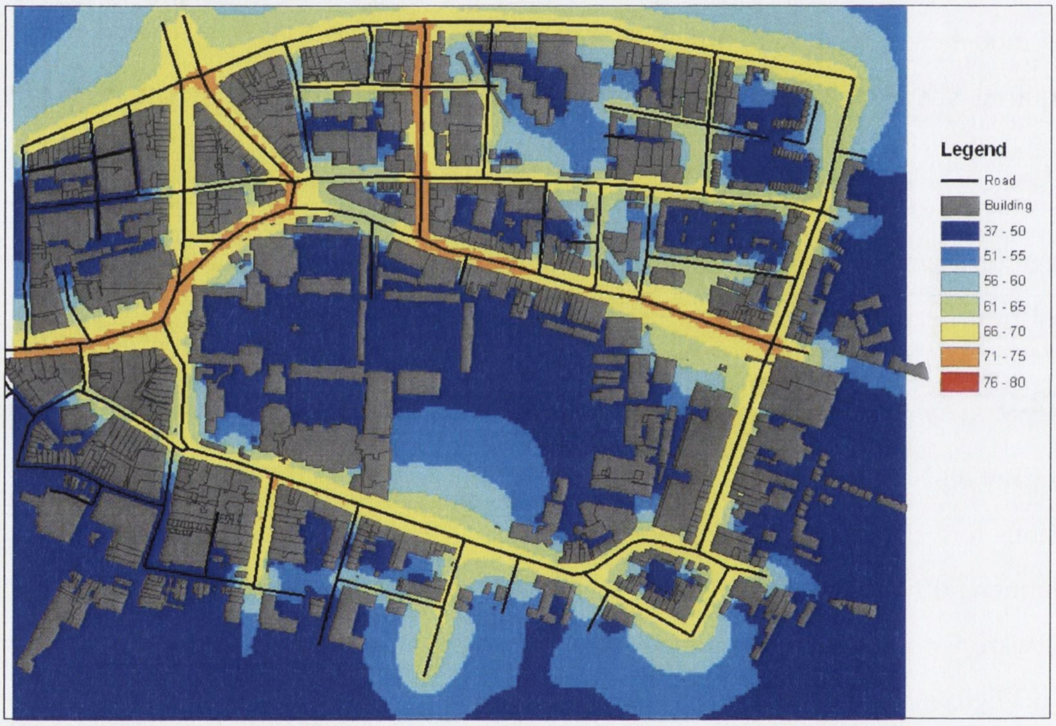

FIGURE 4.14: Noise map obtained from commercial software with no reflections

Chapter 5

Refining baseline noise maps

The development of a strategic noise map in a typical fashion involves a number of steps, with each stage presenting a number of difficulties that must be addressed before proceeding. Firstly accurate input data has to be collected and compiled. In some cases certain variables may be unknown resulting in average values being used or introducing certain assumptions in the model. Once the data is collected it must then be exported to predictive software which will involve data manipulation in order to produce results. The predictive software is usually expensive, subject to certain restrictions and takes an unreasonable amount of time to compute. In addition, a certain amount of time and thought must be spent evaluating results to ensure noise levels are accurate in order to try to combat the 'black box' effect that may be associated with using this software. User's should be aware of how results were obtained and if results satisfy all the requirements of the Directive.

Once the map is created it should be noted that the noise study is not complete at this stage. Results must be displayed in a suitable fashion and the architects of the map must be sure of it's accuracy. This may involve recording on-site noise measurements and evaluating the accuracy of the data that was used to develop the map. The level of variation according to the averages and assumptions at the start of the study should be quantified and it should be determined how those assumptions impacted on final results. Additionally, the impact of various action plans must be assessed and presented to the public.

Once action plans are introduced, particularly if they impact directly on public life, noise maps may be subjected to widespread scrutiny. As such a detailed variation and uncertainty analysis should be performed on all noise studies throughout the development process. In fact Ten Wolfe has stated that the estimation and management of the uncertainties involved in noise measurements and prediction should be one of the priorities in future research within Europe [16].

5.1 Error and variation analysis

It is reasonable to assume that results from strategic noise maps will be scrutinised and opposed, particularly if the implementation an associated action plan directly impacts a proportion of the public, for example, the converting of a road to serve one way traffic, imposing a ban on heavy goods vehicles on certain roads, erecting a noise barrier beside a residential area, etc. Another feasible impact of noise maps is the effect they will have on housing prices. It may arise that property exposed to a certain level of noise may reduce in value as reported in [41] who found that houses situated near an airport suffered in value. Another study in Korea found that a 1% increase in traffic noise, in dB, is associated with an approximate 1.3% decrease in land prices. Based on this figure, the average cost per kilometre due to traffic noise was approximately $347,000 dollars per year [42]. Thus if a noise map causes an area to be devalued, the accuracy of the noise map will almost certainly be called into question.

Once noise maps are released to the public, relevant authorities must be prepared for independent validations to take place. This will involve noise measurements being taken and compared to results displayed in the map. These measurements may not match predicted results exactly so the discrepancies must be explained. It should be made clear that L_{den} is a weighted year long indicator and as such cannot be directly compared to short-term measurements. Also short-term measurements will be influenced greatly by a number of factors that vary throughout a day. Thus a clear distinction should be made between *error* and *variation*.

Errors in computation will occur in both the emission model and the propagation model, with the largest source of error generally resulting from poor input data. The level of error associated with the test site is now explored.

5.1.1 Error at the source

A major cause of error in noise maps will arise from an inaccurate noise emission model. If this model is incorrect it will influence all aspects of the model - thus it is essential to quantify the level of uncertainty associated with the source.

The level of noise resulting at the source is dependent on a large number of variables. Each of these variables will effect the noise produced to a certain extent. In some cases not enough data is available to accurately represent each of these variables, therefore assumptions are made and default values are assumed.

The influence of each of the input parameters was examined and the overall effect of inaccurate input data was thus determined.

Average traffic speed

If the road traffic speed data is unavailable one possible solution suggested by the GPG is to use the signposted speed limit. It then suggests that this assumption will be accurate to within 2dB. It is therefore possible to assume that due to this assumption, final results will be within an error of 2dB. The GPG also suggests a more accurate method which involves driving in the average traffic flow conditions, yielding results to an accuracy of 0.5dB.

Examining different average speeds for a test road, with 1000 vehicles of varying composition, yields the graph displayed in figure 5.1. The minimum noise level of 84.4dB occurs at a speed close to 50km/hr, which is approximately the speed limit of most urban streets in Ireland. The max level of 87.8dB occurs at a low speed of 20km/hr. It is evident if traffic is slow moving there will be a 3dB difference between the actual noise and predicted noise if it is assumed that the traffic is travelling at the signposted speed limit. The phenomena of traffic travelling at lower speeds producing more noise is also reflected in calculations according to Harmonoise Road Source model, see figure 5.2.

These figures suggest that the average traffic speed or signposted speed may not be the most appropriate input to use, particularly in urban scenarios, as the traffic will travel at considerable lower speeds, particularly during rush hour periods. In fact it has been reported that the average speed of a bus in Dublin is just 13.58km/hr in

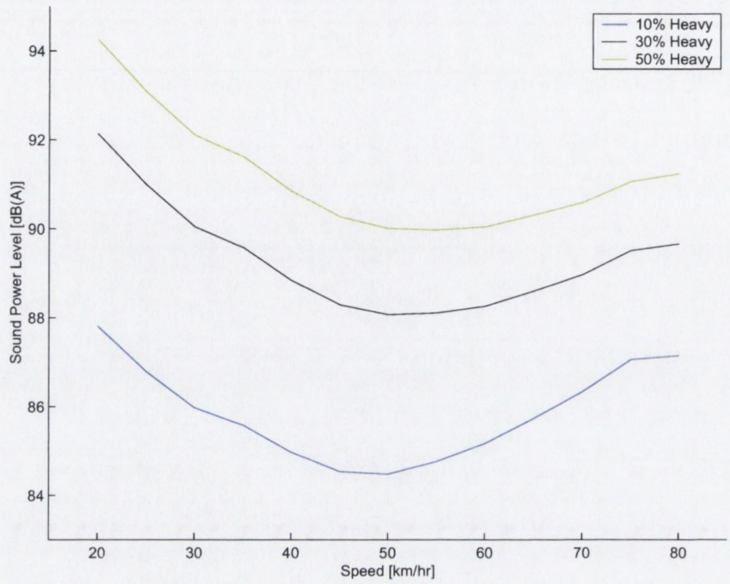

Figure 5.1: Noise level vs Average Speed for varying traffic compositions - XP S 31-133

the morning peak [43].

The average traffic speed for the roads surrounding Trinity College were then determined by employing the method suggested by the GPG. A number of journeys were made in a car at different times throughout the day period - yielding different results to the signposted speed limit, see table 3.2, reproduced here in table 5.1

Table 5.1: Average Traffic Speed

Method	*% Average Speed [km/hr]*
Signposted Speed Limit	50
Average Free Flow Speed	36
Average Radar Speed	32
Average Driving Speed	14

Thus comparing the average driving speed as recorded by car against the signposted speed limit would yield a difference of approximately 3dB at the source. This method would only be accurate for certain times throughout the day period, when driving took place. It is assumed the average speed would be slower at peak times and close to the signposted speed limit at times of low flow, for example during the night period. This

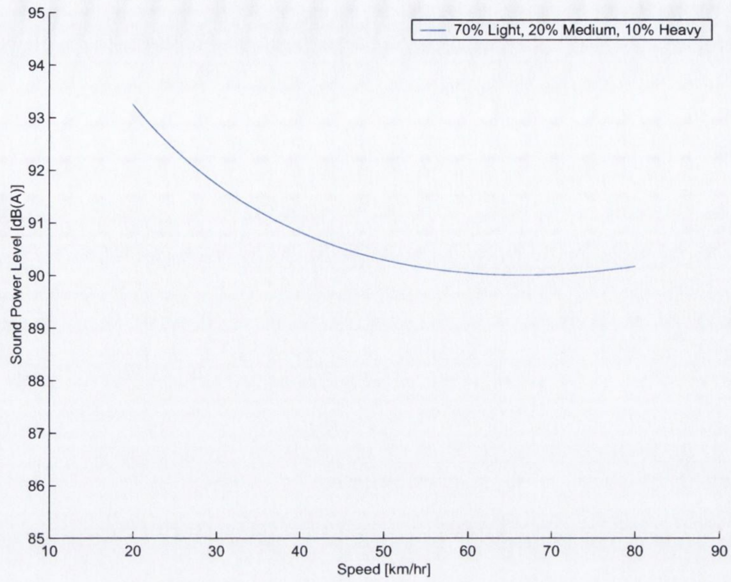

Figure 5.2: Noise level vs Average Speed - Harmonoise

would suggest that the traffic speed is constantly changing at different times of the day and a more accurate manner of representing this as an input for noise calculations should be developed.

However it would be impractical to employ this technique for every street in an agglomeration, at every hour of the day. Thus by accepting the average speed is going to result in an error of between 0 and 3dB at different times throughout the day, it can be identified as a source of variation when comparing predictions with measurements.

Traffic composition

Figure 5.1 also shows the variation of the noise level at the source given different traffic compositions. It is evident that the presence of more heavy vehicles will result in louder noise levels at the source. It is also evident from the graph that the increase in noise levels is independent of the average speed of the traffic. It may be observed that for the simple test in the figure, an increase in composition of heavy vehicles from 10% to 50% yields an increase of approximately 6 dB(A) at the source.

For the test case a number of traffic counts were recorded throughout the day period. The chosen standard, XP S 31-133, classifies only light and heavy vehicles as opposed to the light, medium and heavy contained in the Harmonoise standard. These traffic counts yielded an approximate proportion of heavy goods vehicles in traffic flow of 8% to 10%.

Road surface characteristics

The surface of the road will influence the noise generated by the tyre/road interaction phenomenon. Detailed information on the types of road surface in the test area was unavailable. To account for this the GPG suggests using a default value of dense asphalt for every road, meaning the corresponding correction for each road will be zero. The accuracy of this guideline will be within 3dB.

However the acoustical properties of a road surface will be subject to certain variations. During rainy days the level of background noise will increase. The rain will also influence the level of noise produced at the source. As reported by [44] in [45], the presence of water depending on it's quantity, the surface type, the vehicles, the tyres, etc, on a road surface will increase the vehicle noise emission level, with respect to the dry condition, by amounts ranging from 0 to 15dB. Thus, a rainy day in Ireland may be significantly louder than a dry day in Ireland (although sometimes few and far between). This should be identified as another source of variation in noise levels.

Intersections

As vehicles approach intersections the speed at which they are travelling at will reduce until they have either come to a rest or have accelerated away from the junction. This will effect the level of noise produced close to junctions due to the change is speed of vehicles and the rise in engine noise causing the vehicle to accelerate or decelerate. In a study investigating the impact of accelerating and decelerating traffic it was reported that the effects are generally not more than 3dB(A) and occur within 15m of the junction [46].

However in a separate study, the impact on noise levels of traffic decelerating before a speed bump and accelerating after it was examined [47]. This study reported that if an average value is used to express the relevant exposure dose, than the influence of speed bumps become insignificant, as the average noise level is approximately the same with or without the presence of the speed bump. However, if the *maximum* noise level is examined, the effect of the speed bump becomes highly significant, as the maximum level with no speed bump was exceeded by up to 13dB for the case with a speed bump caused by passenger cars. It may be argued that the L_{den} noise indicator is not the most appropriate indicator to use in a widely varying situation such as this case as the extent to which people are annoyed may be linked more strongly to the maximum noise level in a periodic event.

5.1.2 Error in propagation

While it is evident that a large number of variables will effect the noise level at the source, a number of factors may also influence the propagation of noise from source to receiver. With the introduction of the Harmonoise model some of these effects have been addressed as they are not accounted for in XPS 31-133. However it is evident that there will always be some factors outside the scope of the new complex model so it again raises the issue as to how necessary a detailed and complex model is.

Inaccurate Feature Positioning

An inaccurate shapefile containing the inaccurate geographical positioning of features will greatly influence the final noise map. If buildings are missing from the shapefile, the noise will not attenuate as severely as it should, or if roads are incorrectly represented, it will significantly impact the source model. Inaccurate feature positioning is a relatively easy flaw to identify, particulary for the non-expert, thus an inaccurate shapefile will significantly compromise the integrity of the noise map.

Seasonal changes

Seasonal changes will affect the level of traffic on the roads, as some cities may see an influx of tourists, while some may become dormant. The change of season may also change the average speed at which motorists drive whether there is predominantly sun, fog or rain present. In addition the seasonal changes in meteorological conditions will also affect the acoustical properties of the surroundings. Over the course of a year tress and bushes may go from being full of leaves to bare branches and green areas may change from freshly cut lawn to frost covered hard ground. Thus the year long average noise map may not accurately reflect these effects which will directly impact noise levels. This may be identified as another source of variation.

Meteorological conditions

As weather conditions may vary considerably in time, these conditions may heavily influence the day to day, or even hour to hour, noise level. In addition to this, meteorological effects may not only influence noise propagation but also noise emission. As such one must recognise the dangers in presenting only the noise propagating in average meteorological conditions. Meteorological conditions have a major effect on the propagation of sound, through a variety of mechanisms, in particularly wind distributions and vertical temperature gradient. However, despite the fact that atmospheric attenuation can cause deviations of ±20dB, it is widely overlooked in all propagation methods to date [48]. This would appear true with the exception of the new Harmonoise standard. Except for the atmospheric absorption coefficient, which is defined in some detail in ISO 9613-1, other effects are ignored. In the CRTN method no allowance whatsoever is made for prevailing meteorological conditions, while XPS 31-133 only provides a method which may be used for two different meteorological conditions, conditions favourable to propagation and homogeneous conditions.

Due to the variation in noise levels for a number of reasons, it would be most appropriate for measurements to be carried out in conditions which would be considered average for a calendar year, as certain weather conditions will influence the noise environment. For example rainfall and hail can produce wide band noise that can significantly change the general background noise. High frequencies propagate better in fog because of the high humidity. Snow will effect ground absorption and may modify the absorption expected from shrubs and trees.

Ground effect

In the test case it was assumed that all areas of the city had a constant ground surface type. Displayed in figure 5.3 is the predicted attenuation arising due to propagation over various different ground surfaces, G, over a distance of 200m, from a source at a height of 0.5m to a receiver of height 4m. It is apparent that the majority of attenuation occurs between 250Hz and 1000Hz.

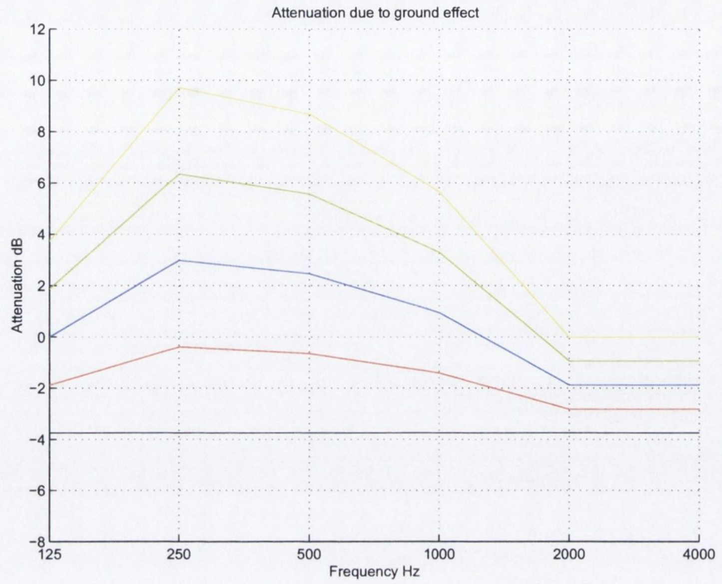

FIGURE 5.3: Attenuation due to ground effect

While in an urban environment, the ground surface is predominantly the same, it is worth noting the effect green areas will have on noise, particulary as these are the areas that are most likely to be regarded as quiet areas, which should be protected.

However, it is worth noting that, again, the ground effect will be subject to a certain amount of variation. The natural cycles in the growth of vegetation can change the acoustic impedance of the ground surface due to leaves falling on the ground etc.

5.2 Integrating measurements with maps

Noise measurements may be used to validate noise maps. They will also serve as a useful tool in building confidence in predicted results if they can be used by members of the general public to independently validate noise maps. However a poorly conducted measurement campaign may serve to obstruct the process. It is therefore important to determine factors which will effect the measurement process. Additionally a clear understanding of the variation of noise should be developed and certain guidelines may be presented along with noise maps to assist members of the public in comparing measurements with maps.

5.2.1 Comparing short-term measurements with L_{den}

A number of measurements were recorded throughout the course of the project. In one case measurements were recorded at a 4th floor office window on Dawson Street over the course of one week. In order to relate a short-term 15 minute measurement to the long term indicators maps are expressed in, the data was analysed assuming that the week was an average week of a full calendar year.

Upon an examination of the manner in which L_{den} is calculated it is evident that the L_{den} indicator is weighted to account for extra annoyance in both the evening and night periods. In fact, the value for L_{den} may far exceed the loudest hourly levels measured throughout a full 24 hour period representative of an average day, as is the case in figure 5.4. This figure represents the average day over the measurement period of one week. The noise variation over each individual day is shown in figure 5.5. It is evident that a direct comparison of a short-term measurement with L_{den}, regardless of the length of the time period during which the measurement was conducted, is not appropriate.

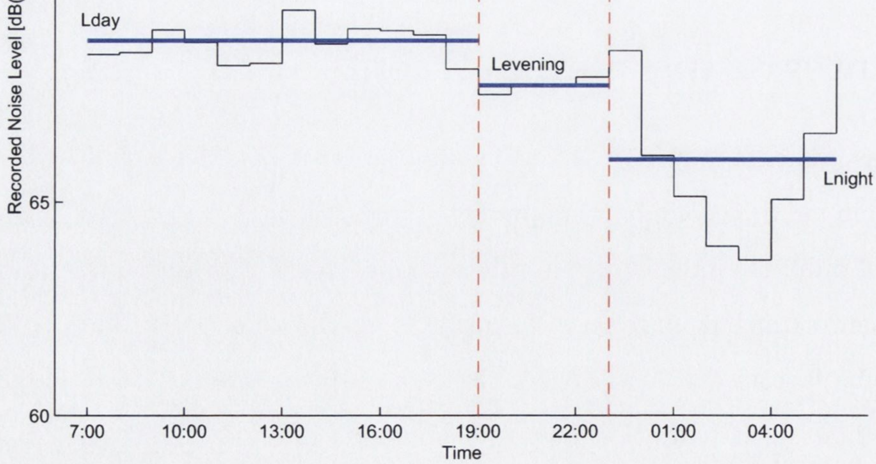

FIGURE 5.4: Average variation of $L_{eq,1hr}$

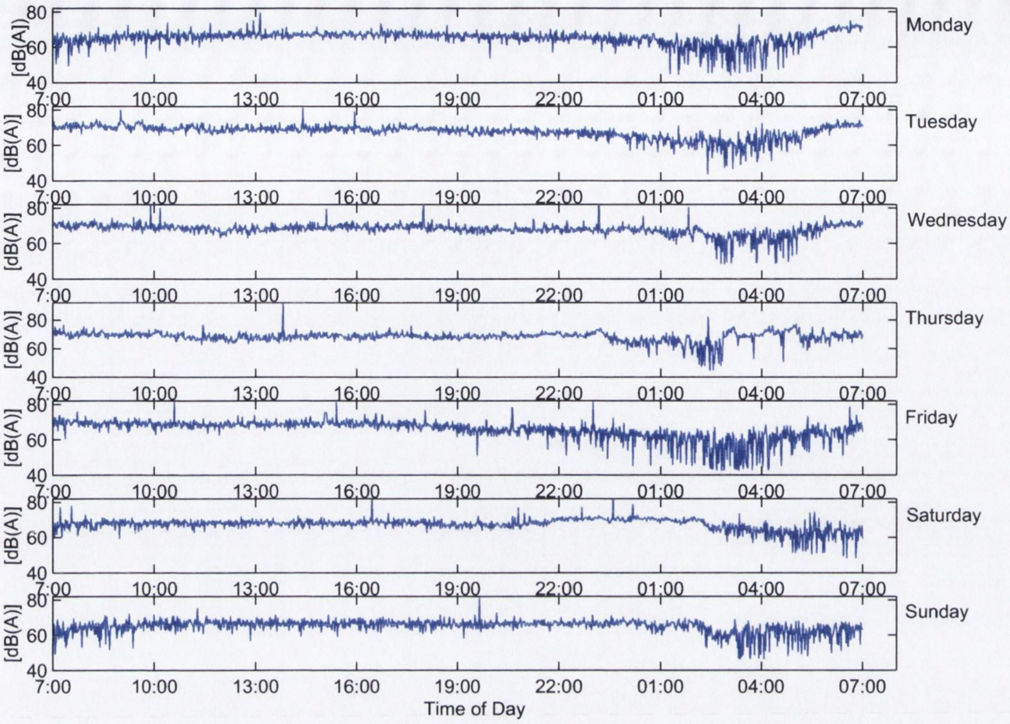

FIGURE 5.5: Noise variation over complete week

However it would not be unfeasible to relate a short-term measurement to it's relevant periodic noise indicator, particularly throughout the day period (between 07:00 and 19:00). Figure 5.4 shows that the average day and evening periods do not fluctuate greatly from the equivalent L_{day} and $L_{evening}$ indicators. In the diagram, the values for L_{day}, $L_{evening}$ and L_{night} are 68.79 dB(A), 67.74 dB(A) and 66.00 dB(A) respectively which results in an L_{den} value of 73.05 dB(A). The night period changes from loud to quiet and remains quiet for approximately 4 hours, before noise levels begin to rise again, resulting in a L_{night} value lying between the louder levels and the quietest level recorded in the early hours of the morning.

It should also be noted that the measurement unit was placed above a popular nightclub in Dublin's city centre, thus readings throughout the night period may have been affected by the patrons of the club congregating outside and also by the clubs entertainment system. It may be concluded that the noise readings recorded throughout the night do not accurately reflect environmental noise as it is defined by the directive. This characteristic is particular noticeably on Wednesday night at 23:00 (a popular night to socialise in Dublin) and on Saturday night.

The deviations in the night period and the fact that it occurs between 23:00 and 07:00 makes it an inappropriate indicator to compare with results. In addition, it is expected that most independent validations will take place throughout the day period and not during the night period. As such the L_{day} indicator may prove to be the most appropriate indicator to use to relate short-term measurements with the long term average.

It is then interesting to determine how each day period varies with respect to the average day period. The following characteristics of each day should be noted:

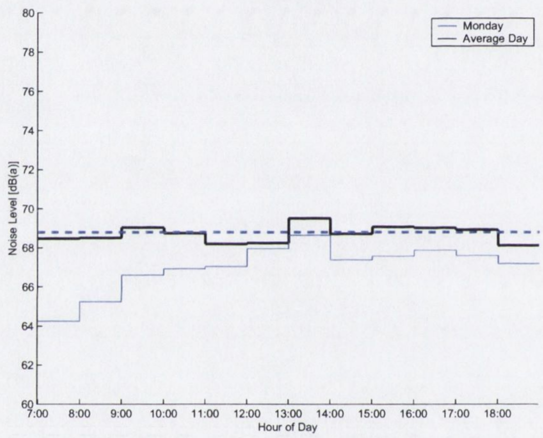

FIGURE 5.6: Monday vs Average Day

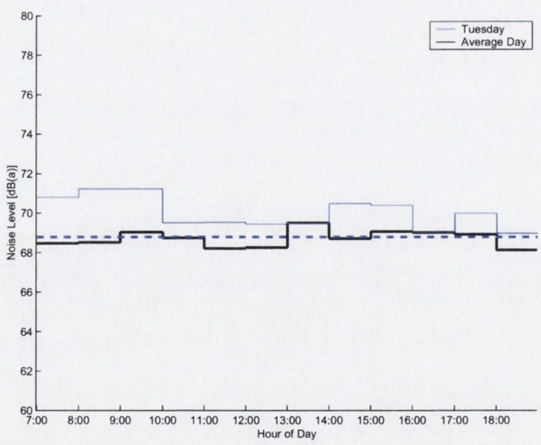

FIGURE 5.7: Tuesday vs Average Day

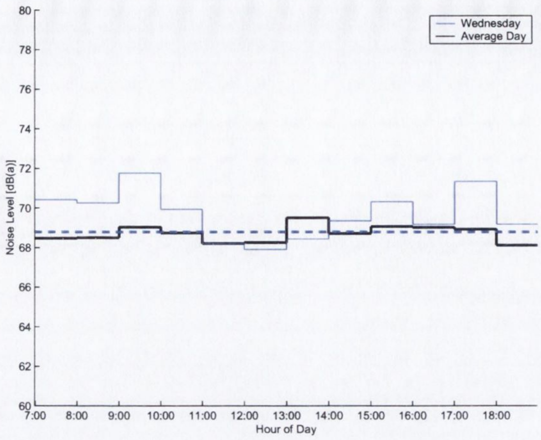

FIGURE 5.8: Wednesday vs Average Day

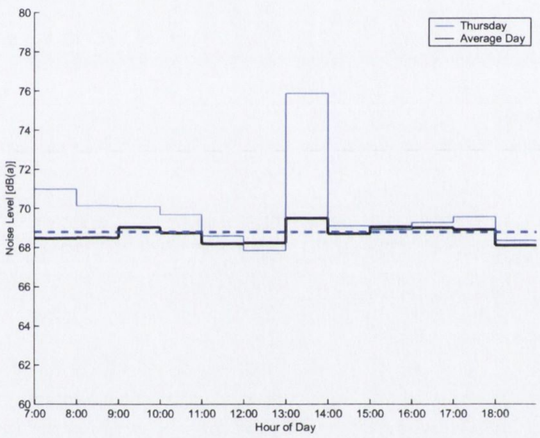

FIGURE 5.9: Thursday vs Average Day

- *Monday*

  The day period is significantly quieter than average, up until about 11:00 in the morning. This is presumably related to a reduction in working traffic present on the roads on a Monday morning. This is also reflected in average traffic counts obtained from Dublin City Council. On the whole the noise on a Monday seems to be slightly lower than average

- *Tuesday*

  On average a typical constant noise level throughout the day. It is slightly higher than the average day, although the low noise Monday may have reduced

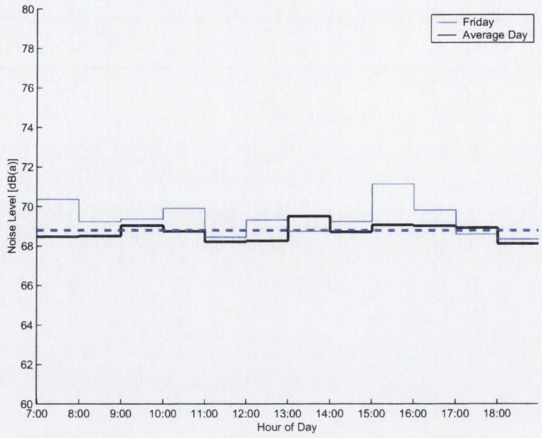

FIGURE 5.10: Friday vs Average Day

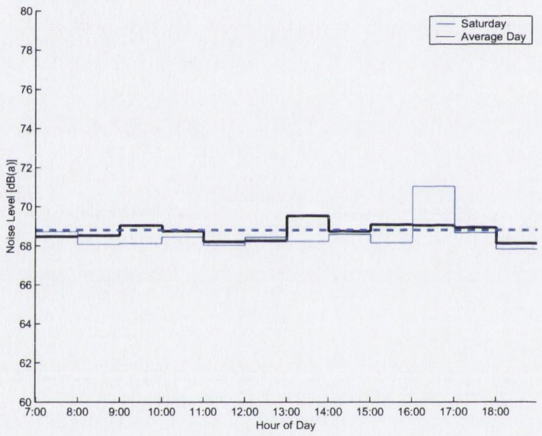

FIGURE 5.11: Saturday vs Average Day

the overall average, which should be investigated.

- *Wednesday*

  Similar characteristics to Tuesday and again reflective of the average day.

- *Thursday*

  Again the plot is reflective of the average day, except for an abnormally high noise level between the hours 13:00 and 14:00, which was due to one particular noise event, for a period of 1 minute as may be identified in figure 5.5. This value may be regarded as an outlier and adjusted accordingly.

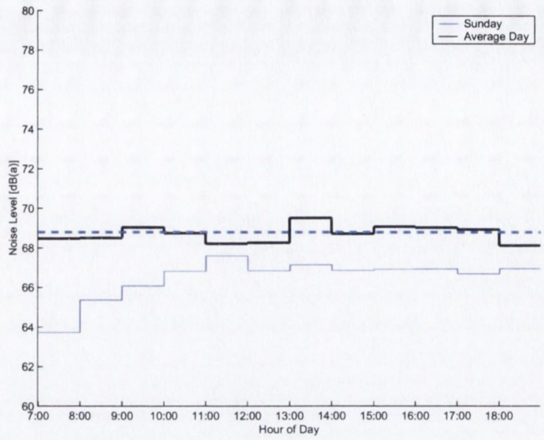

FIGURE 5.12: Sunday vs Average Day

- *Friday*

  Similar characteristics to Tuesday, Wednesday and Thursday. The plot is again reflective of the average day.

- *Saturday*

  Surprisingly similar in noise levels to those of day periods throughout the week, as a drop in noise levels was expected over the weekend.

- *Sunday*

  The noise levels for Sunday are lower than average throughout the day period. Again this is expected upon analysis of relevant traffic counts.

It may be concluded that the days from Tuesday through to Saturday are most reflective of an average week. Monday's and Sunday's results should be considered separately and not part of the analysis for a typical week as they will reduce the average noise level. In addition the outlier noted on Thursday may be corrected.

Adjusting calculations accordingly will lead to an average day as displayed in figure 5.13.

Direct comparison

The average day is determined by ignoring the effects of Sunday and Monday, as they are unreflective of an average weekday and serve to reduce the average noise level.

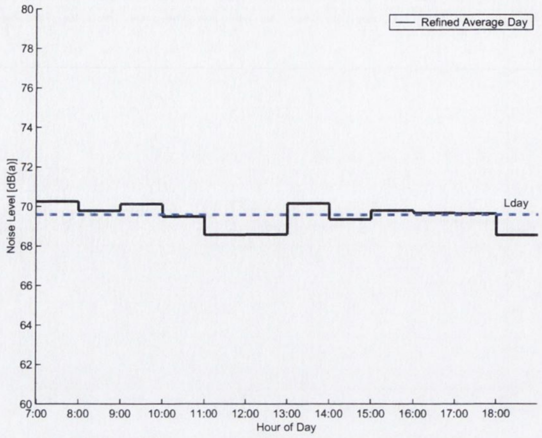

FIGURE 5.13: Refined Average Day compared to L_{day}

This leads to a relatively constant average day level, displayed in figure 5.13, fluctuating around the value for L_{day}, providing a constant level which may be satisfactorily compared with a short-term noise level.

Presented in figure 5.14 is a comparison of the 15 minute periods that were used to produce hourly levels and hence the average graph.

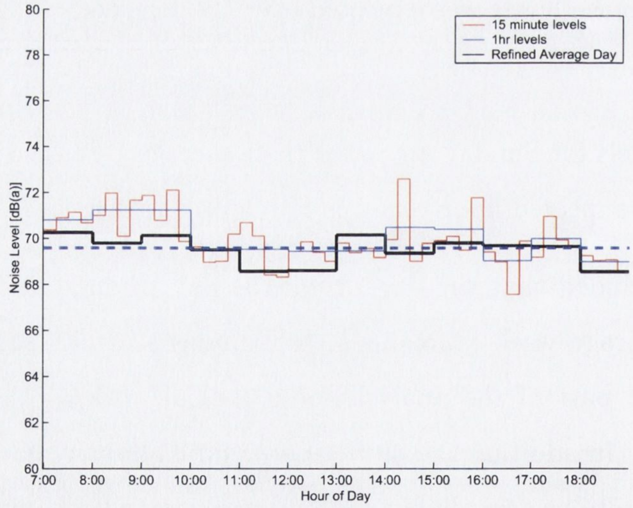

FIGURE 5.14: 15 minute levels compared to hourly levels, the average hourly levels and L_{day}

It is apparent that the length of time over which measurements are taken will influence how the short-term measurement will relate to an average day. This is due to the fluctuating nature of environmental noise and does not imply that either the measurement or the average value is incorrect. It is apparent that the measurement result will agree with the average day if the measurement period is longer. However in most cases a 15 minute interval produced results within 3dB to the average day.

Thus a number of guidelines may be produced to aid the public independently validate noise maps, these guidelines are available in Appendix D. It must be stressed that noise maps present the average noise level for a particular location over a complete calendar year, and may not be reflective of the noise levels over one particular day, particular if that day is not similar to an average day in the year. However by following some simple guidelines and comparing short-term measurements with the L_{day} indicator, certain satisfactory comparisons may be drawn.

5.2.2 Measurement height

Figure 5.15: Measuring at a height of 4m

Another important factor to consider when comparing predicted results with measurements is that receiver points in the noise map are placed at a height of 4m. It is doubtful that the general public will go to the trouble of measuring at this height but rather measure at a standard height of approximately 1.5m, as it involves a certain amount of time and effort fashioning a suitable device, as displayed in figure 5.15, which must be manually held in place. Thus it is important to quantify the effect of placing receiver points at different heights.

Figure 5.16 shows a noise map plotting the corresponding noise levels in a vertical cross section of the area surrounding 2 simple point sources positioned at heights of 0.3m and 0.75m. There are a number of receiver points also displayed, at a standard level of 1.5m and 4m, in steps of 1m from the sources. The line in black displays the difference between the calculated values at 4m and 1.5m and it is evident that the closer the receiver points are to the source, the more influence the altering heights will have. A difference as high as 10dB is noted directly beside the source, but reduces to below 1dB over 8m from the source.

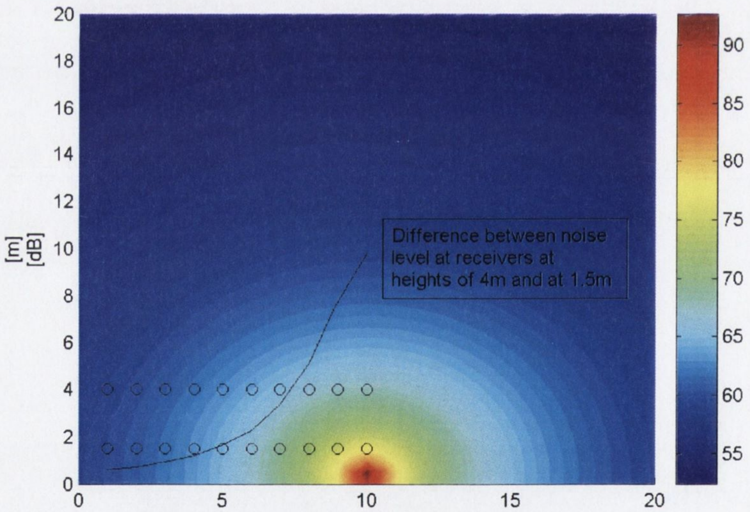

FIGURE 5.16: Comparison of different receiver heights - vertical view

This simple analysis would seem to suggest that the difference in receiver height is less influential as the receiver points are placed further away from the source. This point is reiterated by comparing the differences between a noise map made with receivers at a height of 1.5m with a map made with receivers at a height of 4m as shown in figure 5.17.

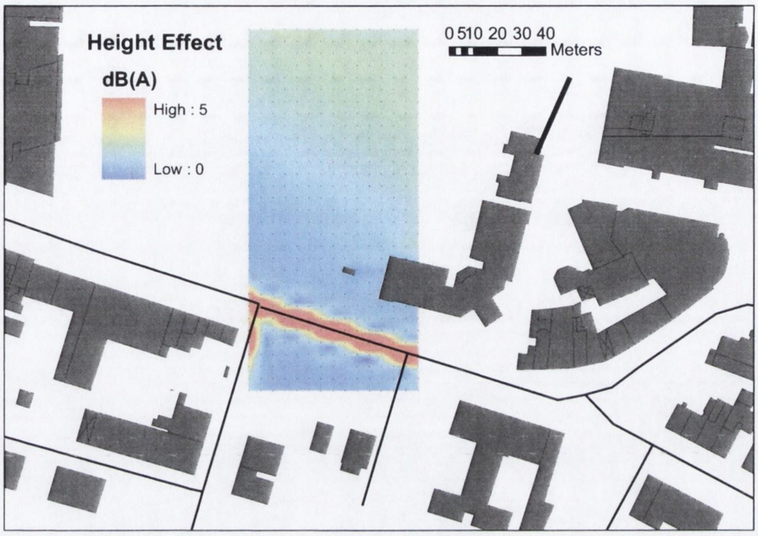

Figure 5.17: Comparison of different receiver heights over test area - horizontal view

Figure 5.17 was created by simply calculating a noise map at a height of 4m and another at height of 1.5m and subtracting results. It is evident that the highest differences arise at receiver points close to the road, while the difference is less significant at receiver points away from the road although the influence of neighbouring barriers should not be ignored. In fact the mean difference over the entire area was only 0.59dB. A map similar to this one could be displayed along with a noise map to encourage people making casual measurements to locate a suitable place to measure.

Table 5.2: Comparison of different measurement heights

Location	*Height*	L_{eq}
Street-side Westland Row	4	72.2
Street-side Westland Row	1.5	76.7
Chemistry Building	4	65.5
Chemistry Building	1.5	66.1

This was also observed upon an analysis of a number of measurements which were made in two locations, at the Chemistry Building and along Westland Row, see figure 5.18, at both a height of 1.5m and 4m, the results of which are displayed in table 5.2.

5.2.3 Direct comparison of measurements

After quantifying the various factors that may influence short-term measurements it is possible to make a general comparison of measured and predicted results. A number of measurement locations were chosen as indicated in figure 5.18. Most measurements were taken by the street side although the site at the Chemistry Building is a green area within Trinity College, while Grafton Street is a pedestrian street with no traffic allowed. A comparison of measured results with predicted results is displayed in table 5.3.

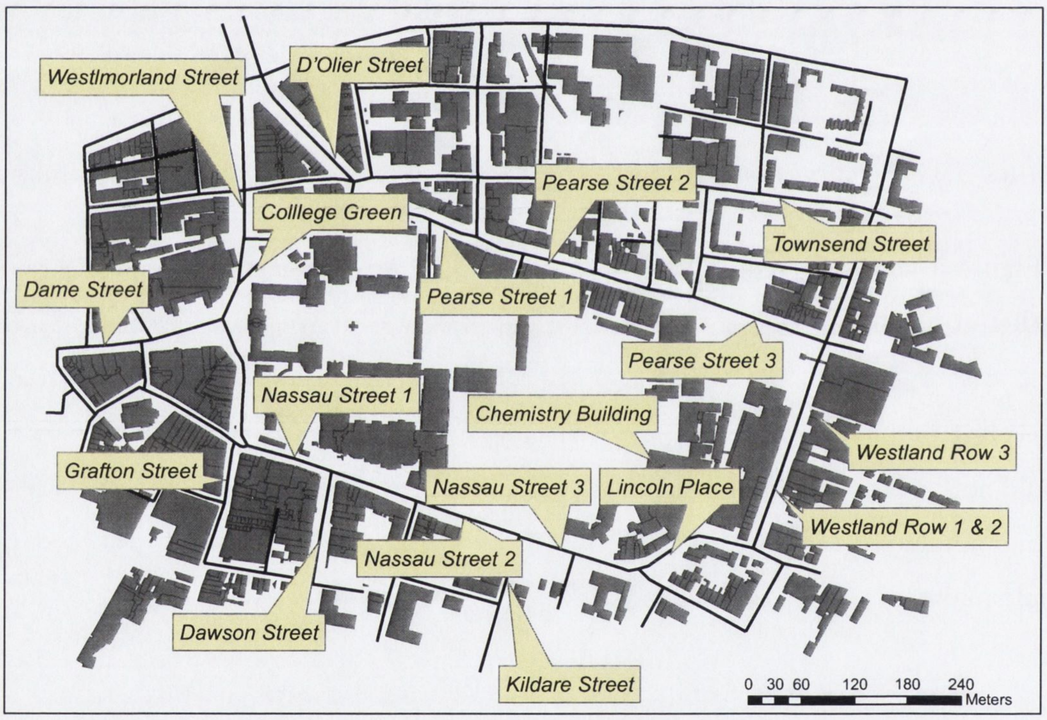

FIGURE 5.18: Locations of various measurement points

The measured L_{day} in the table is the average L_{eq} calculated in each case for a number of measurements over the course of the day period. It is presumed this is reflective of the overall L_{day} level. All measurements were recorded at a height of 4m. The calculated L_{day} displayed in the table is the value for L_{day} predicted by the model.

It is worth noting that the quiet area beside the Chemistry building is not ac-

TABLE 5.3: Comparison of results for each location

Site Num.	Location	Calculated L_{day}	Measured L_{day}
1	Westland Row 1	68.9	73.5
2	Westland Row 2	69.6	73.9
3	Westland Row 3	68.3	81.1
4	Pearse St. 3	71.7	75.5
5	Pearse St. 2	71.8	74.2
6	Pearse St. 1	71.4	74.9
7	College Green	70.4	73.4
8	Westmorland St.	67.5	70.1
9	D'Olier St.	70.1	71.3
10	Dame St.	68.1	73.6
11	Grafton St.	49.1	66.8
12	Dawson St.	69.2	70.4
13	Kildare St.	66.8	67.8
14	Nassau St. 1	68.3	71.1
15	Nassau St. 2	68.7	70.8
16	Nassau St. 3	66.4	70.3
17	Lincoln Place	66.1	73.4
18	Chemistry Building	47.8	65.5

curately predicted compared to measurements. However, the measured noise in this location may not be regarded as completely environmental noise as defined by the directive as it was influenced by ambient noise present at the time, such as people talking, walking and activity in the surrounding buildings. This is also noticeable on Grafton Street where measurements were influenced by people and not road traffic.

It is clear however that measurements are predominantly louder than predicted levels throughout the map, and as such it is reasonable to assume that the source model is not accurately represented. Measurements are predominantly louder than predicted levels near the roadside. Also, when predicted results fall below the ambient noise level, the comparison between predicted levels and measurements is futile.

5.3 Development of measurement system

It is evident that an essential part of completing any noise study is the inclusion of an on-site noise measurement campaign. In some studies measurements are used to supplement predicted maps whilst in other cases measurements form the complete basis of the noise-mapping process. The WG-AEN Good Practice Guide, [3] also recognises the need for on-site measurements. It states "Noise measurements may be used to validate noise maps at selected sites, boost public confidence in these maps, help develop detailed action plans and show the real effect of action plans once they are implemented". Unfortunately necessary measurement equipment is quite expensive and in addition to this, as with the prediction software, users are limited to the capabilities of the accompanying software. The ETI Capability Development Project recognised the need for a flexible low-cost measurement system and has endeavored to develop one.

Outline of system

Under Work Package 3 in the ETI capability development project, a pc type low power system has been designed and built with facilities for pcmcia data acquisition and gsm/rf data relay. It runs on a Linux based operating system. The unit was modified to accommodate electret microphones for determining noise levels which would be stored on a 4GByte compact flash memory card. The unit is surrounded by a robust all-weather metal casing, as shown below in figure 5.19

Figure 5.19: Noise monitoring unit

The omnidirectional Panasonic WM-61 electret microphone was selected for use with the unit. These microphones have a relatively flat frequency response up to 20kHz and a sensitivity of -35 ± 4dB. The microphone specifications make it a suitable choice with the added bonus that they are extremely cheap, less than 1 Euro each, meaning they can be easily replaced at an insignificant cost. Each microphone was mounted in a rugged weatherproof casing, see figure 5.20, and testing is ongoing to determine how effective this enclosure is. Initial tests have yielded positive results.

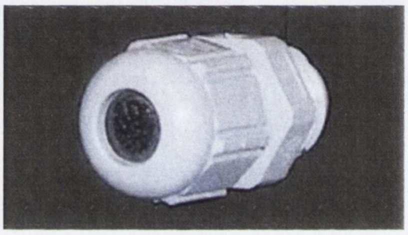

FIGURE 5.20: Microphone casing

Analysis of data

Software written in ANSI (American National Standards Institute) compatible C was written to analyse the raw data acquired by the system. The system acquired voltage readings which fluctuated depending on the noise level, this raw data had to then be interpreted to produce meaningful results. The unit is designed to acquire sound data for each of the four available channels at up to 44,000 samples per second. This data is then filtered to account for A weighting and the statistical levels, L_{eq}, L_{10} and L_{95} are then determined over a five minute period. $L_{eq,5mins}$ may then be used to determine $L_{eq,1hour}$ and as such L_{day}, $L_{evening}$ and L_{night} as desired, leading to an overall value for L_{den} if required.

Figure 5.21: Installing unit at traffic lights near the IFSC in Dublin

Initial results

For an initial study the unit was stationed near the IFSC along the quays in Dublin's city centre, figure 5.21. An obvious cyclic drop in noise levels during the night period was observed, which was reflected in traffic counts for that particular area. Results from the four different channels available on the measurement unit were examined. It was noted that channels 1 and 2 correlated well as did channels 3 and 4. Channels 3 and 4 yielded louder results than 1 and 2. This was because the latter two microphones were placed inside the casing, while channels 3 and 4 were outside, and thus subjected to louder noise levels.

Channel	Overall L_{eq}	L_{max}	L_{min}
Channel 1	74.35 [dBA]	84.09 [dBA]	58.90 [dBA]
Channel 2	74.33 [dBA]	83.31 [dBA]	58.03 [dBA]
Channel 3	78.64 [dBA]	98.40 [dBA]	55.19 [dBA]
Channel 4	76.83 [dBA]	97.78 [dBA]	56.59 [dBA]

Table 5.4: Results from separate channels in test unit

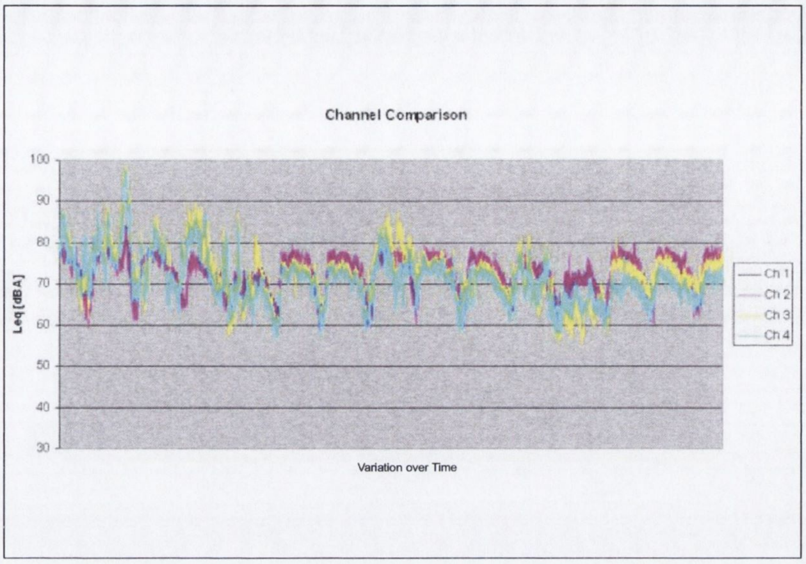

FIGURE 5.22: Comparison of results obtained from each channel

5.4 Presenting noise maps

Upon completion of the noise map, a measurement campaign, and a detailed error and variation analysis, the developer must then endeavour to present their findings in a clear, comprehensible and accessible manner. All elements of the study should be displayed in conjunction with the map, and relevant instructions on how to read the noise map should accompany it. In addition it may be desirable to create a map that may be relevant to public needs in addition to satisfying the requirements of the directive.

Upon an initial analysis of measurements it is evident that the noise map for the test site is not accurate enough to stand up to scrutiny so it should therefore be improved. The source model should be recalculated to represent a louder source model. This would improve the map's accuracy in all areas of the site.

5.4.1 Simple inclusion of measurements

Measurements may be included in a rudimentary manner as displayed in figure 5.23. This technique would only be appropriate when including long term measurements taken at a height of 4m as it does appear to be presenting a direct comparison of measured and predicted results. A more detailed and refined method of integrating measurements with the noise map is presented in Chapter 6.

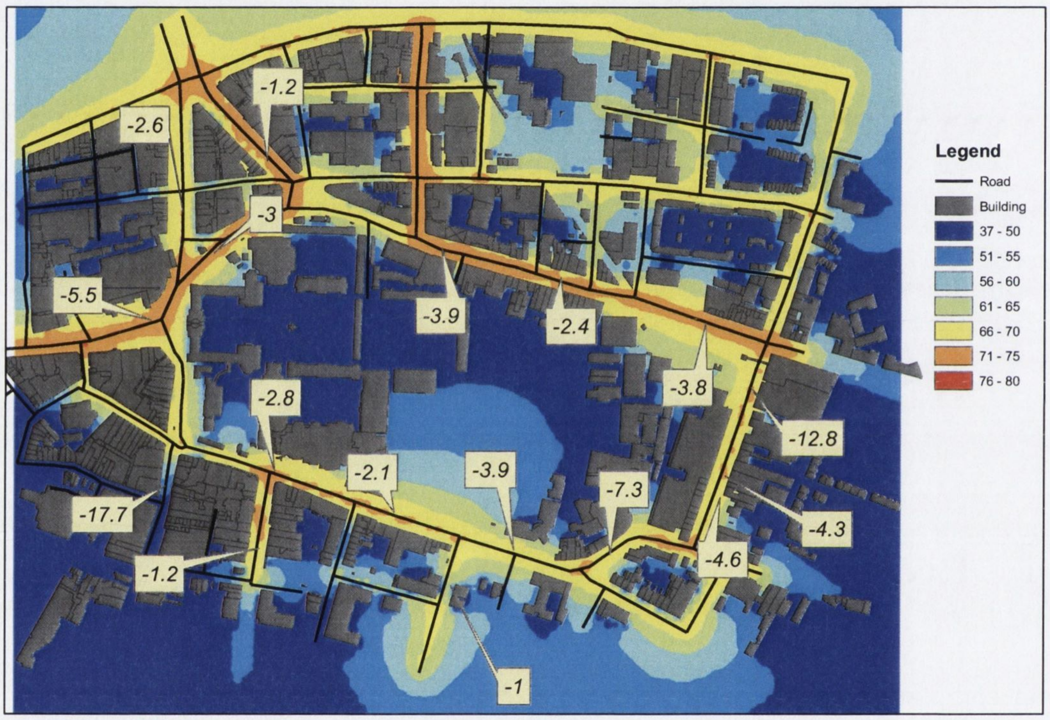

FIGURE 5.23: Simple display of measurements with predicted noise map

5.4.2 Interactive noise map

It is possible to present online an interactive noise map which the user may adapt to his/her scenario, see figure 5.24. For example the interactive map could be adapted to show L_{day} and $L_{evening}$ in addition to L_{den} and L_{night}. The effect of different meteorological conditions may also be presented.

This type of interactive map could also be used to display the impact of various

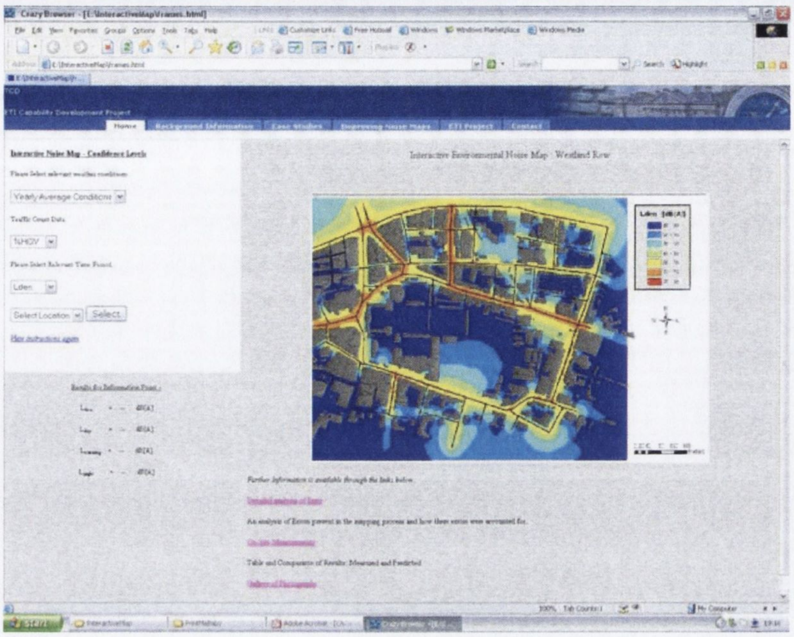

FIGURE 5.24: Interactive Noise map

action plans, showing the before and after situations with respect to the changing noise levels.

5.4.3 Confidence level map

Presenting the uncertainty associated with strategic noise maps in a lucid and consistent fashion is crucial in order to gain public confidence. Thus, if errors can be justified and identified from the onset, maps will satisfy public analysis. Following a measurement campaign and an uncertainty analysis, a supplementary map may be created displaying the associated confidence level with calculated results, an example is presented in figure 5.25. Thus areas of high confidence, i.e. areas where the architect of the noise study expects measured levels to correspond to predicted levels to within a defined decibel level, are easily identifiable. Similarly areas of low confidence may also be presented, thus providing a useful tool for the validation of noise maps. This would also serve a useful guideline which the public may reference when making noise measurements. For example location 3 in the test case was underneath a railway

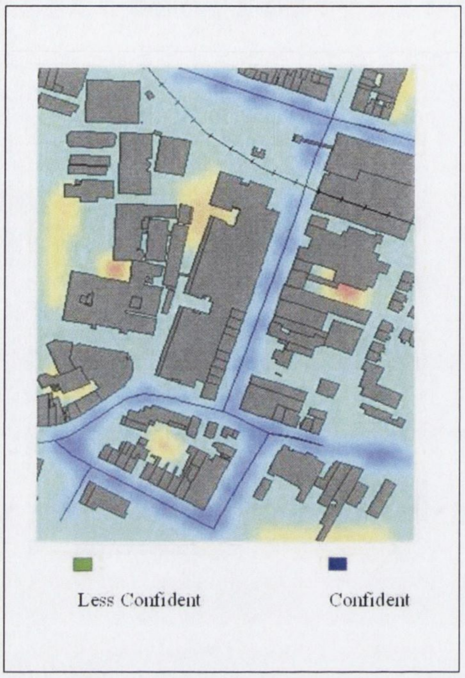

Figure 5.25: Confidence Level Map

bridge. The confidence level map could present an area of low confidence underneath bridges and other geographical features outside the scope of the prediction model.

It may then be argued that while certain areas of low-confidence exist, the overall accuracy of the map is upheld. Noise maps are generally created for strategic purposes and as such continuity across the map holds the greatest significance. Provided the overall accuracy of the map is acceptable it will be acceptable for maps to be used for strategic purposes.

5.4.4 Development of noise information website

The Directive places a large emphasis on public involvement throughout each stage of the noise mapping process. It also states that maps must be presented in a “clear, comprehensible and accessible manner”. It was decided that a purpose built website would be an ideal tool to display results of noise studies to the public in an obvious and comprehensible manner [49]. This website could then act as a control center for all involved in a noise mapping project, providing a focal point for the presentation of all results associated with different studies.

The website is aimed primarily at the general public and provides an introduction to the concept of environmental noise. It explains how people may be effected by noise and why the EU intends to address the problem. The need for monitoring environmental noise is addressed and the concept of creating noise maps is introduced. A video download of a noise mapping animation with narration explaining the meaning of the map is also available for users. In addition, users can play audio clips of different noise levels thus introducing the relative scale of the decibel indicator. The goal is to educate the general public in the area of environmental noise and present studies in a fashion that will be relevant to their needs.

The website also presents results from various different case studies undertaken throughout the course of the project. Additional case studies may be added to the site as they are undertaken. This will lead to a core database of all relevant studies which will be available to future researchers, in addition to providing the public with an overview of all noise studies conducted here, thus further educating the public in the area of noise management, with the added bonus of raising the profile of noise studies in Ireland.

It is also possible to display noise maps representing various different acoustic scenarios, in an interactive fashion. This makes it possible to show the effect of how several different factors will effect noise levels, for example different times of the day, different meteorological conditions etc. Instead of just displaying maps in terms of L_{den}, maps could be adapted to show hourly levels. This could then lead to the impartial validation of noise maps from independent individuals, thus raising the public credibility of results.

Further development of the website is also possible. It could be developed further to become the central source of information for all things related to noise in Ireland. It may be possible to present real-time noise levels online having been obtained through the networked monitoring instrumentation. It would be interesting then for users to check noise levels at various times of the day, or when various initiatives are taking place, eg car free day. Finally, if Predict-a-*Flash* is released in the public domain, it would be available for free download on this site.

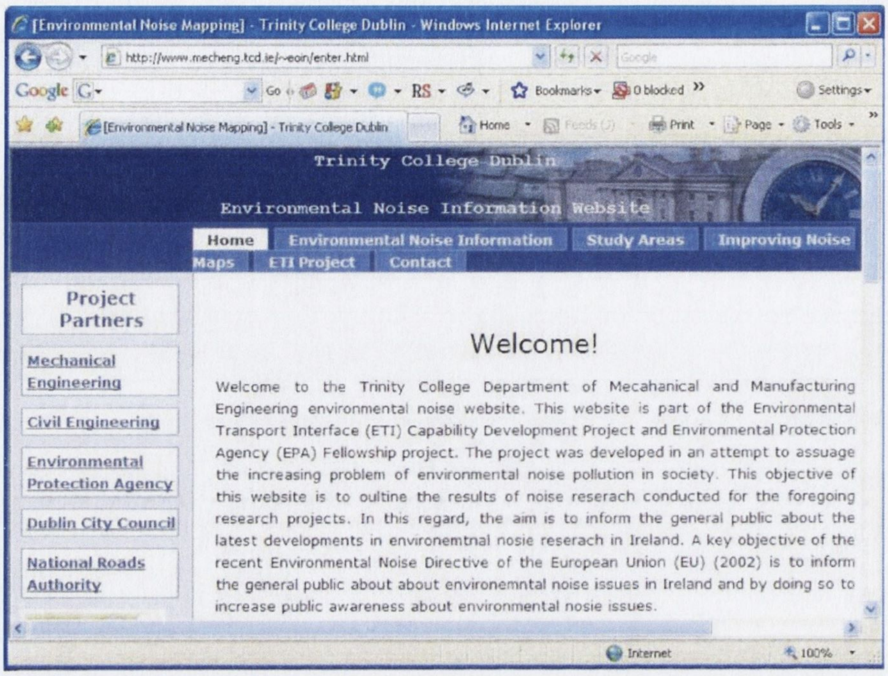

Figure 5.26: Welcome screenshot of noise website

5.5 Evaluating Action Plans

Once noise maps have been produced and released in the public domain it will become clear what action needs to be taken in order to improve the general acoustic situation. Inevitably this will lead to the introduction of several noise mitigation measures into an area. Some examples of mitigation measures include the erection of noise barriers, the introduction of low noise road surfaces, or reducing noise through the use of traffic management schemes. Several mitigation measures seek to reduce the noise level at the source as opposed to interfere with the propagation of noise. Consequently this means that action plans which involve reducing noise at the source can be evaluated by calculating the change in noise levels at the source.

Predict-a-*Flash* has been developed to accommodate these calculations as a clear distinction exists between the source model and propagation model. Each model is completely separate and the models are only amalgamated at the final stages. This makes it possible to easily determine the impact of changes at the source without the need for recalculating the propagation model.

This means if a proposed action plan involves altering a factor influencing the emission model, and does not directly impact the propagation model, for example, restricting the flow of heavy vehicles, changing a speed limit, pedestrianising a road, etc, the entire model does not need to be recalculated. The new source model can be re-compiled and the impact can be determined almost instantaneously. This is perhaps best described in the diagram showing the alterations to the work flow structure presented in figure 5.27.

5.5.1 Evaluated Action Plan

Figure 5.28 shows the effect of removing all traffic from Pearse St. and Tara St., thus representing the possibility of pedestrianising these roads, assuming the neighbouring road's traffic flow remain constant, while Figure 5.29 shows the effect of a blanket ban on all heavy vehicles around Trinity College. These maps were calculated by altering the input variables of the source model and the propagation model remained unchanged.

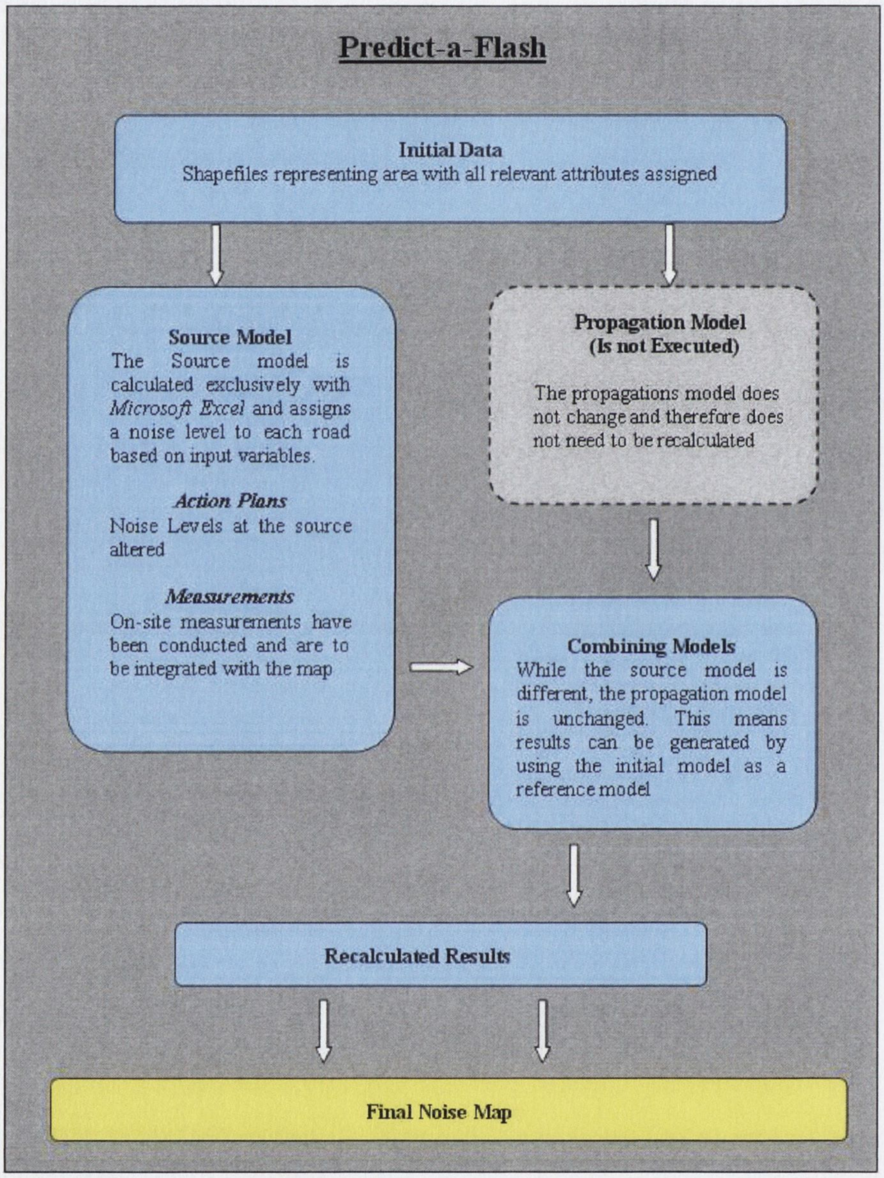

FIGURE 5.27: Predict-a-*Flash* revised work-flow

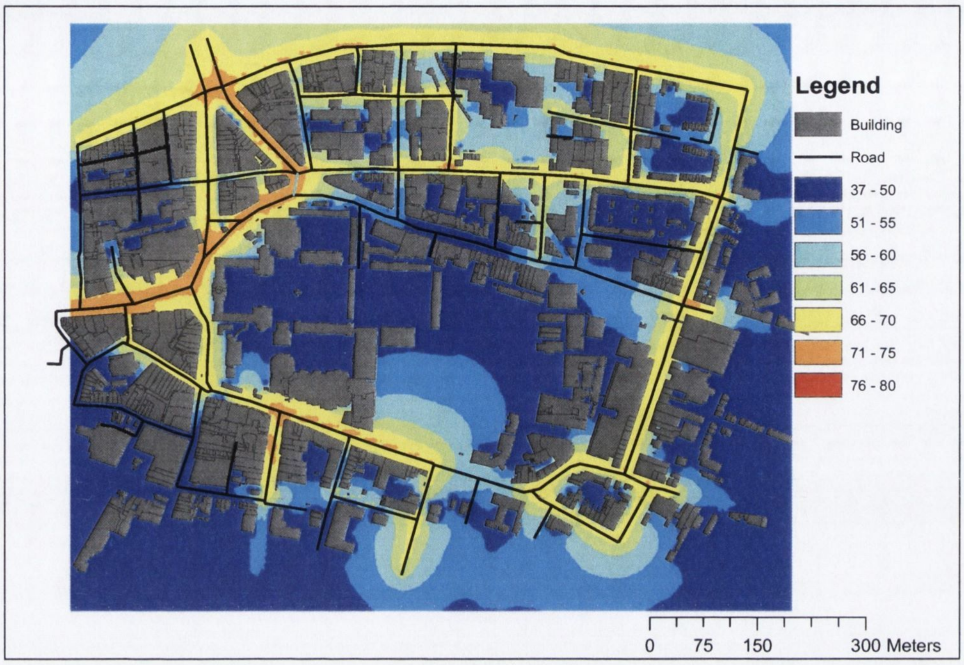

FIGURE 5.28: Noise Map with traffic on Pearse Street and Tara Street removed

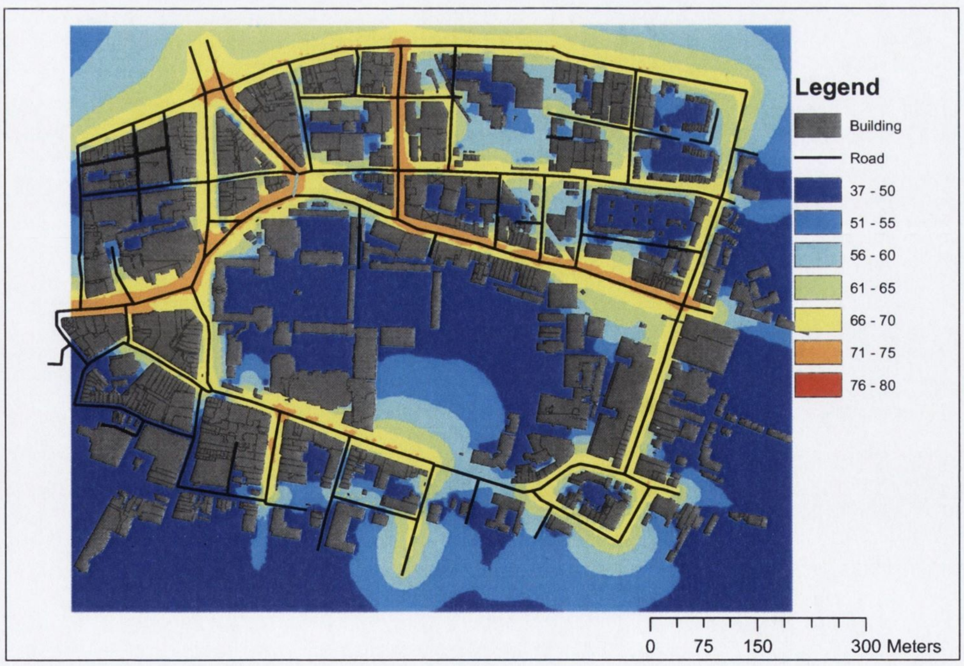

FIGURE 5.29: Noise Map with no HGV's

Chapter 6

Refined integration of measurements

Following a direct comparison of predicted noise levels with measured noise levels it is evident that maps predicted by Predictor and Predict-a-*Flash* yield consistent results, while, in general, predicted results do not agree completely with measurements taken on-site. Throughout the calculation stage a number of assumptions were introduced to the mapping process. It is evident that these assumptions, along with possible factors outside the scope of the models, introduced some degree of error to the process. This error is primarily associated with an inaccurate representation of the source. Noise maps would present a more realistic acoustic scenario if sources were more accurately represented. However, given that the source is influenced by numerous variables, many of which are unknown and not represented in the noise model, it not feasible to presume the source could be *calculated* more accurately. This means a more accurate source should be determined by a method other than prediction.

By integrating measurements with a noise map the source of the noise can be refined to yield a more realistic representation of the source. Integrating measurements in this manner ensures the integrity of the propagation model is upheld as only the noise levels at the source are altered.

6.1 Previous studies

In some noise studies measurements are used to supplement predictive mapping whilst in others, measurements form the complete basis of the noise mapping process. It is recommended in the Good Practice Guide that maps are created using computation methods while noise measurements should be used for the development and validation of computation methods [3]. While most noise studies are performed using calculations some studies have been undertaken with a heavy reliance on noise measurements.

6.1.1 Creating maps with measurements

In 2002 a noise map for the agglomeration of Madrid was made based on 4395 measuring points. This measurement based noise map was very expensive and complex to produce. A new system has since been initiated in Madrid to comply with the Directive in a more effective manner, known as the SADMAM system. The main goal of SADMAM is to produce fast and cheap measured noise maps that combine both long term and short term noise levels along with a realistic propagation model. Measurements are generally taken by mobile noise monitoring terminals, see figure 6.1, over short time periods at strategic locations in the city. These measurements are used to determine source strengths that are then fed into a prediction model that creates the map. The source strengths are determined by measuring noise at receiver positions and using a reverse engineering approach to determine the noise levels at the source. It was observed that if there are several sources, the sound power level of the various sources become more difficult to determine. This problem is solved by careful choice of the receiver positions based on knowledge of the behavior of the different sources in the area [50].

This approach was also adapted to map the main campus of Pusan National University, in the Republic of Korea [51]. Again the maps produced were based on source strengths determined from measured data while it was noted that the quality of the map depended on the number and accuracy of the measured data.

6.1.2 Validating maps with measurements

Maps created by predicted methodologies may also incorporate measurements to some degree. As described in section 5.2.3 maps created for the test area were compared directly to measurements and it was found that results did not concur. A more refined approach may be adopted to include measurements within predicted results. The

Figure 6.1: Mobile Monitoring Unit, Madrid

difference between predicted and measured values can be identified and integrated with the map. The following methods of calibrating noise maps with measurements were identified in [52] which gave an outline as to how measured levels can be used in noise mapping.

- *Global Correction of noise levels*

  Adjust the overall map by a global correction based on the difference between measured and predicted values.

- *Local correction of noise levels*

  Measure close to sources to estimate source levels by an iterative technique. This helps determine unknown source parameters.

A global alteration as described in method 1 would imply that the author believes the error to be constant for every source in the test area. This is unlikely to be the case but offers a simple solution to what could be considered a complex problem. Method 2 provides a more refined approach than Method 1 as it assumes the error at each measurement point is independent and arises from separate sources. Following an evaluation of the uncertainties in the source model, the most appropriate factor to be adjusted in order to best improve the overall uncertainty may then be determined.

6.2 Predict-a-*Flash* methodology

The work described in 6.1.1. explains how maps may be created by using measurements to determine the source strength. These maps are dependent entirely on measurements and are as such validated by the initial measurements. However as measurements were not reported after the map was created, it is not possible to determine the validity of the map, and if errors arise, it is not clear which set of measurements will be used to correct the map. Additionally this method can not be used to determine the effectiveness of proposed action plans or used to *predict* noise in a new area. It would also be unfeasible to introduce this technique in an agglomeration where measurement units are not readily available and a large dataset of measurements do not exist.

Thus the most practical course of action is to develop a noise map based on computational methods and then adjust results through the integration of measurements. Of the two methods described above, the most reliable is the second method, as the error associated with each road will not be identical in all areas of the map and not accurately accounted for by a global correction. This method uses an iterative technique to best fit emissions to measured data. Predict-a-*Flash* adopts a similar approach although measurements are explicitly integrated into the map following a direct comparison between measured and predicted values.

This is an ideal technique computationally as it identifies the error in the map as being associated with the source and is separate to the propagation calculations. This means measurements can be used to refine noise levels at the source and, in the same manner as evaluating action plans, the resulting noise map can be determined in a straightforward manner. This will result in a refined map based on a corrected emission model.

The following assumptions are inherent to using this method:

- The emission model has been misrepresented, either through inaccurate traffic data or through unknown sources outside the scope of the model.

- The propagation model yields accurate results.

- A local correction may be applied to each source of noise in the vicinity of the measurement. For each receiver point it is assumed that the error is associated with its most influential source.

6.2.1 Computational procedure

As previously outlined, the developed model performs source calculations and propagation calculations separately. This means that the propagation model does not need to be recalculated if changes are made to the source of the noise. This feature can be developed to allow for the effective integration of measurements with predicted results yielding a noise map which has been corrected to match reality.

Computationally, the integration of measured data can be achieved in a similar manner to the evaluation of proposed action plans. Instead of the user defining a difference in the source, i.e changes in traffic speed, composition, etc, the difference is automatically interpreted from measurements on site.

The user inputs the co-ordinates at which measurements took place and the noise level measured. This is then directly compared with the predicted level at those co-ordinates. The difference is attributed to an error at that location's most influential source i.e. the road that produces the loudest noise at the point under examination. This source is then corrected by the measured difference.

If multiple measurements yield different levels of correction for the same road source, then the average correction is determined. It is expected that corrections should be similar for all sources so any outliers showing an extreme difference will be flagged for further investigation and a more in-depth examination.

Figure 5.19 in Chapter 5 displayed the averaged measured noise level at various locations throughout the area compared to the predicted noise map. These differences are displayed again in tabular form in Table 6.1. By inputting each measurement into Predict-a-*Flash* it was possible to identify those roads erroneously represented and the correction factor for each road was determined. These corrections are also presented in Table 6.1.

TABLE 6.1: Comparison of results for each location

Site Num.	Location	Calculated L_{day}	Measured L_{day}	Correction
1	Westland Row 1	68.9	73.5	4.6
2	Westland Row 2	69.6	73.9	4.3
3	Westland Row 3	68.3	81.1	12.8
4	Pearse St. 3	71.7	75.5	3.8
5	Pearse St. 2	71.8	74.2	2.4
6	Pearse St. 1	71.4	74.9	3.5
7	College Green	70.4	73.4	3.1
8	Westmorland St.	67.5	70.1	2.6
9	D'Olier St.	70.1	71.3	1.2
10	Dame St.	68.1	73.6	5.5
11	Grafton St.	49.1	66.8	17.8
12	Dawson St.	69.2	70.4	1.2
13	Kildare St.	66.8	67.8	1.0
14	Nassau St. 1	68.3	71.1	2.8
15	Nassau St. 2	68.7	70.8	2.1
16	Nassau St. 3	66.4	69.3	2.9
17	Lincoln Place	66.1	73.4	7.3

Note: Location 3 was situated under a railway bridge and as such measurements made at this location would have been influenced by multiple reflections. Location 11 was on one of the main shopping streets in the city and it was noted during measurements that noise from traffic was negligible compared to the ambient noise of the busy pedestrianised street.

This yields the new noise map displayed figure 6.2. For the purpose of clarity, the original noise map calculated by the developed software is displayed again in figure 6.3. It should be noted that the map presents noise levels in intervals of 5dB so on first impression the refinements may be negligible. Nonetheless, the source model has been refined from the measured data and each of the above roads are now represented with a louder noise level. Corrections are particularly evident around Westland Row, as measurements have yielded a louder source on Westland Row. In general it may be observed that the overall map shows louder noise levels.

As outlined in the note above, Locations 3 and 11 were flagged in calculations and subjected to investigation. It was noted that measurements conducted at Location 3

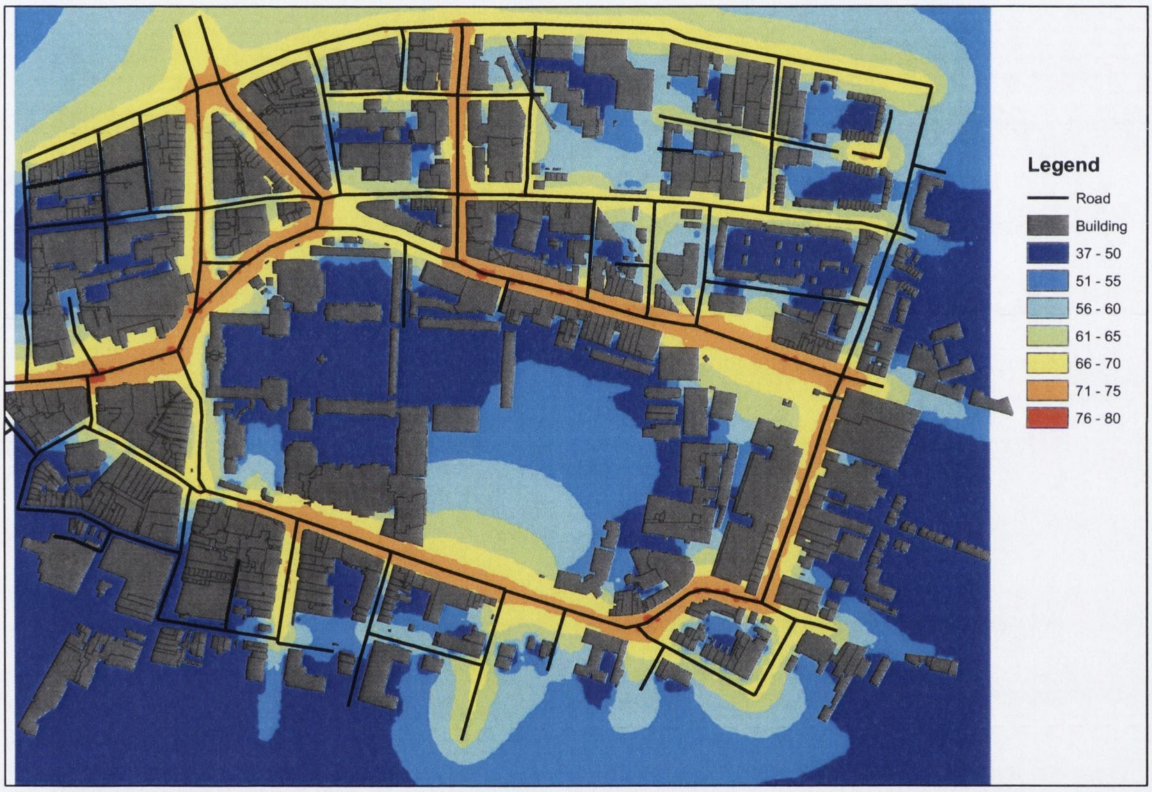

FIGURE 6.2: Recalculated Noise Map

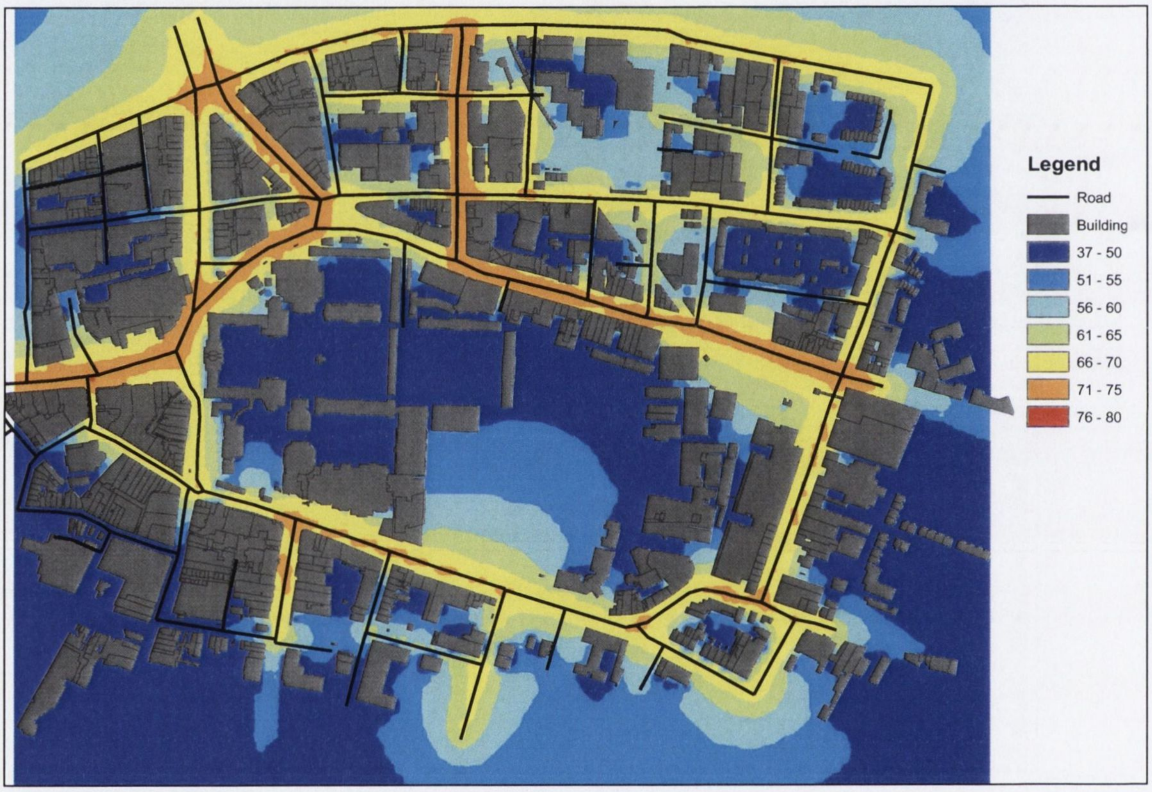

Figure 6.3: Original noise map created with Predict-a-*Flash*

FIGURE 6.4: Measuring noise on Grafton Street

were influenced by the presence of a railway bridge while measurements at Location 11, on Grafton Street which is a street completely reserved for pedestrians, were influenced heavily by passing pedestrians, figure 6.4, and shop noise and as such did not represent noise from road traffic, or any type of environmental noise as defined by the Directive.

It is worth noting that reflections have been omitted from calculations and as such will influence results. If we take a uniform correction of 3dB for corrections along each street and ignore locations 3 and 11, the predictions appear to yield much more accurate results, as displayed in Table 6.2. This term would also serve to account for the variability and uncertainty of the measurement process.

Further integration methodology

In addition to automatically determining the error of the emission model, two alternative methods were developed to aid the user develop a more accurate noise map.

- *Simple user-defined procedure*

  If the user is confident that one particular road is louder than calculated, a correction can be manually input at the source.

TABLE 6.2: Comparison of corrected measurement results for each location

Site Num.	Location	Calc L_{day} + 3dB	Measured L_{day}	New Correction
1	Westland Row 1	71.9	73.5	1.6
2	Westland Row 2	72.6	73.9	1.3
4	Pearse St. 3	74.7	75.5	0.8
5	Pearse St. 2	74.8	74.2	-0.6
6	Pearse St. 1	74.4	74.9	0.5
7	College Green	73.4	73.4	0.1
8	Westmorland St.	70.5	70.1	-0.4
9	D'Olier St.	73.1	71.3	-1.8
10	Dame St.	71.1	73.6	2.5
12	Dawson St.	72.2	70.4	-1.8
13	Kildare St.	69.8	67.8	-2.0
14	Nassau St. 1	71.3	71.1	-0.2
15	Nassau St. 2	71.7	70.8	-0.9
16	Nassau St. 3	69.4	69.3	-0.1
17	Lincoln Place	69.1	73.4	4.3

- *Local point correction*

Following an analysis of the site another method of measurement-influenced correction was developed. It was observed that some sections of roads did not produce a uniform level of noise for various reasons. Two observed reasons included a loose manhole cover and a portion of road under a bridge. It should be recommended that measurements are not taken in situations such as these. However receivers in this area may be weighted by an extra factor to account for the extra noise source. This correction should be used primarily for presentation purposes.

6.3 Measurements

Measurements may become a powerful tool in the development of an accurate noise map, provided they are interpreted and treated in a correct manner. It is important that when noise maps are adapted based on measured data, the measurements are not influenced by factors that will compromise their accuracy. Ultimately maps are presented in terms of a year long average so the process of refining a source based on a short term measurement may be flawed. However, provided it is accepted that refinements are based on measurements, the overall accuracy will improve, particularly if measurements are taken at several times throughout a year. This will also help to develop a model for the seasonal variation of noise.

Additionally when these corrections are introduced to the map it is important they are based on measurements that were dominated by environmental noise sources specific to the EU Directive. A number of points were noted when measuring in the test area:-

- *Manhole Cover.* It was observed at measurement location 1 that there was a loose manhole cover on the road that produced a loud grating sound as vehicles drove over it. While this is outside the scope of the prediction model, it could still be considered environmental noise as defined by the directive, (unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport).

- *Nightclub Noise.* It was observed during the week-long measurements on Dawson Street, location 12, that L_{night} was influenced by noise from a nearby nightclub throughout the night, particularly on Wednesday and Friday. This is not regarded as environmental noise (see above definition) and these values should therefore be ignored if used to determine a correction factor.

- *Ambient Noise.* In green areas away from busy roads the ambient noise may be considerably louder than environmental noise resulting from road traffic. Thus noise levels below 50dB may be presented in noise maps. However these levels may not be reflected in measurements as the ambient noise due to people walking, running, socialising, playing sports may exceed the presented levels. Therefore it will be important to stress that noise maps present only levels of environmental noise. For the benefit of public presentation, it may be useful to introduce an ambient noise level, based on measurement in the area, and identify areas in the map where environmental noise is negligible.

- *Measurement Location.* It was identified that measurements taken underneath a bridge were much greater than expected. This is because multiple reflections would have influenced the measurements and were not included in the calculated model.

6.3.1 Adapting short-term measurements

In accordance with the Directive, all maps are presented in terms of L_{den}, which is a year long average indicator, whereas most measurements will be representative of a short time period. Therefore a method must be developed to relate the two quantities if short term measurements are to be used to either calibrate the source or independently validate a map.

While the L_{den} tool may be a powerful tool for assisting with environmental noise managements and control, it is not suitable for the independent validation of noise maps. As described in Chapter 5 it was found that the L_{day} indicator is a much more suitable indicator for drawing preliminary conclusions about predicted noise maps. A comparison of predicted L_{day} levels with measurements taken throughout the day period should give an initial estimate of the accuracy of maps. It would therefore be advantageous if noise maps presented with the L_{day} indicator were also made available in the public domain.

However, as the Directive does not require a map presented in terms of L_{day}, it may not be a straightforward task to derive L_{day} levels after maps have been produced. As such it would be beneficial if a relationship between the long-term L_{den} indictor and L_{day} was developed to enable a comparison of indicators.

This may be achieved by using a similar method developed by TRL which described a mathematical procedure which converted values of $L_{10,18hr}$ to L_{den}. The TRL method predicts the noise level over a 24-hour period from the noise level predicted or recorded over 18 hours of that 24 hour period [33]. A similar relationship can be developed to relate the 12-hour day period, represented as L_{day} to L_{den}.

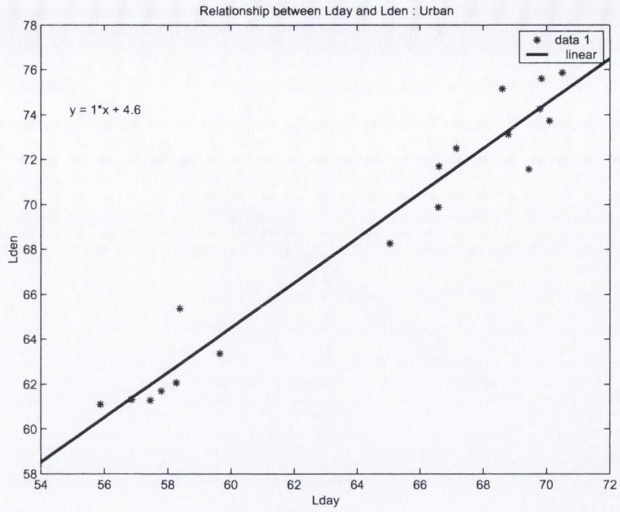

FIGURE 6.5: Urban Roads Relationship

6.3.2 Development of relationship

Urban Roads

By performing a regression analysis on all measurements performed in an urban environment it is possible to develop the relationship between L_{day} and L_{den}. The measurements analysed are the long term measurements undertaken throughout the study. L_{den} is calculated for each 24 hour period and L_{day} is calculated for each day between the hours of 07:00 and 19:00. The regression analysis is displayed in figure 6.5 and yields the relationship:

$$L_{den} = L_{day} + 4.6 \tag{6.1}$$

This means if L_{day} is determined for one day in an urban environment it may be converted to L_{den} and compared with the noise map.

The above relationship, determined from measurements taken on-site, was also supported by a similar relationship developed from purely predicted levels. Values for L_{den} and L_{day} were predicted and a regression analysis was performed, yielding a comparable relationship:

$$L_{den} = L_{day} + 4.3 \tag{6.2}$$

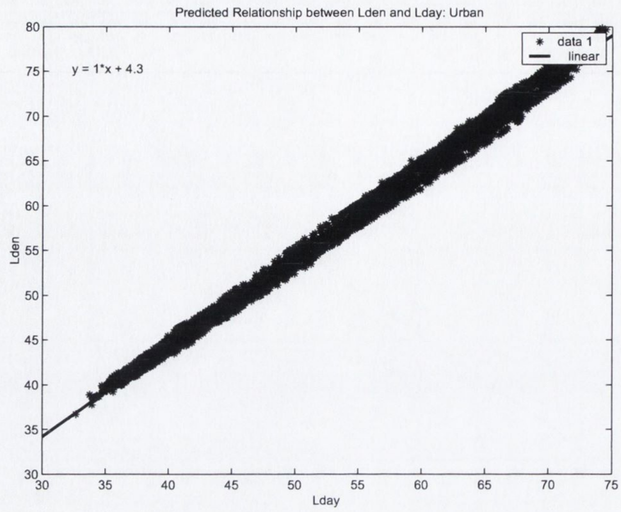

FIGURE 6.6: Predicted Urban Roads Relationship

Sub-Urban Roads

The same analysis was performed on measurements obtained from the National Roads Authority for various measurements around the country near national roads. This yielded a slightly different relationship, which is expected as national roads would have a different diurnal pattern to roads in an urban environment.

$$L_{den} = 0.99L_{day} + 3.2 \tag{6.3}$$

6.3.3 Implications of relationship

The relationship above can be used to determined L_{den} based on L_{day}. It is a "best guess" approach and should primarily be used to aid public perception of predicted noise maps. It can only be used if the environment under examination is similar in characteristics to the environment from which the relationship was established. However the relationship will aid in the validation of noise maps as it will be possible to identify areas that do not correspond to predictions.

In order to determine a value for L_{day} based on short term measurements, it would be ideal to follow guidelines set out by the National Roads Authority which outlines a method to determine $L_{10,18hr}$ [53]. Measurements should be made at each location

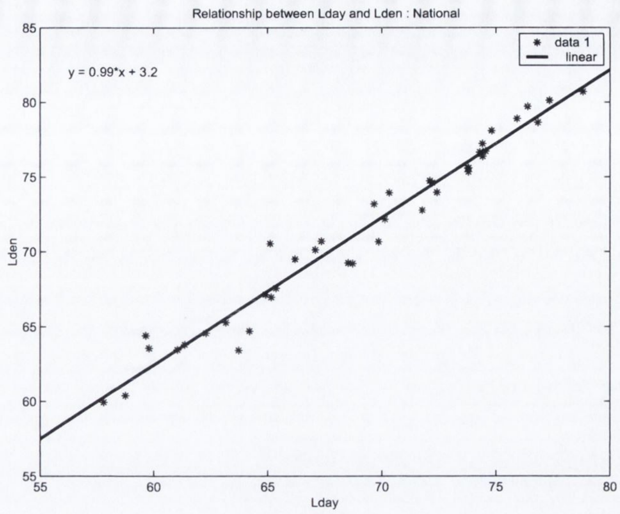

FIGURE 6.7: National Roads Relationship

over any three consecutive hours between the hours of 10:00 and 17:00. Where road traffic noise is the principal source of noise, L_{day} values may be derived by calculating the mean of the measured L_{eq} values for the three sample periods, each of at least 15 minutes. The use of 15 minute sample periods should permit measurements to be made at a total of three locations in any given 3 hour period, provided they are sufficiently close together. This guideline may then be added to the list presented in Appendix D.

Chapter 7

Discussion

It was identified from the early stages of this project that the use of commercial software for the development of strategic noise maps will restrict users when carrying out environmental noise studies. As such it was important to move away from commercial software and instead be free to use a tool that was versatile and efficient. This led to the development of an independent noise prediction model.

It should however be noted that the goal of this research was not to develop a commercial tool which would replace the expensive packages available for purchase today, but rather to investigate the possibility of developing a simple substitute. As such "Predict-a-*Flash*" now forms a solid basis from which a number of improvements can be made, and an effective alternative to today's commercial package can be reached.

Initial tests have shown that the core calculation engine compares well with the benchmark commercial software, Predictor, and is completely adaptable to the needs of the final user. Additionally the propagation model may be developed to be as complex, or as simple, as required.

7.1 Comparing noise maps with measurements

Upon an analysis of measurements performed at several locations throughout the test site it was observed that they did not agree conclusively with predicted results. This was due to a number of factors such as the unavailability of input data resulting in a number of assumptions and averaging of data, impacting on the accuracy of results, along with a number of factors outside the scope of the prediction model influencing measurements.

Thus it may be concluded that in a real-life scenario, noise measurements will never be truly independent of sources separate to those causing environmental noise, and the input data will most likely never be as accurate as the predictive model requires in order to produce a *perfect* noise map.

The most important and influential aspect of noise prediction is an accurate representation of the source, as if the source is modelled incorrectly, then the associated calculations for propagation will be erroneous. Thus more time and effort should be spent collecting accurate data then developing calculation models. Therefore a simple propagation model producing reasonable results will be far superior to the time consuming complex one, especially considering the uncertainties contained in the input data to begin with.

This theory could be applied against the use of the new Harmonoise model. While the author recognises the importance of a universal approach to the development of noise maps, it may be argued that the source and propagation models in the Harmonoise method are too complex, especially considering the lack of accurate input from an end-user's point of view, and a simpler version should be developed for use by Member States.

A more appropriate technique in producing noise studies would involve the integration of measurements with predicted results. If measurements are used to "fine-tune" the predicted noise map, a more efficient computational methodology is necessary. This would involve the re-running of models to produce a more realistic map based on measurements. Measurements may be integrated in a number of ways, but care must be shown so that, as measurements are presented along with the noise map, they serve to validate the map and boost confidence in the map instead of conflicting entirely with results. However it is clear that measurements should be taken to supplement the predicted noise maps.

Additionally, a balance must exist between the complexity of computational procedures and the accuracy of final results. It has been shown that a number of computational simplifications coupled with a complete stripping down of all features available with a standard commercial tool will result in a noise map being computed in a fraction of the time while still providing comparable results.

7.2 Types of noise maps

Over the course of this work, a number of methods have been described which may be used to either create or adapt a noise map. In an effort to create the most accurate noise map a clear distinction must be made between the various noise maps created by different techniques.

- *Strategic Noise Map*

  A strategic noise map as defined by the Directive means "a map designed for the global assessment of noise exposure in a given area due to different noise sources". It is, in essence, a map to be used for strategic purposes. If noise maps are created in a consistent manner then they will be sufficient for strategic purposes, i.e. quiet areas will be easily identifiable, as will the loudest areas. This means that representing the exact scenario is not imperative and certain errors are acceptable. However, issues will arise if maps are found to be erroneous if associated action plans are challenged by members of the general public.

- *Refined Strategic Noise Map*

  Once a baseline strategic noise map is created it can then be validated and possibly refined by the integration of on-site measurements. This map will therefore present a more accurate acoustic scenario and will be more credible in the public domain. This map will be based on measurements and as such will be influenced by any factors that may have influenced measurements during the sample period. It will however yield a noise map which is more reflective of the actual scenario experienced by the public.

- *Action Plan Noise Map*

  Following the dissemination of noise maps in the public domain, action plans will have to be evaluated and adopted. The impact of these action plans should be determined and presented to the public in order to arrive at the best possible action plan that is widely accepted as a viable solution.

- *Dynamic Noise Map*

  In an effort to increase public knowledge a dynamic, interactive noise map could be presented displaying different levels due to different acoustical conditions, e.g. different types of weather, different times of day, etc. This would also serve to educate the general public on the basic principles of environmental noise.

7.3 Future Work

The goal of this work was to investigate the possibility of developing methodologies which circumvent the restrictions caused by today's commercial noise prediction software. This has been proven possible and the model demonstrates a viable framework to form the basis of a complete package.

At a more complex level, a number of improvements to the model could be made.

- *A detailed measurement campaign*

  A more detailed measurement campaign should be conducted at different locations throughout the test area. Ideally permanent units should be in place in order to assess the variation of noise over an entire year. These results could then be integrated with the developed model to establish seasonal variations and provide a noise map based on different times of the year. It would also lead to determining a more accurate average day period.

- *Rail Noise*

  The model has only been developed for road traffic noise to date. It would be ideal to incorporate the recommended interim standard for rail noise also, which would be straightforward to implement. It would then be possibly to easily combine both maps, road and rail, for use in the public domain.

- *Harmonoise*

While it remains to be seen how viable the Harmonoise standard will be, it is reasonable to assume that all Member States will have to attempt to implement it. It would seem that a specific software will be necessary to transport this standard into an effective calculation procedure.

- *Accurate source representation*

While the Harmonoise model develops a complex propagation procedure and a more precise source model than previously available, there is still room for improvement in terms of accurate source representation. This may include additional weighting for more annoying traffic conditions, a more detailed allowance for varying traffic speeds and the inclusion of specific characteristics associated with certain roads. The source model is the most important part to the prediction model and as such should be developed as accurately as possible

- *Further Propagation Procedures*

The current model does not accommodate reflections or a ground surface attenuation factor. This should be addressed in order to improve the overall accuracy of the model and make it appropriate for use in certain complicated scenarios.

7.3.1 Towards a complete solution to EU Directive 2002/49/EC

The role of a noise map is to assist with the management and control of environmental noise, in the most appropriate manner, through applying the expertise of environmental acousticians along with important contributions from the general public. Noise maps should not be seen as just one step in the process of satisfying another directive. Noise maps could form an integral part in a detailed noise study, meeting the requirements of the END and beyond. A complete solution to the END could be achieved by incorporating noise maps with the following:

- *Utilising the internet*

The internet should be used to its full potential in displaying noise studies. A versatile noise map capable of displaying not only long term levels but the situation with regards to noise given various different acoustic scenarios would be beneficial. This would be particularly helpful in terms of educating the general public on the variation of noise levels. In addition, if the versatile map was capable of showing the impact of various action plans, it would serve to help the public decide on which action plan to implement.

- *Networked Monitoring Instrumentation*

  With the development of networked monitoring instrumentation it would be possible to have a live feed from the monitoring station to a website displaying current noise levels. It would then be straightforward to provide a history of the noise variation for the previous day, month, or year at the click of a button. This would provide the public with a detailed history of levels of noise they have been exposed to and would provide the environmental acoustician valuable information on how noise levels vary with time. Additionally, the time-history plot of noise levels would provide a useful tool in determining the effectiveness of action plans following their implementation.

- *Raising public awareness*

  It will be important to raise public awareness on the issue of noise mapping as it is expected that the results of studies will eventually impact on their daily life. It may happen that noise maps will have an impact on house prices, a tax might be imposed on loud vehicles or a traffic ban might be imposed on some streets at certain times of the day.

  In Madrid, Spain there is a publicly visible fleet of Smart Cars that drive the streets with a microphone raised at 4m above them. These cars serve as a mobile measurement unit and as an advertisement campaign. The drivers wait by the car as measurements take place and endeavor to answer any questions the passing public might have. Something similar could be adopted in Ireland.

  In addition to this it would also be beneficial to hold public consultation sessions in every affected area in Ireland. This would serve to inform and educate the public and also serve as the platform from which public consultation may begin.

- *Enhanced visualization techniques*

An interesting aspect of the E.T.I. project involved integrating the results of noise maps with the Google Earth platform. This enabled results to be presented in a realistic three-dimensional environment, which users are able to navigate at ease. Additionally to this it ensures that the results from noise studies are freely accessible to a large portion of the public who have access to the internet.

This level of interaction may also be taken a step further by integrating with the new Metropolis project initiated in Trinity College at the start of 2007. This project involves accurately recreating Dublin's streets and buildings with animated people and traffic. Results from noise maps could be linked with this project to produce real time noise from the speakers providing the user with a realistic experience in both sound and vision.

- *Further Advances*

The benefits of a nationwide noise monitoring network would be limitless. Such a network could then be integrated with various other environmental factors such as:-

  - Air Quality

    A combined study would see the noise study reaching a wider audience while the air quality study would benefit for the enhanced visualisation techniques associated with the noise study.

  - Traffic Congestion

    A live feed of noise levels, openly available online, would help in the identification of highly congested areas and areas that should be avoided. In addition it is possible to configure microphones to act as traffic counters by analysing tyre noise [54], which could be connected to the noise monitoring terminal, providing actual traffic counts for use in noise studies and for the public to examine on a day to day basis.

It is apparent that the implementation of the END poses a noteworthy challenge to the responsible authorities in Ireland. Compared to other Member States in Europe, Ireland is in a somewhat enviable position when it comes to realising the key deliverables of the directive. Dublin in the only agglomeration in the state that is required to be mapped, which is modest compared to some of the other Member States who have a multitude of cities to examine (Spain 19, Italy 13). This means that Ireland, because of the relatively low requirements at present, is well placed to introduce innovation in noise mapping strategy.

Chapter 8

Conclusion

In order to ensure the effective development of noise mapping studies and subsequent action plans the framework described in this thesis should be applied. Software used for calculations should be structured with a clear distinction made between the source model and the propagation model. This approach has been successfully adopted and has been developed to form a practical framework for future strategic noise mapping studies.

- The propagation model described to date is a simplified version of the recommended calculation method. It has been shown to be comparable with results obtained from benchmark software and the structure of the model allows for further improvements to be easily introduced.

- The input data required to create a noise map is not always available and as such, several assumptions must be introduced which will have an impact on results. It would therefore seem appropriate to strive for a balance between the complexity of the problem and accuracy in final results.

- The source model is the most influential aspect of the overall noise study. Due to the structure of the model changes made to the source can be evaluated almost instantaneously. This makes the simple evaluation of several source dependent action plans possible.

- The model is also capable of fine tuning results based on the integration of measurements. A simple reverse engineering approach is adopted to refine the source model and means the propagation model does not need to be recalculated.

- It is clear that measurements should be made to supplement the predicted noise map. These measurements will account for an inaccurate representation of the source, as the accuracy of the model will always be directly limited by the accuracy of the input data.

- It should be noted that a noise map will generally present noise levels resulting from only one type of source, in this case, road traffic. This is an important consideration when comparing noise maps with measurements.

- As the software is independently developed and completely accessible, it may be easily adapted to the final user's needs. It is completely free from licensing restrictions and reduces the dangers of the "black box" approach that may be associated with commercial packages.

- One goal of Directive 2002/49/EC was to establish a uniform approach to the assessment and management of environmental noise. However to truly achieve complete standardisation in studies it would be required for all competent authorities to not only apply the same calculation procedures but also use the same software format. The framework for the software developed in this project may accommodate this distribution. At a European level this could be achieved with the establishment of a repository making simple software available to competent authorities who may wish to avail of it.

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Appendix A

NMPB Routes 96

Table 30 – Parameters to calculate Guide du Bruit road traffic noise emission data for light vehicles

Light vehicles									
	Slope	v	E_0	a		Slope	v	E_0	a
Continuous fluid	Flat or Down	v < 44	29.4	0	Non-differentiated pulsed	Flat or Down	v < 40	34.0	- 9.3
		v / 44	22.0	21.6			40 ≤ v < 53	31.2	0
							v / 53	22.0	21.6
	Up	v < 43	37.0	- 10.0		Up	v < 43	37.0	- 10.0
		43 ≤ v < 80	32.1	4.8			43 ≤ v < 80	32.1	4.8
		v / 80	22.0	21.6			v / 80	22.0	21.6
Pulsed Accelerated	Flat	v < 50	37.0	- 10.0	Pulsed Decelerated	Flat	v < 60	29.4	0
		50 ≤ v < 64	33.0	0			60 ≤ v < 100	13.0	34.3
		v / 64	22.0	21.6			v / 100	22.0	21.6
	Up	v < 32	37.0	- 10.0		Up	v < 40	34.0	- 9.3
		v / 32	34.0	5.2			40 ≤ v < 53	31.2	0
	Down	v < 40	34.0	- 9.3			v / 53	22.0	21.6
		40 ≤ v < 53	31.2	0		Down	v < 60	27.4	0
		v / 53	22.0	21.6			v / 60	11.3	33.8

Table 31 - Parameters to calculate Guide du Bruit road traffic noise emission data for heavy vehicles

Heavy vehicles									
	Slope	v	E_0	a		Slope	v	E_0	a
Continuous fluid	Flat or Down	v < 51	47.0	-10.3	Non-differentiated pulsed	Flat or Down	v < 51	47.0	-10.3
		51 ≤ v < 70	42.8	0			51 ≤ v < 70	42.8	0
		v / 70	32.3	19.4			v / 70	32.3	19.4
	Up	v < 63	48.0	-10.4		Up	v < 63	48.0	-10.4
		63 ≤ v < 70	42.8	0			63 ≤ v < 70	42.8	0
		v / 70	32.3	19.4			v / 70	32.3	19.4
Pulsed Accelerated	Flat or Down	v < 51	47.0	-10.3	Pulsed Decelerated	Flat	v < 65	36.0	3.9
		51 ≤ v < 70	42.8	0			v / 65	16.7	41.7
		v / 70	32.3	19.4		Up	v < 65	41.0	0
	Up	v < 63	48.0	-10.4			v / 65	27.9	25.7
		63 ≤ v < 70	42.8	0		Down	v < 51	47.0	-10.3
		v / 70	32.3	19.4			51 ≤ v < 70	42.8	0
							v / 70	32.3	19.4

FIGURE A.1: Table of Values developed by Wolfel

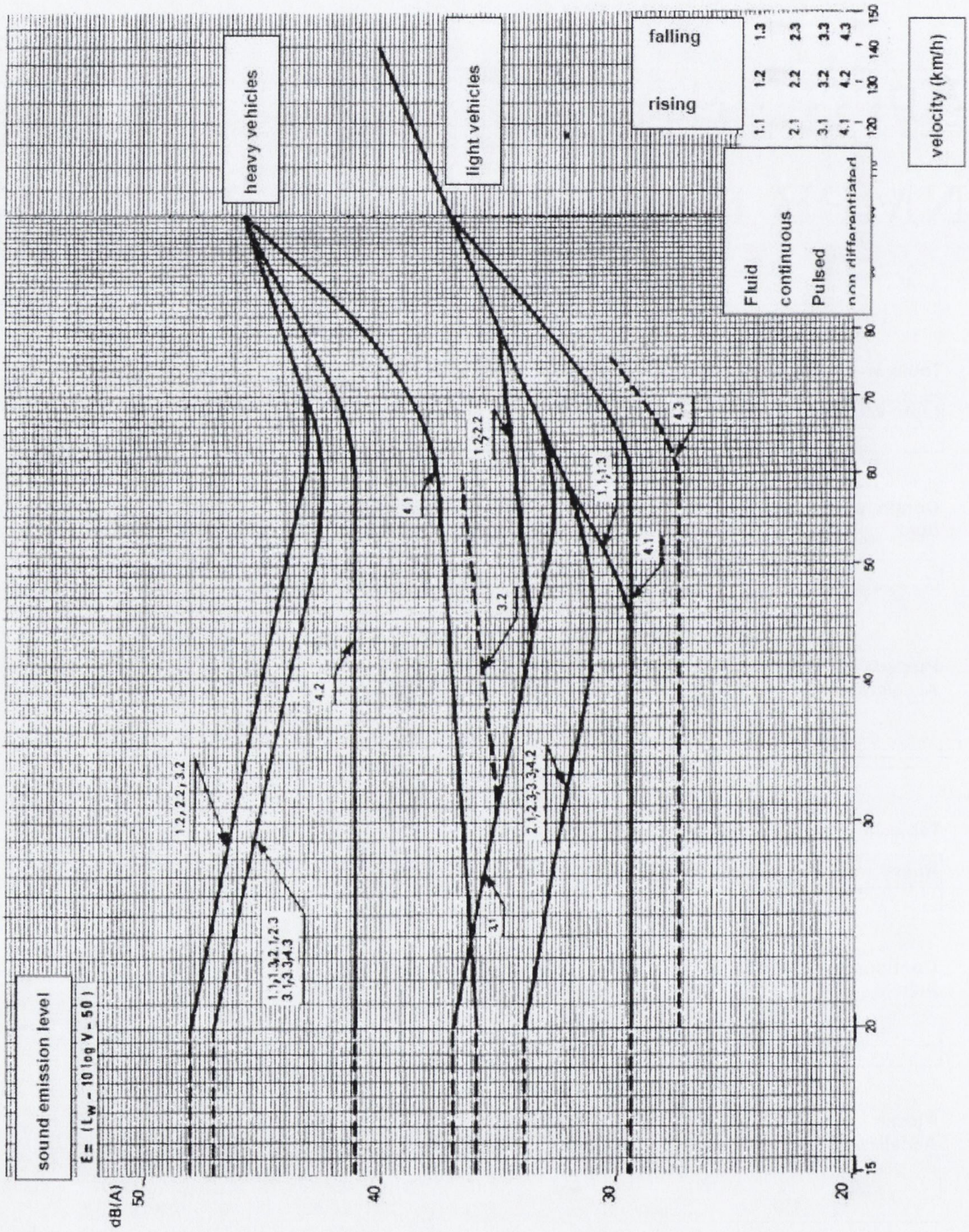

FIGURE A.2: Nomogram 1 from NMPB Routes 96

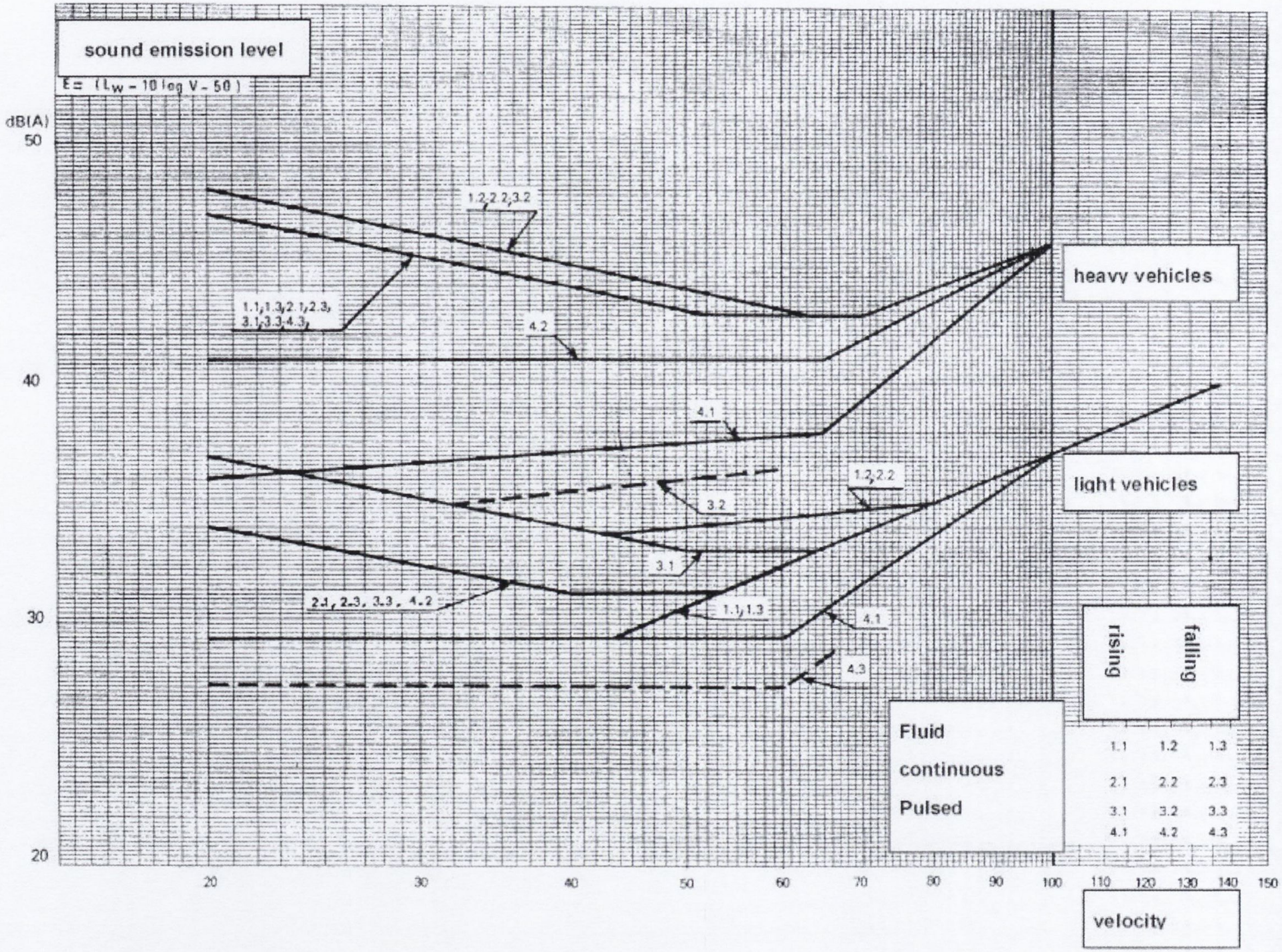

Figure A.3: Nomogram 2 from NMPB Routes 96

Appendix B

Equations for the Harmonoise Source Model

0.01m - Vehicle Category (m) = 1, 2, 3 : Tyre/Road Noise Dominates

$$L_{WRN1,m,i} = \alpha_{RN,m,i} + \beta_{RN,m,i} log_{10}(\frac{v_m}{v_{ref,m}}) + 10 log_{10}(0.8) + C_{dir,1,i} + C_{surf,m,i} + C_{region,m,i} \tag{B.1}$$

$$L_{WTN1,m,i} = \alpha_{T,m,i} + \beta_{T,m,i}(\frac{v_m - v_{ref,m}}{v_{ref,m}}) + 10 log_{10}(0.2) + C_{dir,1,i} + C_{dc,m} \tag{B.2}$$

0.3m Vehicle Category (m) = 1 : Propulsion Noise Dominates

$$L_{WRN2,m,i} = \alpha_{RN,m,i} + \beta_{RN,m,i} log_{10}(\frac{v_m}{v_{ref,m}}) + 10 log_{10}(0.2) + C_{dir,2,i} + C_{surf,m,i} + C_{region,m,i} \tag{B.3}$$

$$L_{WTN2,m,i} = \alpha_{T,m,i} + \beta_{T,m,i}(\frac{v_m - v_{ref,m}}{v_{ref,m}}) + 10 log_{10}(0.8) + C_{dir,2,i} + C_{dc,m} \tag{B.4}$$

0.75m Vehicle Category (m) = 2, 3 : Propulsion Noise Dominates

$$L_{WRN3,m,i} = \alpha_{RN,m,i} + \beta_{RN,m,i} log_{10}(\frac{v_m}{v_{ref,m}}) + 10 log_{10}(0.2) + C_{dir,3,i} + C_{surf,m,i} + C_{region,m,i} \quad \text{(B.5)}$$

$$L_{WTN3,m,i} = \alpha_{T,m,i} + \beta_{T,m,i}(\frac{v_m - v_{ref,m}}{v_{ref,m}}) + 10 log_{10}(0.8) + C_{dir,3,i} + C_{dc,m} \quad \text{(B.6)}$$

where α_{RN}, β_{RN}, α_T and β_T represent the rolling and traction noise coefficients respectively. These coefficients are presented below and are dependent on the vehicle category and the frequency of the sound. These coefficients apply to cruising vehicles on a dry reference road surface and a reference road surface temperature. When deviation from these conditions occur, corrections should be applied.

The reference road surfaces for the Harmonoise model are:

- Stone Mastic Asphalt (SMA): SMA 11-13, SMA14-16

- Dense Asphalt Concrete (DAC): DAC 11-13, DAC 14-16

For alternative road surfaces the correction C_{surf} should be applied.

$$C_{surf,m,i} = \alpha_{surf,m,i} + \beta_{surf,m,i} log_{10}(\frac{v_m}{v_{ref,m}} + K(T_{atm} T_{atm,0}) \quad \text{(B.7)}$$

where α and β are road surface coefficients expressed in dB, K is the temperature coefficient, dB/^{o}C, T_{atm} is the air temperature and $T_{atm,0}$ is the reference air temperature, 20^{o}C

Alternative driving conditions must also be examined. No corrections are required for crossings without traffic lights and calculations should be carried out as if the traffic flow is uninterrupted. For acceleration and deceleration, the following correction should be applied:

$$C_{dc,m} = C_m a_m \qquad for - 2 \leq a \leq 2m/s^2 \quad \text{(B.8)}$$

where a is the acceleration/deceleration and C is the acceleration/deceleration as outlined in the table below.

TABLE B.1: Values for C depending on vehicle type

$VehicleType$	C
m = 1	4.4
m = 2	5.6
m = 3	5.6

	Category 1		Category 2		Category 3	
freq [Hz]	α_{RN}	β_{RN}	α_{RN}	β_{RN}	α_{RN}	β_{RN}
25	69.9	33.0	76.5	33.0	80.5	33.0
31.5	69.9	33.0	76.5	33.0	80.5	33.0
40	69.9	33.0	76.5	33.0	80.5	33.0
50	74.9	15.2	78.5	30.0	82.5	30.0
63	74.9	15.2	79.5	30.0	83.5	30.0
80	74.9	15.2	79.5	30.0	83.5	30.0
100	77.3	41.0	82.5	41.0	86.5	41.0
125	77.5	41.2	84.3	41.2	88.3	41.2
160	78.1	42.3	84.7	42.3	88.7	42.3
200	78.3	41.8	84.3	41.8	88.3	41.8
250	78.9	38.6	87.4	38.6	91.4	38.6
315	77.8	35.5	88.2	35.5	92.2	35.5
400	78.5	31.7	92.0	31.7	96.0	31.7
500	81.9	21.5	94.1	21.5	98.1	21.5
630	84.1	21.2	93.8	21.2	97.8	21.2
800	86.5	23.5	94.4	23.5	98.4	23.5
1000	88.6	29.1	93.2	29.1	97.2	29.1
1250	88.2	33.5	90.6	33.5	94.6	33.5
1600	87.6	34.1	91.9	34.1	95.9	34.1
2000	85.8	35.1	86.5	35.1	90.5	35.1
2500	82.8	36.4	83.1	36.4	87.1	36.4
3150	80.2	37.4	81.1	37.4	85.1	37.4
4000	77.6	38.9	79.2	38.9	83.2	38.9
5000	75.0	39.7	77.3	39.7	81.3	39.7
6300	72.8	39.7	77.3	39.7	81.3	39.7
8000	70.4	39.7	77.3	39.7	81.3	39.7
10000	67.9	39.7	77.3	39.7	81.3	39.7

FIGURE B.1: Rolling Noise coefficients for the Harmonoise Model

	Category 1		Category 2		Category 3	
freq [Hz]	α_T	β_T	α_T	β_T	α_T	β_T
25	90.0	0.0	94.0	0.0	97.7	0.0
31.5	92.0	0.0	94.7	0.0	97.3	0.0
40	89.0	0.0	95.5	0.0	98.2	0.0
50	91.0	0.0	95.5	0.0	103.3	0.0
63	92.4	0.0	98.5	0.0	109.5	0.0
80	94.8	0.0	98.4	0.0	104.3	0.0
100	90.8	0.0	94.0	0.0	99.8	0.0
125	86.8	0.0	93.5	0.0	100.2	0.0
160	86.2	0.0	92.2	0.0	98.9	0.0
200	84.5	0.0	92.6	0.0	99.5	0.0
250	84.5	9.4	93.7	11.7	100.7	11.7
315	84.8	9.4	94.0	11.7	101.2	11.7
400	83.5	9.4	94.3	11.7	100.6	11.7
500	81.8	9.4	91.2	11.7	100.2	11.7
630	81.4	9.4	89.4	11.7	97.4	11.7
800	79.0	9.4	89.1	11.7	97.1	11.7
1000	79.2	9.4	90.8	11.7	97.8	11.7
1250	81.4	9.4	91.3	11.7	97.3	11.7
1600	85.5	9.4	92.2	11.7	95.8	11.7
2000	85.8	9.4	91.9	11.7	94.9	11.7
2500	85.2	9.4	90.3	11.7	92.7	11.7
3150	82.9	9.4	88.2	11.7	90.6	11.7
4000	81.0	9.4	86.3	11.7	89.9	11.7
5000	78.2	9.4	84.3	11.7	87.9	11.7
6300	77.2	9.4	82.3	11.7	85.9	11.7
8000	75.2	9.4	81.3	11.7	83.8	11.7
10000	74.2	9.4	80.3	11.7	82.2	11.7

FIGURE B.2: Traction Noise coefficients for the Harmonoise Model

Appendix C

Determining Average Traffic Speed

An accurate representation of the source is paramount when creating accurate environmental noise maps. The speed at which traffic is travelling at plays an integral part in calculating source noise levels. As such, the average speed should be determined as accurately as possible. The table below shows that different techniques for determining the average speed may yield significantly different values. As such a more accurate representation of the source should be developed for future mapping studies.

TABLE C.1: Average Traffic Speed

Method	*% Average Speed [km/hr]*
Signposted Speed Limit	50
Free Flow Speed	36
Average Radar Speed	32
Average Driving Speed	14

FIGURE C.1: Determining Traffic Speed by Radar

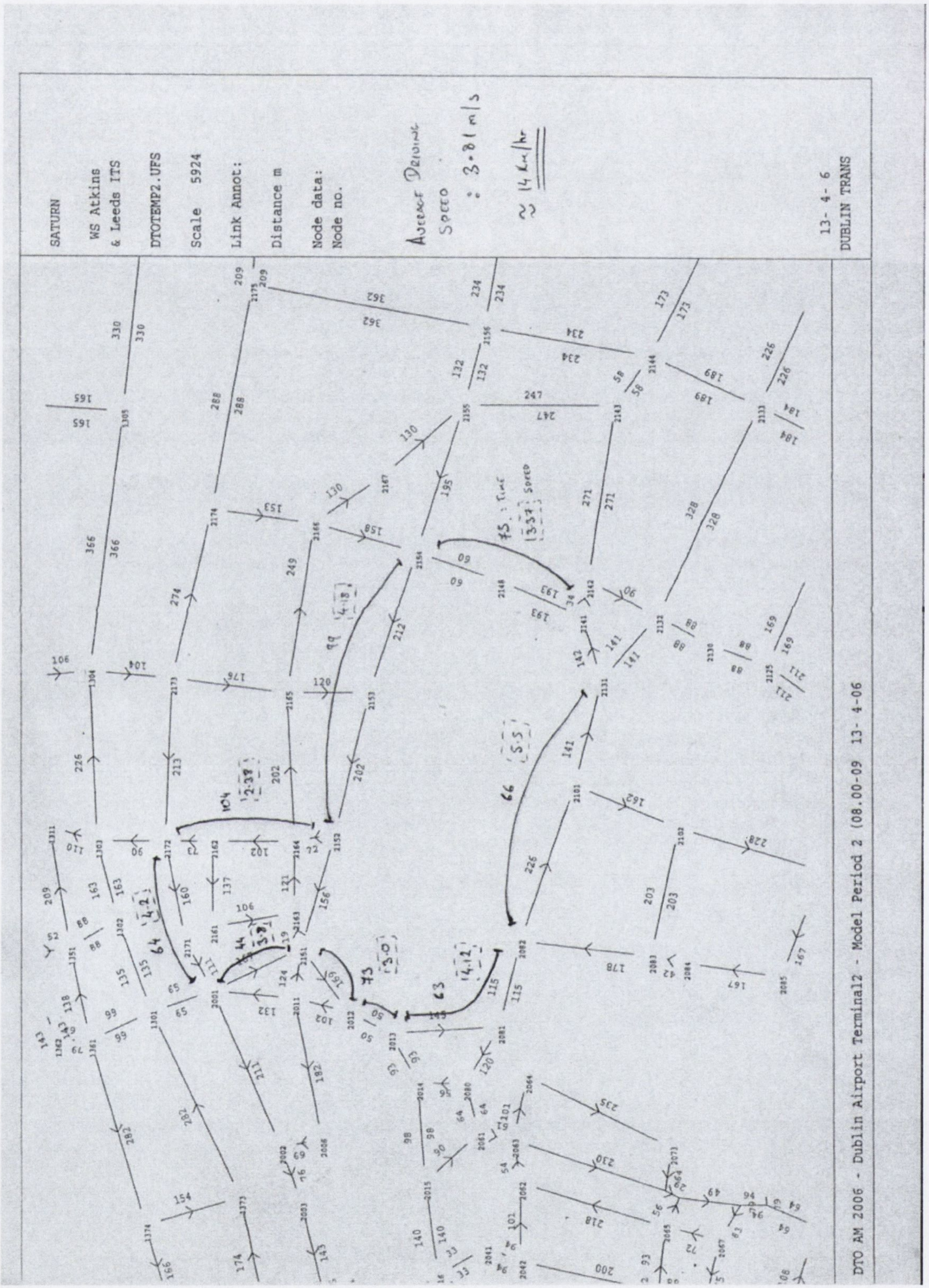

FIGURE C.2: Determining the Average Driving Speed

Appendix D

Draft Guidelines for the Measurement of Environmental Noise

When measuring noise it is important to realise that noise is a constantly varying quantity, which fluctuates very much throughout the day. As such an average noise level might not correspond to a short-term measurement taken on-site over one particular time period. It is also important to realise that the L_{den} indicator is a weighted year-long indicator and accounts for the average noise levels over a complete calendar year.

However, some conclusions may be drawn from short-term measurements but in order to ensure the overall quality of measurements it is important to adhere to the following guidelines.

Measurement Height

Noise maps are displayed at a height of 4m. If possible you should try to measure at 4m. If this is not possible a standard height of 1.5m should be adopted. However it should be noted that measurements taken at this height will be closer to the road so louder noise levels would be expected. To combat this, do not measure the noise at the roadside edge. The extent of louder levels at 1.5m will diminish the further you are from the road.

Measurement Locations

A number of factors will influence the level of noise. Try to measure at least 2m away from walls and building to minimise the effect of reflections. Do not measure in enclosed spaces like tunnels or underneath bridges.

The confidence level map that accompanies the noise map is a good indicator of areas in which it would be ideal to measure. Avoid areas of low confidence as it is assumed that these values may be erroneous.

Non-Environmental Noise Sources

Be aware that your measurements will be influenced by all kinds of noise, both environmental and non-environmental noise. Neighbourhood activities such as mowing of lawns, barbeques, sporting activities, etc. will influence noise measurements. Sometimes nighttime levels may be influenced by nearby nightclubs. Additionally if the noise map presents noise levels resulting from road traffic noise it will not include noise from industrial sites, rail traffic or airports. If you are concerned over exposure to a number of types of environmental noise, request a noise map presenting the combined scenario.

Measurement Time

The day period is the most stable period in which to measure noise. Studies have found that a 15-minute measurement period generally gives a good indication for the overall L_{day} level. However try to avoid measuring during the morning and evening peak. Try also to measure at a number of times throughout the day in order to get a broader picture of the noise levels. Ideally you should take several 15-minute sample measurements between the hours of 10:00 and 17:00 in order to determine an acceptable measured L_{day} value.