Strategic environmental noise mapping: methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications

Abstract. This paper explores methodological issues and policy implications concerning the implementation of the EU Environmental Noise Directive (END) across member states. Methodologically, the paper focuses on two key thematic issues relevant to the Directive: (1) calculation methods and (2) mapping methods. For (1), the paper focuses, in particular, on how differing calculation methods influence noise prediction results as well as the value of the EU noise indicator L_{den} and its associated implications for comparability of noise data across EU states. With regard to (2), emphasis is placed on identifying the issues affecting strategic noise mapping, estimating population exposure, noise action planning and dissemination of noise mapping results to the general public. The implication of these issues for future environmental noise policy is also examined.

1. Introduction

In 1994 it was estimated that during day-time, approximately 22% of the total population of the EU were exposed to noise levels from road traffic exceeding a daily equivalent sound pressure level of 55 decibels (dB(A)) (Lambert and Vallet, 1994). Moreover, 49% of the population (77 million) were considered to live in ‘grey areas’ of acoustical discomfort to residents. During night-time, more than 30% were considered to be exposed to equivalent sound pressure levels exceeding 55 dB(A) which is considered to be disturbing to sleep (Berblund et al, 1999). Clearly then, the scale of environmental noise is large. Given the recent enlargement of the European Union (EU) to take in member states in Eastern Europe, it is reasonable to expect that the foregoing figures considerably underestimate the extent of the problem within the existing Union.

The relationship between environmental noise and public health is perhaps the most significant reason why environmental noise has emerged as a major issue in environmental legislation and policy in recent years (European Commission, 1996; Berblund et al, 1999; World Health Organisation and European Centre for Environment and Health, 2002). Moreover, much research has emerged over the last two decades linking environmental noise with detrimental health impacts. Most important of these are annoyance (Michaud et al, 2005) and sleep disturbance (Carter, 1996; Ohrstrom and Skanberg, 2004). However, other dose-effect relationships include negative emotions such anger, disappointment, unhappiness, anxiety and even depression as well as mental health impacts (Fidell et al., 1991; Fields, 1998; Miedema, 2003; Michaud et al., 2005; La Torre et al, 2007). A further area of concern is the link between noise exposure and cardio-vascular disease (Babisch et al. (2003, 2005) while noise has a particularly negative impact on children’s health (Evans and Lepore, 1993; Evans et al, 2001; Evans and Maxwell, 1997). Indeed, it is within this context that the EU Environmental Noise Directive emerged.

Bearing this in mind, this paper explores methodological issues and associated policy implications concerning the implementation of the EU Environmental Noise Directive (END) across member states. Methodologically, the paper focuses on two key thematic issues relevant to the Directive: (1) calculation methods and (2) mapping methods. For (1), the paper focuses, in particular, on how differing calculation methods influence noise prediction results as well as the value of the EU noise indicator L_{den} and its associated implications for comparability of noise data across EU states. With regard to (2), emphasis is placed on identifying the issues affecting strategic noise mapping, estimating population exposure, noise action planning and dissemination of noise mapping results to the general public. The implication of these issues for future environmental noise policy is also examined.

2. The EU Environmental Noise Directive

In 2002 the European Union (EU) passed Directive 2002/49/EC, also known as the Environmental Noise Directive (END) (EU, 2002). The Directive dealt with four key areas relating to the assessment and management of environmental noise in member states: (1) strategic noise mapping; (2) estimating population exposure; (3) noise action planning and (4) dissemination of results to the general public. The aims and scope of each area will be dealt with briefly.

2.1 Strategic noise mapping

Broadly defined, noise mapping is simply a means of presenting calculated and/or measured noise levels in a representative manner over a particular geographic area. However, the END defines noise mapping in more specific terms as 'the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator' (EU, 2002, 14). For the END, noise maps are multi-dimensional in the sense that they incorporate not only measured/calculated noise levels for a particular area, but also information concerning breaches of statutory limits as well as levels of population or dwelling exposure to environmental noise.

Within the Directive, 'Strategic noise mapping' is defined in somewhat different terms to 'noise mapping'. A strategic noise map is defined as 'a map designed for the global assessment of noise exposure in a given area due to different noise sources for overall predictions for such an area' (EU, 2002, 14). Thus, while 'noise mapping' is focussed primarily on the presentation of noise data, 'strategic noise mapping' is more concerned with the assessment of noise exposure under the terms of the Directive. Indeed, the mapping requirements of the Directive are concerned primarily with 'strategic noise mapping'. Therefore, they are focussed on the assessment of noise exposure rather than on the presentation of data itself.

In this regard, assessment of exposure to environmental noise is to be achieved using 'strategic noise maps' for major roads, railways, airports and agglomerations using the harmonised noise indicators L_{den} (day-evening-night equivalent sound pressure levels) and L_{night} (night-time equivalent sound pressure levels).[1] In the first phase (June 2007), strategic noise maps were compiled for all agglomerations with more than 250,000 inhabitants and for all major roads (with more than 6 million vehicle passages a year), railways (with more than 60000 train passages a year) and major airports (with more than 50000 movements a year) within the territories. The Second Phase (June 2012) requires that strategic noise maps are produced for

[1] Issues surrounding these indicators will be dealt with in more detail in a later section as well as further explanatory information.

agglomerations with a population in excess of 100,000 individuals. Thereafter, strategic noise maps are to be produced at five year intervals.

2.2 Estimating population exposure

The second key element of the END is the determination of levels of exposure to environmental noise through the aforementioned common indicators L_{den} and L_{night}. The Directive requires competent authorities in each member state to provide estimates of the number of people living in dwellings that are exposed to values of L_{den} and L_{night} in various categories[2] at the most exposed building façade and separately for road, rail, air traffic and for industrial noise (EU, 2002, 24). In addition, where it is deemed appropriate and where the information is available, people living in dwellings that have special insulation against environmental noise or have a quiet façade[3] should also be reported. This implies that strategic noise maps must be accompanied by relevant assessment data detailing the level of exposure for each area under consideration. However, the END does stipulate that strategic noise maps can take the form of graphical plots or numerical data in table or electronic form (EU, 2002, 22).

2.3 Noise action planning

The Directive requires that noise action plans are drawn up by competent authorities for the major roads, railways and agglomerations specified already. According to the END, action plans refer to 'plans designed to manage noise issues and effects, including noise reduction if necessary' (EU, 2002, 14). The Directive also requires that action plans are reviewed, if deemed necessary by the competent authority, when a major development occurs that may affect the existing noise situation. In addition, action plans are to be reviewed every five years after the initial date of approval. This suggests that noise action planning as perceived within the Directive is process-oriented in the sense that it is continuous and evolving and regularly takes account of major changes that are likely to affect the soundscape of the area under consideration.

The Directive also introduces the notion of 'acoustical planning' which has direct relevance to the development of action plans for noise. 'Acoustical planning' refers to 'controlling future noise by planned measures, such as land-use planning, systems engineering for traffic, traffic planning, abatement by sound-insulation measures and noise control of sources' (EU, 2002, 14). By virtue of including the word 'planning', the END points directly towards the role that can be played by national planning systems as a means of mitigating environmental noise in the future.

A further element of this strand of the Directive relates to public consultation. Competent authorities are required to 'ensure that the public is consulted about proposals for action plans' and that they are 'given early and effective opportunities to participate in the preparation and review of the action plans' (EU, 2002, 16). Authorities are also required to ensure that 'the results of participation are taken into

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[2] The categories stated in the Directive are 55-59, 60-64, 65-69, 70-74 and > 75 for L_{den} and 50-54, 55-59, 60-64, 65-69 and > 70 for L_{night}.

[3] A quiet façade refers to the façade of a dwelling at which the value of L_{den} is more than 20 dB(A) lower than at the façade having the highest value of L_{den} (EU, 2002, 24).

account and that the public is informed on the decisions taken' (EU, 2002, 16). Clearly then, public participation represents a fundamental basic principle of noise action planning under the terms of the Directive. The Directive also establishes clearly a set of minimum requirements for noise action planning as well as pointing to a series of measures that may be used for the mitigation of environmental noise. They are summarised in Table 1.

Table 1. Minimum required elements for actions plans and potential noise mitigation measures in the END

Minimum Required Elements for Action Plans	Potential Mitigation Measures
➢ Description of agglomeration, major roads, major railways or airports ➢ The authority responsible ➢ The legal context (national legislative compliance) ➢ Limits values (if applicable) ➢ Summary noise mapping results ➢ Evaluation of human exposure; identification of problems potential improvements ➢ Record of public consultation ➢ Noise reduction measures in force or in preparation ➢ Actions to be taken in next five years ➢ Estimates of the reduction of the people affected ➢ A long-term strategy ➢ Financial information (cost-effectiveness assessments etc) ➢ Provision for evaluation of action plan implementation and results	➢ Traffic planning ➢ Land-use Planning ➢ Technical measures at noise sources ➢ Selection of quieter sources ➢ Reduction of sound transmission ➢ Regulatory or economic measure or incentives

Source: Annex V of the END (EU, 2002, 23)

2.4 Dissemination of results to the general public

The final major element of the Directive centres on the dissemination of information derived from the strategic noise mapping process to the general public. Indeed one of the Directives central objectives is to ensure that 'information on environmental noise and its effects is made available to the public' (EU, 2002, 13). The Directive requires that strategic noise maps and action plans are not only made available to the public but also disseminated in accordance with Directive 90/13/EEC on the freedom of access of information to the environment. The availability of the information must also conform to the minimum requirements for strategic noise mapping and action plans laid down in Annexes IV and V of the END (EU, 2002, 22-23). Information presented to the general public is required to be 'clear, comprehensible and accessible' (EU, 2002, 16).

To summarise, the foregoing discussion has outlined the major thematic areas of interest within the END providing a generic overview of the key areas of influence of the Directive. The following sections look at the Directive from a more critical perspective. From the viewpoint of the practical implementation of the Directive, particular attention is paid to the methodological issues concerning its implementation focussing, in the first instance, on noise calculation issues and thereafter, on mapping issues.

3. Methodological Issues arising from the Directive

3.1 Calculation methods

Numerous calculation methods exist for predicting noise levels at specific receiver points. Similarly, the results obtained from calculations may be expressed using a variety of noise indicators. For noise studies, both issues are problematic because these difficulties make comparison between studies extremely difficult. One objective of the END was to establish a uniform approach to the assessment and management of environmental noise. In this regard, the END has addressed the later issue relating to noise indicators through the introduction of the L_{den} noise indicator[4]. However, in relation to the former issue, a standardised noise calculation model has yet to be fully developed. Thus, for the first phase of noise mapping (June 2007), member states were free to use alternative calculation methods in the development of strategic noise maps. Because of this allowance, results from different member states are difficult to compare directly. This is a major shortcoming of the current approach.

The END recommended several standards to be used by countries with no national standard or by those who wished to change computation methods. These standards were envisioned to be interim standards for use until a standardised European method was developed by the EU.

For road traffic noise the chosen standards were the French national computation method ‘NMPB-Routes-96 (SETRA-CERTU-LCPCCSTB)’, referred to in ‘Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, Article 6’ and in the French standard ‘XPS 31-133’. For input data concerning emission, these documents refer to the ‘Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR 1980’. For railway noise, the Netherlands national computation method published in ‘Reken- en Meetvoorschrift Railverkeerslawaai ’96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 20 November 1996’ was selected as the recommended interim method while for aircraft noise ECAC.CEAC Doc. 29 ‘Report on Standard Method of Computing Noise Contours around Civil Airports’, 1997 was selected. Of the different approaches to the modelling of flight paths, the segmentation technique referred to in section 7.5 of ECAC.CEAC Doc. 29 will be used. For industrial noise ISO 9613-2: ‘Acoustics - Abatement of sound propagation outdoors, Part 2: General method of calculation’ was to be used. Suitable noise-emission data (input data) for this method can be obtained from measurements carried out in accordance with one of the following methods:

- ISO 8297: 1994 ‘Acoustics - Determination of sound power levels of multi-source industrial plants for evaluation of sound pressure levels in the environment — Engineering method’,

[4] An explanation of each of the noise indicators contained within this document appears in Appendix 1.

- EN ISO 3744: 1995 'Acoustics — Determination of sound power levels of noise using sound pressure - Engineering method in an essentially free field over a reflecting plane',
- EN ISO 3746: 1995 'Acoustics — Determination of sound power levels of noise sources using an enveloping measurement surface over a reflecting plane'.

Table 2 outlines the calculation methods used by seventeen member states as reported to the EU for the first phase of noise mapping. It is evident that many member states used calculation procedures other than the recommended interim methods. It is notable that seven different methods were utilised for the calculation of road traffic noise, eight for railway and aircraft noise and finally five for industrial noise. This highlights the variety of standards in use across the EU today and emphasises the need for a standardised prediction methodology.

Table 2: Calculation methods used by each member state for the first stage of strategic noise mapping (2007)

3.1.1 Variation in results of several road traffic noise prediction standards

Calculation methods for road traffic noise consist generally of two parts: a method to calculate the level of noise at the source and a method to describe how noise will propagate away from the source. An analysis of a number of commonly used calculation methods shows that while all methods generally share the underlying mechanisms associated with noise generation and the related propagation, the details and formulae presented in each method do differ considerably from one standard to the next. Numerous differences are evident:

- Roads are treated as a collection of incoherent point sources in a number of noise prediction standards including NMPB/XPS31-133 and the Nord 2000 method. By way of contrast, the CRTN method treats roads as a line source.
- The representation of the noise source varies from standard to standard (Harmonosie, 2003). For example the German RLS method describes the source using an emission index in terms of L_{Aeq} at a distance of 25m from the road lane while the Nordic model uses the sound exposure level at a distance of 10m during pass-by of light and heavy vehicles in conjunction with maximum noise levels. The CRTN method defines a basic noise level 10m away from the nearside carriageway in terms of the L_{A10} index.
- The CRTN method does not calculate attenuation in terms of frequency bands; rather, it offers an overall A-weighted result while the French method outlines an octave band analysis approach.
- The Swiss StL-86 method considers traffic flow in both directions as one roadway which impacts on the calculation of the gradient of the road (Steele, 2001). Most other methods do not consider two way traffic on individual road links.
- The German RLS 90 method includes a method for calculating noise for parking lots (Steele, 2001) which is uncommon for most calculation methods.
- Prediction methods across Europe use different source heights for point sources, ranging from 0.3m to 0.75m. The proposed Harmonoise method will use two sources at different heights to represent rolling noise and propulsion noise separately (Harmonoise, 2003).

Clearly then, the foregoing methodological differences result in different noise levels being predicted when applying different standards to an identical road. It has been observed that all methods currently being used for noise prediction are empirical or semi-empirical methods which contain many simplifying assumptions and use a simplified representation for the source. Accordingly, differences of five decibels for the outcomes of different calculation methods are by no means exceptional (Wolde, 2002). Furthermore, Wolde (2002, 16) states that “it is obvious that the differences in computation methods seriously undermine the possibilities for comparison of results”.

Nijland and Van Wee (2005) summarise previous studies that investigate the variance between different calculation methods. They report that Van den Berg and Gerretsen found differences of 6-10 dB(A) when calculating different road traffic situations using the Austrian, German, French and Dutch methods (Van den Berg and Gerretsen,1996). A separate study observed varying results when different computational methods were applied to a simple road setup including the effect of a simple noise barrier (Van Leeuwen and Ouwerkerk, 1997). Table 3 shows the results of this study at 30m and 50m from the noise source at a receiver height of 2m.

Table 3. Noise results with different noise calculation methods applied

	Distance 30 m	Distance 50m including screening	Noise reduction (mainly by screen)
Austria	76	65	11
France	75	64	11
Germany	77	68	9
Great Britain	78	66	12
the Netherlands	74	61	13

Source: Van Leeuwen and Ouwerkerk (1997) as reported in Nijland abd Van Wee (2005).
Note: Van Leeuwen and Ouwerkerk used the Dutch method, RMV2, from 1981. This method was revised in 2002 (Ministerie van VROM, 2002). However, this is unlikely to influence the result of Van Leeuwen and Ouwerkerk’s research.

Another calculation issue relates to the fact that different software packages yield different results while applying the same national computational method. A study conducted in the UK observed the extent of variation between several commercial packages implementing the CRTN standard (Hepworth, 2006). Results obtained from the commercial software were compared over a $1km^2$ calculation area. The greatest mean difference was 2dB(A) and the greatest individual difference at a single calculation point was 11dB(A). These results indicate that the use of different software packages implementing the same standard, with the same input data, will have a significant affect on resulting noise maps. Other research has reported variances of up to 6dB(A) due to different interpretations of the Dutch national calculation method RMV2 (Nijland and Van Wee, 2005). Indeed, King and Rice (2009) argue that to truly achieve standardisation in noise studies competent authorities would be required not only to apply the same calculation procedures but also to employ the same calculation software.

3.1.2 The L_{den} indicator

The calculation methods described above were developed prior to the introduction of the L_{den} indicator. Because of this further discrepancies are likely to arise when converting results from current standards to the standardised indicator. For example, the UK and Ireland use the CRTN method to predict noise levels in terms of the L_{10} index and subsequently apply conversion formulae to determine L_{den} (Abbott and Nelson, 2002; O'Malley et al, 2009). The conversion methodologies were developed so that authorities would not have to change existing models or software in order to comply with the EU standard. However, a number of discrepancies were evident; the conversion methodologies perform poorly for conversion of night-time noise levels to the EU standard. This is due to the fact that no simple relationship exists between observations of $L_{A10,1h}$ and $L_{Aeq,1h}$ observed through the night-time period.

Additionally, L_{den} is an annual noise indicator which describes the average day-evening-night-time equivalent sound pressure level over a complete year. Over the course of a year varying meteorological conditions are likely to have a significant impact on noise levels and as such, the manner in which meteorological conditions are incorporated into the calculation model will influence final results. The French method accounts for meteorological conditions using the percentage of time conditions favourable to propagation occur whereas the CRTN method does not include a correction for meteorological conditions. This implies that standardised noise indicators are only one part of the methodological jigsaw; if varying results are emerging from calculation methods then these will be inherent in the results using standardised indicators.

It is notable also that member states are free to deviate from the default time periods set out in the Directive provided that the overall time period adds to 24 hours. Thus, the chosen definitions should be taken into account when comparing the results from different member states because this may also affect the comparability of results.

3.1.2.1 The limitations of the L_{den} indicator

Steele (2001) performed a critical review of six commonly used traffic noise prediction models. The study notes that the CRTN standard is distinguishable by its extensive use of curve fitting between empirical data and the fact that it treats L_{10} as if it were a Lebesgue measurable. Steele states that the descriptor is therefore a pseudo L_{10} which greatly simplifies noise calculations, albeit with a concomitant loss of validity. Indeed, he found that models providing L_{eq} results are capable of easily correcting for interrupted flow, multiple streams and multiple roads.

However, Steele's study observed that the models under review were limited and, while suitable for roadway engineers to determine the need for local screening, were unsuitable for several groups of people including acoustical engineers, expert witnesses in civil or criminal courts, acoustic specialists who prepare the acoustic section of an environmental impact statement (EIS) or acoustic consultants engaged by clients that may be adversely affected by road traffic noise. The reason for this is that the models does not meet the requirements of users of traffic noise models who may wish to make further use of noise indicators and modelling traffic light cycles, traffic routings, pedestrian crossing locations and other controls. Similarly, L_{den} describes the long-term average noise level but offers little means of describing the nature of the noise under investigation including short term variations in noise levels or the existence of possible tonal aspects in the noise environment. These aspects of noise are often a source of greater annoyance and generally result in more complaints from the public.

Accordingly the END states that in some cases it may be advantageous to use special noise indicators and related limit values (EU, 2002). 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. It would seem, therefore, that the L_{den} indicator alone is insufficient for the effective assessment and management of environmental noise.

Furthermore, the EU published a position paper on EU noise indicators in 2002 stating that 'the Working Group took into account that sleep disturbance is more often associated with individual events than with the totality of noise experience through the night (European Commission, 2000a, 45.) However the Working Groug defends the definition of the L_{night} indicator in terms of L_{eq} by stating that 'this type of event based indicator cannot take into account the number of events. Additionally there is no agreed method for defining a long-term average L_{Amax} or SEL. The main advantage of using a L_{Aeq} indicator is both the average max levels of events and the number of those events are taken into account' (European Commission, 2000a, 45)

3.1.3 Equivalence

The END also states that in cases where a member state adopts a different calculation method from the recommended interim method it must show that the method chosen yields equivalent results. However, the level of equivalence was not defined explicitly. This requirement is designed to ensure comparability of results across member states. Yet, the manner by which to determine 'equivalence' was not described in the Directive which has led to some considerable confusion among competent authorities in member states. Given the foregoing discussion it would appear that results from member states will not yet be directly comparable while a universal procedure to determine equivalence in results is currently unavailable.

3.1.4 The proposed Harmonoise/Imagine model

The most practical way to ensure noise maps and related population exposure statistics are directly comparable across member states is to introduce a universal calculation method. While member states may have used interim methods in the past, in the longer term a more robust, universal procedure is required. At the European level this led to the initiation of the Harmonoise project. The main objective of this project was to establish a common European noise prediction method. Numerous authors have noted that the second phase of noise mapping (2012) should be undertaken using harmonised prediction methods with the proposed EU Harmonoise/Imagine method the most likely choice (Watts, 2005; de Roo, Noordhoek, 2004; de Vos, 2004).

A transition from each of the current methods to the proposed Harmonoise method may not be a straightforward task. In its current form, the Harmonoise method is highly complex. Several sub categories of vehicle type exist along with different meteorological classes. The input variables required for the proposed method exceed the level of data required for many existing national calculation methods. Accordingly, it is unlikely that a complete data set will exist in any member state to satisfy completely the requirements of the Harmonoise approach. This will of course lead to several to assumptions being introduced to the model resulting in further variation in results. It is envisaged that the *Good Practice Guide for Noise Mapping* (WGAEN, 2006) will need to be revised if the Harmonoise model is made compulsory. Additionally some concern over the present form of the Harmonoise method exists. It has been observed that the current description of the Harmonoise method contains a number of unclear phrases and inconsistencies implying that it is not yet a robust document for software implementation (Hartog zan Banda and Stapelfeldt, 2007)

3.2 Mapping methods

3.2.1 Strategic noise mapping

The first issue to emerge relates to the type of noise calculation package that is used for noise mapping analysis. There are a number of commercial software packages available and each provides different facilities in relation to strategic noise mapping. However, capability of the mapping software available within the calculation packages varies significantly. In addition, none of the packages compare positively with the mapping techniques available in commercial Geographical Information Systems (GIS) packages. In particular, the ability of GIS packages to deal with numerous types of spatial data far outweighs that available within commercial noise mapping packages. Indeed, as a reflection of this, some commercial software packages offer import/export functionality in attempt to take advantage of the greater ability of GIS to manipulate spatial data in a more sophisticated and customised manner.

The second issue relates more specifically to the noise mapping methods employed within the noise mapping process. The calculation process proceeds by calculating noise levels at receiver points on regular grids ranging from five metres to 20 metres[5]. Noise maps are then completed through a process of spatial interpolation within a GIS or through the mapping facilities available within the commercial noise mapping software packages. However, numerous spatial interpolation methods exist and the Directive does not stipulate which method is to be used for noise mapping studies. Murphy et al (2006) have pointed out that different noise maps are produced when different methods of spatial interpolation are used in noise mapping analysis. Thus, if maps are to be comparable across member states, a standard method of spatial interpolation should be stipulated by the Commission. Perhaps the most appropriate method to be used is the nearest neighbour (NN) method given that receiver grids are generally uniform for the generation of strategic noise maps. At the very least, there should be a requirement on competent authorities to outline the method of spatial interpolation used for the compilation of strategic noise maps in individual EU states.

A third issue concerns the visualisation of noise mapping results. The absence of a standardised colour scheme makes it difficult to compare maps from different EU states. Very often noise maps are produced with different colour coding despite the fact that an IS0 standard exists for the presentation of acoustics graphics (ISO 1996 – 2, 1987). Although this standard has since been revised and includes no specifics on colour coding, it is nonetheless the case that a recognised standard has already been established. Moreover, the question of whether results should be presented using graduated colouring techniques or specifically delineated colour contours remains unclear. In comparative terms, this could prove to be problematic given that different methods affect the visual impact of noise mapping results when they are presented to the general public.

[5] The Good Practice Guide for Strategic Noise Mapping (WGAEN, 2006) recommends that a maximum ten metre receiver grid is used.

The results from the first phase of strategic noise mapping (completed in July 2007 demonstrate that different commercial software packages are being used for fulfilment of the terms of the Directive together with unknown spatial interpolation techniques and different colouring display methods. Taken together, all of these issues produce results which make comparison of strategic noise mapping results across EU states extremely difficult.

3.2.2 Population exposure

As it stands currently, there is no standardised method for measuring population exposure. In the Directive, emphasis is placed on providing information about the number of people living in dwellings that are exposed to various noise categories at the most exposed façade. The Good Practice Guide (WG-AEN, 2006) makes a number of recommendations regarding the assessment of population exposure based on the type of data available within each member state. However, the approaches suggested fall far short of a standardised methodological approach.

There is no stipulation in the Directive as to whether population exposure should be assessed at the individual level or at the level of individual buildings. The Directive allows for both and different methods have been used in noise mapping studies in the literature (Murphy et al 2009; Tsai, 2009). However, any comparative analysis of population exposure across EU states requires a common approach to assessing population exposure. Otherwise comparison is highly difficult.

There are additional difficulties. In particular, estimates of the population exposure are likely to be overestimated to a significant degree if assessment is based at the individual level. By counting individuals living in a particular household, the assessment method assumes, particularly during the night-time period, that all individuals living in a particular household are exposed to the noise level at the most exposed building façade. Of course, this is highly unrealistic due to the fact that bedrooms are highly unlikely to be located always at the most exposed building façade in even the majority of dwellings under analysis. Moreover, assessment for exposure to noise is based on the assumption that individuals reside in their dwelling and sleep there all year around. In many EU cities, workers and students leave the city at the weekend to return to rural areas. Thus, the assessment method fails to account for this migrant and transient population when providing estimates of population exposure.

It is notable also that the Directive does not stipulate any guideline limit values for population exposure to L_{den} and L_{night}. The EU did not set common European-wide noise limit values. It was felt that this would be impossible given the large differences in scale and comprehensiveness of implemented noise measures throughout the different member states (European Commission, 2000b). Yet, guideline limit value for environmental noise already exist in World Health Organisation (WHO) policy documents (Berblund et al, 1999) which provides a guideline framework for the establishment of dose-effect relations in relation to environmental noise exposure. Looking to the future, and assuming the more pressing methodological problems have been dealt with adequately, it would appear important that guideline limit values are set by the EU for both L_{den} and L_{night}. In the absence of such a value, it is extremely difficult to assess adequately the extent of dose-effect relationships within and between member states.

3.2.3 Noise action planning

As outlined already, noise action planning is envisioned as a method for the management of noise issues and effects. In this regard, the Directive requires that noise mitigation measures are put in place to deal with areas considered to be of poor sound quality and suggestions have been made within the Directive about measures that could perhaps be utilised by the relevant authorities (Table 1). The difficulty with noise mitigation measures is trying to connect the correct mitigation measure with the appropriate problem. For example, a noise barrier may not be an appropriate measure to be adopted within cities given the potential aesthetic consequences, but it may be appropriate for areas that are less visually sensitive. Similarly, reducing the speed limit on motorways may be less suitable than the erection of a noise barrier. Thus, the key to implementing noise mitigation measures is for decision-makers to take account of the severity of the noise situation as well as the local context for implementing such measures.

Policymakers must also be careful not to lose sight of the need to preserve quiet areas of good sound quality under the terms of the Directive. There is a danger that areas of good sound quality will be neglected or simply ignored if they are considered to be quiet areas. However, action plans should be careful to identify 'quiet areas' within the strategic noise mapping process which would allow for the ongoing monitoring of these areas and the evolution of the sound quality within them. Moreover quiet areas are poorly defined in the Directive which fails to set a guideline decibel value below which quiet areas could be defined. This is a further area for clarification in further legislative amendments.

A second major issue in relation to noise action planning is that of public consultation. The Directive requires that the public is consulted about noise action plans and any decisions that may be taken. To date, public consultation has been limited in many states. For example, in the case of Ireland, public consultation was limited to placing strategic noise maps in the internet and in local libraries while little attempt was made to inform the public of actions to be taken as a result of noise action planning. If public consultation is to become a more meaningful element of the Directive then member states must develop proper procedures for ensuring public consultation and for ensuring the provision of information to the general public. As it stands at present public consultation is seen very much as an afterthought of the strategic noise mapping process where public communication and information dissemination is occurring in a rather ad hoc and tokenistic fashion.

3.2.4 Public dissemination

The main issue surrounding the dissemination of information to the public relates primarily to the method of dissemination of strategic noise mapping information to the public. At present, the methods used are primarily the online availability of strategic noise maps and associated noise actions plans. In addition, some EU cities have interactive noise mapping availability (e.g. the London Noise Map) where end users can alter the parameters of the strategic noise map as desired.

Most strategic noise maps are available only in two dimensions and are often difficult for a relatively uninformed public to understand clearly. Some scholars have attempted to present noise mapping results as a three dimensional representation of two-dimensional information (Murphy et al, 2006; Pilla et al, 2007). Such approaches would appear to offer better visualisation of noise mapping results than the more conventional approaches currently being adopted.

More recent approaches have advocated the incorporation of strategic noise mappings results into virtual urban simulations (Murphy et al, 2007). Such an approach would enable end users to experience strategic noise mapping results in a manner akin to that of an online gaming experience (see Drettakis et al 2007; Tsingos et al 2003). In this way, the end user is able to negotiate the urban environment and experience changes in environmental noise in a more realistic fashion. These changes would also correspond to those incorporated within strategic noise mapping results. Certainly, such innovative approaches would assist in raising awareness about environmental noise in the future although they are likely to be the exception rather than the rule.

4. Policy Implications

The foregoing analysis has a number of implications for policymaking. First, strategic noise maps have a number of outstanding issues that need to be addressed. In particular, there are specific areas where more standardisation of approach is required if the results of strategic noise mapping are to be comparable. This applies to both the standardisation of calculation methodology as well as the mapping methodology being adopted. Of course, there will always be some areas where the methodological approach differs slightly due to, for example, data availability issues in different member states. However, outstanding methodological issues should be dealt with in a more harmonised fashion than they are at present between member states.

Second, estimates of population exposure resulting form strategic noise mapping studies are currently incomparable due to the significant differences in estimation methodology. Thus, in policymaking terms authorities must be careful when basing noise action plans solely on estimates of population exposure in given areas. Account must also be taken of the results emerging from strategic noise maps and these should be followed up by some form of field survey before extensive mitigation measures are approved.

Third, some clear procedural guidelines should be established at the EU level to ensure that public consultation forms a more central role in noise action planning and associated decision-making. This would see a move away from the token public consultation occurring in many states currently and would also serve to raise public awareness about noise issues in specific cities and the communities being affected by excessive environmental noise and associated action plans.

Fourth, the Directive points towards the potential of national planning systems to play a role in future mitigation of environmental noise through 'acoustical planning'. If acoustical planning is to play a key role in noise mitigation, it must become an inherent part of national planning systems in the future. Thus, major new land-use and transport developments should take specific account of potential acoustical impacts prior to planning permission being granted. In some member states such measures are already in place within environmental impact assessments (EIA). However, in others, the acoustical measures required within EIA's are wholly inadequate.

Fifth, broader policymaking in relation to the mitigation of environmental noise must occur at a number of different scales. In particular, there would appear to be a need for each member state to develop a national ambient noise strategy. Some states, such as the UK, are currently in the process of undertaking such an initiative; however, the vast majority are not. Moreover, establishing policy documents at various spatial scales (e.g. regional, local) which adhere to a national ambient noise strategy would not only help the co-ordination of environmental noise mitigation but also aid with the consistency of approach towards mitigation in each member state.

5. Conclusions

The paper has provided a general outline of the main areas of influence of the EU Environmental Noise Directive. The focus has been primarily on the methodological issues concerning the implementation of the Directive and dealing specifically with noise calculation and noise mapping issues. With regard to the former, the paper has pointed towards the various calculation methods currently in use throughout the EU for the implementation of strategic noise mapping studies. The paper has pointed towards the need for a harmonised calculation method if results of the noise mapping process are to be comparable. In addition, the paper has also pointed towards the limitation of the harmonised L_{den} noise indicator currently adopted by the Directive.

In relation to methodological issues the paper has pointed towards the key difficulties concerning strategic noise mapping. More specifically, a number of outstanding issues remain in relation to strategic noise mapping, the estimation of population exposure, noise action planning as well as the dissemination of information to the general public.

Potential policy implications concerning the methodological issues were also discussed with a number of key recommendations being made in relation to improving these issues in the future. Key among these is a more rigorous approach towards implementing standardisation in key areas of methodological uncertainty.

Finally, the paper has also offered a broad based critique of the END in light of the issues that have arisen since its adoption in legislation in 2002. Given that the END provides for amendments to the legislation in the future, some of the issues raised here should be considered in the event any amendments to the legislation.

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Member State	Road	Rail	Air	Industry
Austria	RVS 3.02	Onorm S 5011	OAL 24	OAL 28
Belgium	NMPB/XPS 31-133	RMR (SRM 11)	ECAC DOC 29	ISO9613
Denmark	Temanord 525	NBT85	ECAC DOC 29 (DENL)	Nordforsk 32
Finland	Temanord 525	Temanord 524	?*	Nordforsk 32
France	NMPB/XPS 31-133	NMPB/XPS 31-133	Lden and INM	ISO9613
Germany	RLS90	Schal03	AzB	ISO9613
Greece	NMPB/XPS 31-133	RMR (SRM 11)	ECAC DOC 29	ISO9613
Ireland	CRTN	CRN	INM	ISO9613
Italy	NMPB/XPS 31-133	RMR (SRM 11)	ECAC DOC 29	ISO9613
Luxembourg	RLS 90	Schal 03	ECAC DOC 29	VDI 2714/2720 (ISO9613)
Netherlands	RMW 2002 (SRM I+II)	RMR 2002 (SRMI+II)	RLD/BV-01 & RLD/BV-02	Handleiding Industrieelawaai 1999
Norway	Temanord 525	Temanord 524	?*	Nordforsk 32
Portugal	NMPB/XPS 31-133	RMR (SRM 11)	ECAC DOC 29	ISO9613
Spain	NMPB/XPS 31-133	RMR (SRM 11)	ECAC DOC 29	?*
Sweden	Temanord 525	Temanord 524	?*	Nordforsk 32
Switzerland	StL 86	SEMIBEL	FLULA	ISO9613
United Kingdom	CRTN	CRN	ANCON2 & INM in use **	ISO9613 (BS5228 also in use)

Table 2: Calculation methods used by each member state for the first stage of strategic noise mapping (2007)

Note :
?* Indicates no data was presented
****** ECAC DOC 29 was under consideration for use at time of development of this table.

Index	Description
L_{den}	The day/evening/night long term average sound pressure level including
L_{day}	The day time (07:00 - 19:00) A-weighted long term average sound pressure level
$L_{evening}$	The evening time (19:00 - 23:00) A-weighted long term average sound pressure level
L_{night}	The night time (23:00 - 07:00) A-weighted long term average sound pressure level
L_{Aeq}	The equivalent continious A-weighted sound pressure level
L_{10}	The level of noise exceeded for 10% of the time during the test period
L_{90}	The level of noise exceeded for 90% of the time during the test period
L_{max}	The maximum noise level recorded over the test period.
SEL	Sound Exposure Level: The equivalent noise level normalised to 1 second

Appendix 1. Explanation of several common noise indices