A Sustainable Approach To

Environmental Noise Barrier Design

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Abstract

This thesis recognises the implicit shortfalls in the current methods of noise barrier development. An holistic and integrative methodology was devised, which can be potentially incorporated into general practise, without the unnecessary burdens of excessive cost and environmental impacts. In essence the thesis defines, 'a sustainable approach to environmental noise barrier design'.

The importance of sustainability as a key determinant of a noise barrier's success is demonstrated through the impacts of public participation on the acceptance of a noise barrier. This was achieved through the triangulation of a grounded theory, formulated through the qualitative analysis of a real case study and then tested quantitatively on a larger representative sample. The theory explored the impact of ineffective public participation on the perceived success of a noise barrier.

Noise maps were developed for the comparison of subjective opinions with objective facts. This also illustrated how this technology can be manipulated to focus public participation, and increase success. Demonstrating the utility of this growing resource beyond its current scope.

A methodology for assessing the embodied impacts of noise barrier structures was also devised. By addressing the current lack of availability of a specific model, the means of choosing a noise barrier based on sustainable assets was revealed.

Finally, the thesis concluded with a laboratory experiment, which utilised a RAVE facility and revealed the extent to which preconceptions play a role in the perception of a noise barriers' effectiveness. Revealing that regardless of which noise barrier is presented, that preconceptions of a materials' ability to attenuate noise are imbedded.

The thesis contributed to several areas through the illustration of a sustainable approach to environmental noise barrier design. The methods highlighted, demonstrate how those responsible for building noise barriers, can improve the acceptance by the public and decrease the environmental impacts associated with the construction of these structures.

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List of Abbreviations & Definitions

A	*A Weighting Network*
AAWT	*Annual Average Weekday Traffic*
BF slag	*Blast furnace slag*
BRE	*British Research Establishment*
CFCs	*Chlorofluorocarbons*
CH_4	*Methane*
CO_2	*Carbon Dioxide*
CRTN	*Calculation of Road Traffic Noise*
dB	*Decibel*
DEFRA	*Department of Environment, Food and Rural Affairs*
DRMB	*Design Manual for Roads and Bridges*
EIA	*Environmental Impact Assessment*
EU/ EC	*European Union/ European Community*
FHWA	*Federal Highways Agency (USA)*
HA	*Highways Agency*
HCFCs	*Hydro chlorofluorocarbons*
HGV	*Heavy Goods Vehicle*
Hz	*Hertz*
LA	*Local Authority*
LA_{eq}	*The A Weighted Equivalent Continuous Sound Pressure Level over a given period of time*
LA_{10}	*Sound Level in dB(A) which is Exceeded for 10% of the Time*
LCA	*Life Cycle Assessment*
Lden	*Lden - LAeq determined separately (12 hour daytime period); (4 hour evening period) (8 hour night time period) combined using weightings of 5dB(A) for the evening period and 10dB(A) for the night period*
LGV	*Light Goods Vehicle*
NO_2	*Nitrogen Dioxide*
PC	*Personal Computer*
PMMA	*Polymethyl Methacrylate*
PM	*Particulate Matter*
PP	*Public Participation*
R^2	*Correlation Coefficient*
RAVE	*Reconfigurable Advanced Virtual Environment Suite*
RT	*Reverberation Time*
RTN	*Road Traffic Noise*
SO_2	*Sulphur Dioxide*
SPL	*Sound Pressure Level*
TL	*Transmission Loss*
TOE	*Tonnes of Oil Equivalent*
TRL	*Transport Research Laboratory*
VOCs	*Volatile Organic Compounds*
WHO	*World Health Organisation*

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Chapter 1 Introduction

1.1 An introduction to the discipline

Noise pollution is becoming one of the fastest growing concerns in modern society. Despite its transient nature, the UK government has recently recognized noise pollution as a sustainability issue for the 21st Century (British Government Panel on Sustainable Development 2000).

Of noise pollution, traffic noise is by far the greatest concern to the majority of people. In the UK the BRE recently published a report which concluded that 18% of respondents from a nationally representative sample cited noise as one of the top five environmental problems that personally affected them, with noise being ranked ninth of all 12 environmental pollutants investigated. Of this sample, 21% reported that noise 'spoilt their home life' with 8% reporting that their home life was spoilt either 'quite a lot' or 'totally', which indicates the wide reaching effects of noise on the UK population (Grimwood and Skinner 2001).

Legislation is now much tougher on exposure of workers to noise in industry (Noise at Work Regulations 1989) and the planning of new industries and factories (Town and Country Planning Act 1990), which ensures that acoustic insulation is a prerequisite to gaining permission for their development. Traffic noise, however, is much harder to control and as a consequence it is estimated that when all transportation noise is considered, more than half of all EU citizens are estimated to live in zones that do not ensure acoustical comfort to residents (WHO 1999).

There are several options available to reduce the impacts of noise on the public, including, double-glazing of dwellings, reduction in tyre noise through the introduction of low noise surfaces, modification of vehicle design to control noise stemming from the vibration of vehicle parts and reductions in exhaust noises. This is by no means a comprehensive list, but goes some way to illustrating the options available to reduce the impacts of noise. One of the most common and effective means of noise reduction is by the use of barriers, which, through interrupting the line of sight between the source and the receiver, reflect/ absorb and diffract noise, consequently reducing the energy of sound and decreases its impact at the receiver.

The means of developing noise barriers to date have been fractious in that individual disciplines often work in isolation at worst and in a badly coordinated manner at best, often resulting in a finished project falling short of its potential. In the area of actual acoustic research of barriers, the understanding of forms, and materials for acoustic reduction is well developed, with extensive research covering everything from barrier end effects with the use of boundary element modelling and barrier top construction, to the most effective angling and material for maximum noise reduction.

The more ambiguous disciplines of aesthetic quality and perception, subjective perception of a material's suitability, and public appreciation through participation and ownership, in addition to the sustainable development of barriers are largely overlooked, or only given relatively small importance in the larger scope of a noise barrier's construction.

1.2 Aim of the thesis

One of the key aspects in noise barrier design and implementation is the lack of community involvement through public participation procedures. Through experience of the development process of noise barrier's and consultation with The Highways Agency, the author has identified that development of these structures is largely perceived as an engineering problem, of which only expert opinion can be beneficial. Consequently, the fundamental role of the public as objective valuators is marginalised, and as a result solutions are imposed upon them without their full integration or approval. This patriarchal approach of imposing solutions is detrimental to the overall success of noise barrier projects on two levels. Firstly, local knowledge and preferences are not determined, which may result in a barrier being designed that is not perceived as architecturally sympathetic to the surroundings, by the those that live in close proximity to it.

Secondly, the opportunity to allay any concerns and impart realistic expectations of the noise barriers potential for mitigating noise is denied. This then leaves a greater potential for residents to judge the projects success based on their own preconceptions rather than on realistic grounds.

As a consequence of this shortfall in the design process this thesis has been used as an opportunity to identify the existing weaknesses in the current processes. This is achieved by establishing a clear method of undertaking a noise barrier project focusing on most of the non-acoustic parameters that can often be overlooked. In essence, the thesis defines 'A Sustainable Approach To Environmental Noise Barrier Design'.

This work does not claim to be exhaustive in its scope. Indeed, the fundamental issue of objective acoustical design and full economic factors are not incorporated as these areas are already undergoing a vast amount of research and this is beyond the remit of this work. However, by concentrating on the main areas of neglect, including public participation in design, sustainability in design and perception as a measure of efficiency, many of the existing shortfalls are highlighted and means of assessing and avoiding them are put forward.

In brief, the aim is to understand better the implicit shortfalls in the current methods of noise barrier development in the areas of public participation, sustainable development and understanding of the impacts of subjective perceptions of noise attenuating properties of various materials. Building on this the aims is to define methods to avoid these shortfalls and improve the sustainability of noise barriers using an holistic and integrative methodology which could be incorporated into general noise barrier design to optimise the potential for overall success. The following key objectives underline the structure of the thesis:

- Investigate the impacts of public participation as a means of increasing acceptance of noise barriers.
- Investigate the influence of public integration at the planning stages on whether there are greater perceived noise reductions, than without (using a case study).
- Assess the best practical means of gaining full public integration into the planning and development of noise barriers, embracing all members of society despite minority status.
- Illustrate how to utilise noise-mapping technology, to access noise hotspots and direct participation making it more effective as well as economically viable.
- Assess the economic impacts of full public participation against the more traditional methods of allowing the public to be involved.
- Develop a method of assessing the sustainability and lifecycle assessment of noise barrier materials to inform the design process and achieve sustainability targets.
- Investigate the impact of material type upon the perceived reduction of noise level.
- Integrate these findings into a methodology for the consideration and adoption of a sustainable approach to environmental noise barrier design.

1.3 Layout

Chapter 2 is a review of the literature; the area of noise barriers research is vast so both the scope of where this research fits into the wider context of acoustics and the exact place for it within its own area will be highlighted. Therefore, the references reviewed here do not extend the breadth of each individual area, but illustrate a good example of the research currently being undertaken in all of the individual principles consolidated in this thesis.

Chapter 3 outlines the methodology used to undertake this thesis, revealing how through the integration and understanding of several different aspects of the sustainable design of noise barriers, a more holistic and integrated method can be achieved. It is argues that this might result in the designing of noise barriers that are not only objectively but also subjectively successful. The importance of empowering the public and protecting the environment, are emphasised as key to the integration of a sustainable approach to noise barrier development.

Chapter 4 introduces a case study of an area of South Yorkshire where a noise barrier was erected in 2001. Through the utilisation of the phenomenological research method, 'Grounded Theory Approach' the investigation revealed the existing limitations of current public participation measures in a typical UK's community. Minority groups were accessed through the use of semi-structured interviews, which brought to light existing problems and potential solutions for the participatory phase of planning of the noise barrier.

Chapter 5 triangulated the methods of qualitative research with that of a more positivist method in the form of a wider reaching randomly selected collation of views from a structured questionnaire. The investigation drew out themes from the qualitative results and expanded them to gauge the wider opinion of the affected society. The result of this investigation revealed the extent of the perceived infectivity of both the planning process and the resultant barrier, drawing correlations between the two.

Chapter 6 developed one of the themes that had emerged in the questionnaire (that the participation process had been ill-coordinated and badly directed) by introducing noise mapping as a tool for planners to coordinate public participation exercises and focus attention on the population directly impacted upon by any noise barrier design. The aim of this was to illustrate the potential for a more focused participation engaging all members of society. This is perceived as a better alternative to the current form of engaging those that are physically able and capable of raising issues through attending public meetings, linking the findings of this feasibility exercise with the likely benefits of undertaking it in reality.

Chapter 7 develops a method for lifecycle assessment specifically designed for noise barriers, as currently there is no such tool. The Highways Agency is currently using a combination of methods to undertake what they call 'whole life analysis'. The method developed here therefore has a direct potential for improving noise barrier development by introducing an alternative means of life cycle assessment that removes the loss of accuracy resultant from using many models, by integrating them into one. Current life cycle assessment methodologies are reviewed and then customised and applied to a theoretical case study of a noise barrier project in the UK. The outcome is an insight into the current embodied environmental costs of the most common materials used for noise barrier development, along with practical guidance on how to customise this methodology to suit any project where noise barriers are required.

Chapter 8 reopens the question of the importance of public perception of a noise barrier's success. In this section the quality of various materials commonly used in noise barrier development are judged subjectively in relation to their acoustic performance. This again introduces new means of utilising existing technology to benefit the design of noise barriers, by undertaking research using subjects in a RAVE- Reconfigurable Advanced Virtual Environment Suite.

In Chapter 9 final conclusions are reported, galvanising the importance of non-acoustic parameters in the design of sustainable noise barriers with final contributions, recommendations and limitations of the thesis.

To illustrate further the integrated disciplines and key factors affecting the solution to the design of sustainable noise barriers, two diagrams are presented below. Figure 1(a) illustrates the criteria fundamental to a sustainable approach to noise barrier design. The numbers presented above the boxes are also represented in Figure 1(b), which represents where each individual criteria falls under the three wider areas of political, socio/economic and environment and sustainability. From these figures the integrated nature and the importance of a multi-disciplinary approach to this problem is emphasised.

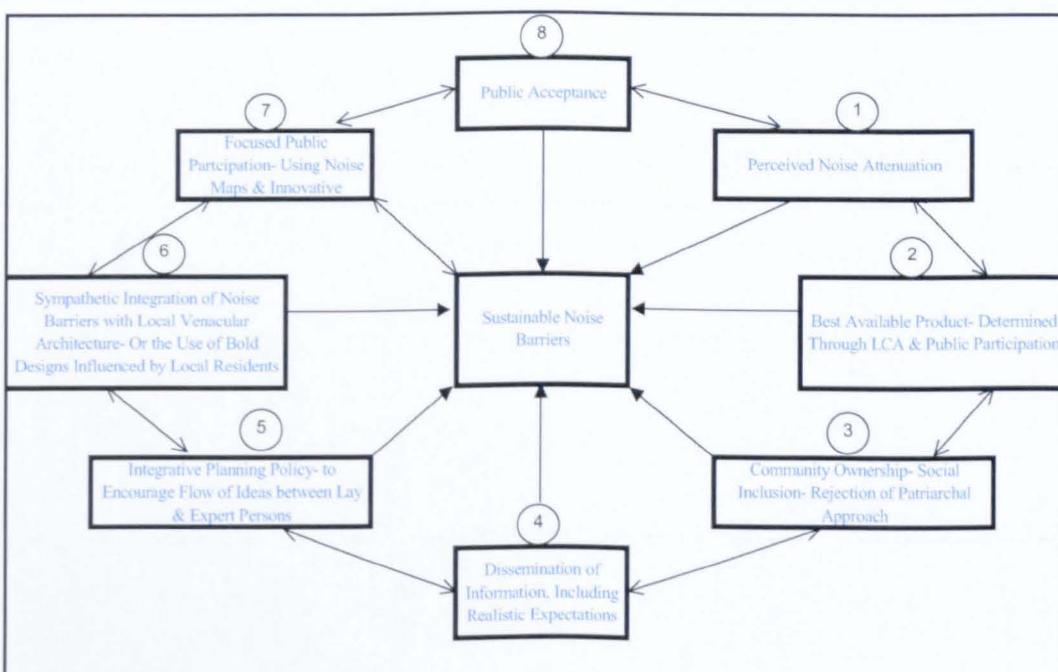

Figure 1 (a) Criteria for a sustainable approach to noise barrier design

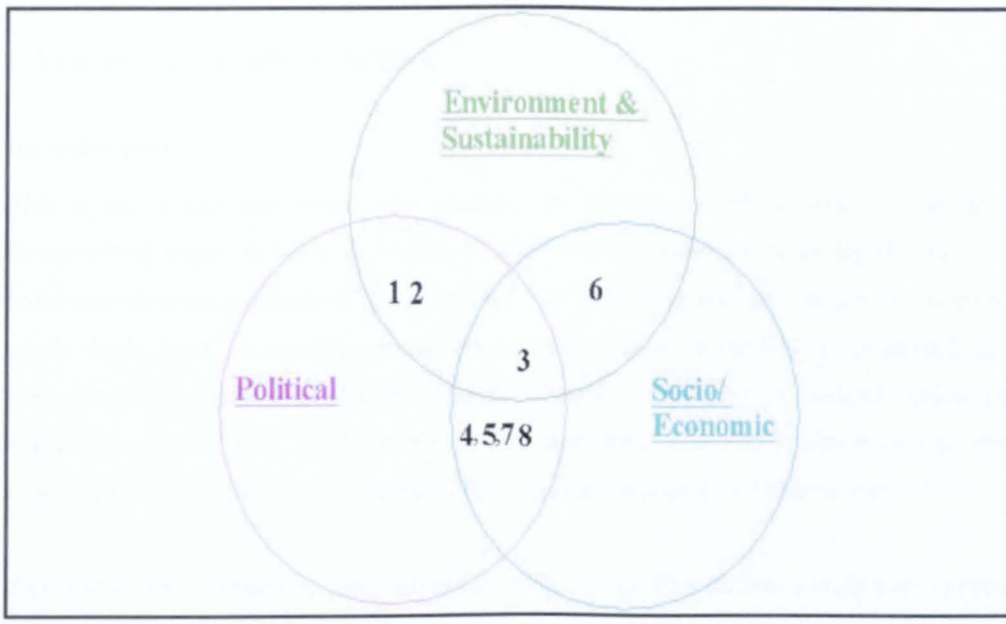

Figure 1 (b) A broader representation of the key areas the individual criteria effect.

Chapter 2 Literature Review

Introduction

This review is split into seven main sections; the sections include an overview of the current situation with regard to noise in the UK. This includes an overview of the legislation controlling noise and also the methods of measurement. The following sections reflect the themes of the whole thesis. First, the current methods for controlling noise in the UK are evaluated, including the principles of noise control using barriers. This is followed by an in-depth review of noise barriers, including their form, properties and materials. The UK situation is also reviewed relative to the rest of Europe to highlight the stage that barrier development is at.

The next section delves into the main point of the thesis. This defines a sustainable approach to noise barriers' design, which includes the best means of developing, and installing barriers, to maximise their performance and also to give the most environmentally effective solution. This is illustrated partly through the acknowledgement of the importance of perception in acoustic science. A historic review of acoustic science puts the importance of perception into a context with the wider science, and reveals the importance that perception plays in the success of any acoustic project, in light of the fact that noise barriers will be ultimately judged for their benefits in relation to how they are subjectively perceived.

A review of the literature of noise barrier development highlights a catalogue of failed projects. This raises the issue of public perception as a reason for their failure. This review acknowledges the prominent role of the public in judging these projects and introduces the idea of the use of noise mapping as a means to direct any participatory measures. An appreciation of the public's expectance for more environmentally benign solutions is also acknowledged and a review of the relative positive and negative impacts of various materials commonly used is revealed. This highlights the various means of quantifying environmental costs, a measure usually ignored in favour of the more commonly understood economic costs.

Finally, a review of how the public perceive barrier forms illustrates that the judgement of a noise barrier projects' success is not just the result of good public participation and environmentally sensitive development, but is also influenced by the preconceptions and aesthetic appeal of various materials.

In all, the review illustrates that noise barrier design is much more than a quick fix to a growing problem, but that it is a multi-disciplinary problem requiring an integrated solution. Consequently the review, as well as the thesis itself, stretches across many disciplines, the aim of which is to highlight not only the pitfalls in noise barrier development but to provide a useful tool to avoid them.

2.1 Noise as an environmentally important issue

2.1.1 Environmental noise: an overview of the issues

Environmental noise has been an area of growing concern for many years, both in the UK and worldwide. Environmental noise (or community noise) is defined as noise emitted from all sources, except for noise at the industrial workplace. The main sources of environmental/ community noise emitted include road, rail and air traffic; industrial; construction and public work; and the neighbourhood (WHO 1999).

Of all noise sources, road traffic noise is responsible for the largest cause of annoyance. It is estimated that approximately 40% of the population in the European Union are exposed during the daytime to road traffic noise with an equivalent sound pressure level exceeding 55dB(A), and 20% are exposed to levels exceeding 65dB(A). When all transportation noise is considered, more than half of all European Union citizens are estimated to live in zones that do not ensure acoustical comfort to residents. At night, more than 30% are exposed to equivalent sound pressure levels exceeding 55dB(A), which is disturbing to sleep (WHO 1999).

According to Mason et al (1993:2), those exposed to traffic noise often accept it as being an unavoidable and therefore an inevitable part of living within today's urban conglomerations. Statistics of adverse reactions to noise, based on recorded complaints, only reflect a small proportion of those actually affected (Mason 1993). Therefore as a consequence, millions of people are living in environments, which could be potentially detrimental to their health, without the knowledge of their rights to a good standard of living, including acoustic comfort.

It is because among other factors, noise is now gaining momentum as a key policy area. In the Government consultation paper 'Towards a National Ambient Noise Strategy, noise was finally put on the agenda as a sustainability issue, as despite its transient nature, the extent of its detriment to the environment was accepted (DEFRA 2001:25This turning point spurred on the development of environmental legislation and policy, which had remained stagnant for many years.

2.1.2 UK legislation for noise control: a history of actions

Pre 1929, there was little legislation controlling noise in the UK. The founding policy in the UK was the 'Motor Cars (Excessive Noise) Regulations 1929'. This was a rudimentary law, based on the judgement of the individual policeman's perception of how noisy a vehicle was, and whether to press charges. This would be followed by a court's judgement as to whether or not the individual vehicle was too noisy (Kotzen & English 1999:2). It was not until the 1960s that this law was superseded following the influential Wilson Report (Wilson 1963).

The Wilson Report was commissioned in 1963 under the guidance of Sir Alan Wilson. The committee found that from analysis of unsolicited complaints of noise, motor vehicles, plus domestic and industrial noise caused the greatest nuisance. The outcome of the findings of this central London study was a scale of expected nuisance at certain noise levels for various noise sources. A noise level of 68dBA($L_{10,\ 18hr}$) was recommended as the limit, below which, extreme annoyance would not be caused. This was based on the findings that stated 'with 95% confidence, that any individual under the conditions of the London Noise Survey will have an annoyance score of less than 5'. Meaning, that there is only a 1 in 40 chance that the average person would be dissatisfied below these levels with noise from free flowing traffic. The 68dB($L_{A10\ 18\ Hour}$) is still used today (The Open University 1978).

Control of road traffic noise at the receiver requires social survey evidence in order to formulate standards and limits. Since the 1960s a number of comprehensive surveys have been undertaken throughout England and Wales. These surveys have enabled comparisons between various indices of noise levels measured at the façades of noise-affected buildings and the annoyance of their occupants. These surveys discovered that the $L_{A10,\ 18hr}$ index closely correlates with the public's dissatisfaction with noise (Highways Agency 1999: 2/2).

Road traffic noise was consequently the subject of considerable legislative activity, particularly during the early 1970s. The White Paper 'Development and Compensation- Putting People First' was published in 1972 and heralded the way for the Land Compensation Act (1973), which has been the most influential Act for road noise control in the UK, and influenced the mitigation procedures considerably.

The Land Compensation Act was passed to compensate existing landowners for any undervaluing of their properties due to public works. This was whether or not that property, and the adjacent land boundary, was encroached upon. The Act stated that 'roadworks will produce eligibility if by prediction, or by measurement and extrapolation (as laid down in the regulations), it is calculated that the forecast maximum use of that road within a period of 15 years from its first use will give rise to an increase in noise of 1dB(A) or more at one or more of the facades of the dwellings and the resultant noise level will reach or exceed 68dB $L_{A10,\ 18hr}$ ("the specified level")'.

The means of compensation include the power of landowners to claim the monetary value of the depreciation of their properties' value and the power of the secretary of state to impose a duty on the provision of noise insulation. This would usually be in the form of double-glazing, compulsory purchase of properties, the provision of noise barriers and the power to pay for the temporary re-accommodation of residents. The preferred means of compensation is generally provided through the use of insulation such as double-glazing, and this gave rise to the Noise Insulation Amendment Regulations (1988).

There are several downfalls of the Land Compensation Act. The first being that it does not account for residents living adjacent to unaltered carriageways, in existing properties that have seen an exponential rise in traffic flows and consequent noise levels. Nor does the Act protect those residents in existing 'tranquil areas', who for example, prior to the development of the new road, experienced levels of 50dB(A), and after completion of the works are exposed for example to levels of 67dB(A). These residents will have an extremely perceivable change in noise levels but still would not qualify under the Land Compensation Act (1973).

2.1.3 UK legislation for noise control and the impacts on noise barrier use

The result of the reliance on insulation at the individual receiver through double-glazing, has limited the use of noise barriers and other noise mitigation measures in the UK. One of the largest problems with double-glazing is that it does not provide for mitigating affects in external spaces.

As of yet, there is no specific UK noise legislation that does offer protection of the environment against noise in internal and external spaces for existing properties adjacent to existing roads. However, with the publication of the World Health Organisation (WHO) Guidelines for Community Noise (1999), the case for the greater protection of properties both internally and externally has been made. The guidelines have raised awareness, not only of the dangers of living in areas of excessive noise (see section 2.2.2 below), but also the levels at which these effects become significant. These are much lower than the previously utilised levels based on potential annoyance (WHO 1999).

As a consequence of the WHO guidelines and the publication of the European Green Paper on Future Noise Policy (1996), and as prompted by the Fifth Environmental Action Programme (1993), steps have been taken to address noise policy throughout Europe. The latest Directive to emerge on this initiative is that relating to the 'Assessment and Management of Environmental Noise (2000)'. This has set in place a program of noise mapping of all agglomerations of greater than 250,000 by 2004 and for all agglomerations with more than 100,000 by 2009. This target has already been slightly breached in the UK. However, with the adoption of the Government initiative, 'Towards a National Ambient Noise Strategy', mapping of all major trunk roads will be completed by the end of 2005. The purpose of the Directive is to identify the extent of the noise problems throughout the EU and develop future policies.

Therefore, it can be expected that the future development of noise barriers to protect residents in these 'grey' areas of excessive noise identified by the latest wave of 'Directives' will start to emerge, making the case for a more coherent approach that will optimise their development.

2.1.4 Measures of road traffic noise

There are various measures used to describe road traffic noise. Currently in the UK $L_{A10,\ 18hr}$ is used. This is the arithmetic mean of the noise levels exceeded for 10% of the time in each of the 18 one-hour periods between 6am and Midnight. The reason this has been favoured in the UK, is that a reasonably good correlation has been shown to exist between the index and residents' dissatisfaction with existing traffic noise over a wide range of exposures (The Open University 1978: 3).

A further reason that the $L_{A10,\ 18hr}$ index is favoured is due to its application in the CRTN methodology (Department of Transport 1988). This is the basis of all road traffic noise exposure assessments in the UK, and it was developed in order to facilitate the Noise Insulation (Amendment) Regulations (1988).

Another reason for the loss of popularity of the $L_{A10,\ 18hr}$ index is due to two factors. Firstly, the UK is one of the very few European member states currently using it for measuring traffic noise. Secondly, with the increasing moves towards assessment of overall community noise from many sources, the use of the L_{A10} for one noise source and L_{Aeq} for others, makes it more difficult to assess the overall noise climate as one (Highways Agency 1999).

Therefore, it is likely that future noise measurements in the UK will start to favour the widely used L_{Aeq}, which is the equivalent continuous sound level as time-averaged over a specified time period (T), which gives a measure of the average sound energy over that period (Garcia 2000). In the European Commission's 'DAMEN', one of the recommendations is for the 'harmonisation of noise indicators and assessment methods' (European-Commission 2002:Article 5), the noise indicators proposed are the L_{den}[1] (day-evening-night level) and the Lnight level, which are based on L_{Aeq} values. Therefore, it is likely that all European states will, in due course, favour this measure.

This standardisation of noise measurement will benefit all countries legislating for noise reduction and coordinating mitigation projects. Examples of case studies in one country could be replicated in other countries. In addition, if the methods of measurement are comparable, the transfer of information with regard to mitigation possibilities will be more feasible and research carried out throughout the EU will be directly relevant to each country, increasing the passage of information between member states.

2.2 Acoustic research from science to social science

2.2.1 The three watersheds of acoustic research: physical acoustics, psychoacoustics & social acoustics

There have been three main watersheds in acoustic research and this section aims to put the development of the area of subjective or perceptive acoustics within the context of a timeline of acoustical research. This is a very broad review, as obviously within each of the main categories there are many different sub-areas branching across many disciplines. However, it is fundamental that this important interdisciplinary field is held with the same esteem as that of the more traditional acoustic research fields.

Although acoustics has many disciplines, such as room acoustics, marine acoustics, musical and environmental, all derive from the fundamental basis of the desire to understand the actual laws and processes of the science. The principle of this pioneering field mainly involved the discovery of the physical laws and principles governing the science of acoustics, and the consequent development of applications of these laws. This led to the development of an

[1] L_{den} combines the L_{Aeq} determined separately for the 12 hour daytime period, the 4 hour evening period and the 8 hour night time period into one indicator using weightings of 5dB(A) for the evening period and 10dB(A) for the night period. Joseph, M. (2000). The European Environmental Noise Directive - Impact on the UK. CIEH Meeting on Noise Barrier.. Lnight is the LAeq for the 8 hour night period without any weighting.

understanding of principles that are in everyday use today, for example ultrasonics, which is used by many industries, especially the medical profession (Institute of Acoustics 2002; Bennett 2003; Institute of Acoustics 2003; Tyler 2003; Institute of Acoustics 2004 (a); Institute of Acoustics (b) 2004).

In addition, the formative research into the physics of acoustics has also led to an understanding of the behaviour of sound in different mediums and under varying environmental conditions, which has led to many important discoveries including, for example, the optimisation of warning alarms such as fog horns and sirens (Bennett 2003) and an understanding of how best to design buildings such as theatres for optimum use.

The next watershed in acoustics to emerge was that of psychoacoustics. This relates to understanding of how humans interact with sound. Psychoacoustics can, therefore, be described basically as the psychological study of hearing and deals with relationships between the perception of sound and physical properties of sound waves. The aim of psychoacoustics research is to find out how hearing works. In other words, the aim is to discover how sounds entering the ear are processed by the ear and by the brain in order to give the listener useful information about the world outside i.e. defining relations between measured features of sound (i.e. frequency) and their subjective counterparts (i.e. pitch of tone).

An important property of the human ear is an absolute hearing threshold. The hearing threshold changes significantly within the normal frequency range. Investigations by many researchers have proven that the human hearing system processes perceived sound in sub-bands called critical bands. In each critical band, sound is analysed independently and each band corresponds with an equal section of the cochlea, approximately 1.3 mm wide within the ear. These critical bandwidths differ within the frequency range; those below 500 Hz are constant and equal 100 Hz, whereas over 500 Hz the width of each next critical band is 20% larger than of the band below (Sounds and Vision Engineering Department 2000:1; Plack 2004:1).

Through this understanding of how sound is perceived and processed by the brain, many problems, such as reduced hearing ability, were improved using hearing aids. These were developed from the findings of psychoacousticians and their understanding of how the human ear responds to sound waves of different frequencies. In addition, the work of psychoacousticians has affected most people in everyday life. This is through better use of communication methods and more protection against hearing damage, as well as enabling a quantifiable standard of noise tolerance, such as the noise annoyance indicator, which in turn informs public law and policies (Johannsen and Holger 2001; Smith et al. 1996).

The current renaissance of acoustic science involves the acceptance of the influence of human perception and subjective opinion on the acceptance of various acoustic environments. Although there are still large numbers of vulnerable people who are unaware, both of the impact of noise exposure and the opportunity to protest about it, on the whole the public will no longer tolerate any adverse environmental impacts. It is now seen as a lifestyle commodity to have a quiet and un-invasive acoustic environment and the general public is more educated on what is an acceptable acoustic environment and are willing to demand it.

The importance of subjective acoustics has been acknowledged in many fields, including architecture, urban design and environmental planning. It has been adopted as a key area of design as opposed to an afterthought. As it is becoming more widely accepted that the success of projects lies mainly in the subjective opinion of the end user, be that in a public park, building or adjacent to a noise barrier, the role of public participation in many areas of design has grown in stature and is now seen as a fundamental element of acoustic science research (Midgley 1986; Sanoff 2000;Yang and Kang 2001; Kang and Zhang 2003; Yang and Kang 2003; Chen and Kang 2004; Kang 2004; Kang et al. 2004; Yang and Kang 2004; Yang and Kang 2005; Kang (In Press).

2.2.2. The detrimental social, psychological and physiological and economic impacts of noise

The inclusion and acceptance of the impacts of noise on humans has never been more acutely felt, with reports emerging continually, which highlight the detrimental social, psychological and physiological impacts of noise. As alluded to above, it is not just the science and medical professionals that understand the potential detrimental effects of excessive noise exposure, but nowadays the general public are more astute to public health risks as well.

It is well documented that the effects of exposure to prolonged road traffic noise is not singularly responsible for any acute medical ailments, with hearing impairments not expected to occur at LAeq, 8h levels of 75dB(A) or below, even for prolonged occupational exposure (WHO 1999; viii; DETR 1998; 2). However, it nonetheless has insidious effects. A WHO task force reported several chronic health effects that may result from community noise including high blood pressure, cardiovascular deficiency, an inability to concentrate on tasks and interruption of sleep. In addition to this, impairment of the understanding of speech is also a related problem and poses particular difficulties for children exposed to environmental noise in classrooms, and for the elderly (Cohen, Glass et al. 1973; WHO 1999; Shield and Docknell 2002; Shield and Docknell 2002).

Table 2.1 below documents some of the key health effects attributable to noise exposure in specific environments as reported in the WHO Guidelines. The table clearly illustrates that levels, which are accepted as being injurious to public health, are not exceptionally high. When this is considered in relation to the fact that more than half of all EU citizens live in areas that do not ensure acoustic comfort, the extent and implications of the noise pollution problem in today's society becomes apparent.

Table 2.1 also illustrates the extent to which the current UK value of 68dB $L_{A10\ (18\ hour)}$, (as outlined in the Noise Insulation Regulations (1988)), is unrelated to the levels at which detrimental effects can be felt. In addition, to giving some quantified reasoning behind the WHO's endorsement of the 55dB(A) and 45dB(A), outdoor levels for day and night time.

Table 2.1 Guideline values for community noise in specific environments. (WHO 1999: 65)

Specific environment	*Critical health effect(s)*	*LAeq [dB]*	*Time base [hours]*	*LAmax fast [dB]*
Outdoor living area	*Serious annoyance, daytime and evening*	*55*	*16*	-
	Moderate annoyance, daytime and evening	*50*	*16*	-
Dwelling, indoors	*Speech intelligibility and moderate annoyance, daytime and evening*	*35*	*16*	
Inside bedrooms	*Sleep disturbance, night-time*	*30*	*8*	*45*
Outside bedrooms	*Sleep disturbance, window open (outdoor values)*	*45*	*8*	*60*
School class rooms and pre-schools, indoors	*Speech intelligibility,*	*35*	*During class*	-
	Disturbance of information extraction,			
	Message communication			
Pre-school	*Sleep disturbance*	*30*	*Sleeping-time*	*45*
Bedrooms, indoors				
School, playground outdoor	*Annoyance (external source)*	*55*	*During play*	-
Hospital, ward rooms, indoors	*Sleep disturbance, night-time*	*30*	*8*	*40*
	Sleep disturbance, daytime and evenings	*30*	*16*	-
Hospitals, treatment rooms, indoors	*Interference with rest and recovery*	*#1*		
Industrial, commercial	*Hearing impairment*	*70*	*24*	*110*
shopping and traffic areas, indoors and outdoors				
Ceremonies, festivals and entertainment events	*Hearing impairment (patrons:<5 times/year)*	*100*	*4*	*110*
Public addresses, indoors and outdoors	*Hearing impairment*	*85*	*1*	*110*
Music through headphones/earphones	*Hearing impairment (free-field value)*	*85 #4*	*1*	*110*
Impulse sounds from toys, fireworks and firearms	*Hearing impairment (adults)*	-	-	*140 #2*
	Hearing impairment (children)	-	-	*120 #2*
Outdoors in parkland and conservation areas	*Disruption of tranquillity*	*#3*		

#1: as low as possible;
#2: peak sound pressure (not LAmax, fast), measured 100 mm from the ear;
#3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;
#4: under headphones, adapted to free-field values

In addition to the health implications, other stress factors such as decreases in house values (Bennett 2001) and social degradation of an area, were found to be caused by the impact of road traffic noise (Joynt and Kang 2002).

The World Health Organisation (WHO) stated in 1980 that background noise levels above 55dBA would progressively impair the understanding of speech. This 55dB(A) threshold is the so-called 'grey area' threshold which is occasionally of concern to public policy makers, but not so much as the 'black spots'- areas with background noise levels in excess of 65dB(A) (Mason 1993).

2.3 Noise mitigation using barriers compared to alternative mitigation measures

2.3.1 Control at source

Noise mitigation at source is one of the main means of noise reduction achieved through actual alterations to the vehicle creating the noise. Below there is a brief overview provided to summarise the methods of how this is achieved.

Noise sources from vehicles can be split in two categories: 1) mechanical sources which can include noise from the engine, transmission, exhaust, and fan and air intake systems. 2) Rolling sources, which include tyre noise, aerodynamic noise and the vibration of body panels (Martin 2001).

The control of mechanical noise is outside the context of this study. However, it is accepted that up to about 30 km/h mechanical sources on most light vehicles and cars are the largest source of noise and on heavy vehicles this dominates up to approximately 50 km/h. Above these two respective speeds it is the rolling noise that is the major source and this increases at a rate of 9dB(A) per doubling of speed. The calculation of the noise produced by a mixed flow of traffic can be calculated using CRTN. This considers the number of vehicles, the percentage of heavy vehicles and their speeds to give an overall noise level (Department of Transport 1988). Additional factors that determine the level of noise are the texture of the road surface, which affects rolling noise and the road gradient, which affects engine noise. In wet conditions tyre noise increases, however, road traffic noise assessments presume dry conditions (Department of Transport 1988: 27).

There are several means of mitigating against rolling noise. These are the basic principles on which the most common noise control measures are based. Technologically the simplest means of noise reduction is achieved through the use of speed controls, provided that it does not interrupt the free flow of traffic. For example a reduction in speed from 70 mph to 50 mph would reduce the emitted noise level by approximately 2.3dB(A). However, it should be borne in mind that speed limits are unlikely to be adhered to if they are not considered to be representative for the type of road.

As this method would be most effective on motorways and dual carriageways, a speed limit is unlikely to be effective on its own. It is believed that any move to place permanent speed traps on free flowing motorways could lead to interruption of the free flow and potential delays (RPS Plc 2005). Another option of rolling noise control is through the adaptation of the road surface to reduce the noise between the tyres and the road. As there are several road surface materials now available, a review of the current findings and research is presented below.

2.3.2 Low noise road surfaces

Recent developments in low noise surfaces include porous asphalt. This was originally developed to reduce water spray on airport runways and was adopted as a useful resource for surfacing roads, following the discovery that the added pores in the surface designed to facilitate drainage also gave noise reductions of up to 85%. This reduction equates to noise levels that are about 5dB(A) less than for a hot rolled asphalt surface (Watts 1994).

There are, however, drawbacks associated with porous asphalt due to its high cost, high maintenance and the diminishing effect of the noise reduction as the surface becomes clogged. The average porous surface will need resurfacing approximately every ten years as opposed to every fifteen years for the traditional asphalt or concrete. The main alternative is whisper concrete, sometimes known as exposed aggregate concrete. Compared with other road surfaces, it reduces traffic noise by some 3dB (Parliamentary Questions (1994: 20-26 Column-619) making traffic noise levels attributable to whisper concrete higher than those achieved with porous asphalt (Watts 1994).

The publication of the 1998 paper entitled 'A new deal for trunk roads in England', stated the following objective: 'In future, whenever a road needs to be resurfaced, we shall ensure that the most appropriate noise reducing surfaces are used for those areas where noise is a particular concern'. Additionally, in the Government's 'Transport 2010: The Ten Year Plan' published in July 2000, the Highways Agency set targets of installing quieter surfaces on over 60% of the trunk road network, including all concrete stretches, by 2010 (Highways Agency 2002: 1).

Evidently, therefore, a reduction at source is both possible and encouraged. However, the most effective measure by far to reduce the effects of road traffic on sensitive receivers, is to remove the line of sight between the source and the receiver (Environmental Protection Department, Hong Kong 2001). This is most commonly achieved through the erection of noise barriers and bunds and in some cases, especially on new developments, by non-residential buildings. This thesis is confined to the investigation of noise mitigation through noise barriers; the basic principles of which and most commonly used materials are described below.

2.3.3 Basic principles of noise control using noise barriers

Noise control by barriers is a common means of obtaining modest reduction in the overall sound pressure level (SPL). Most of the main noise sources including road traffic noise can be shielded by barriers, which intercept the line of sight from the source to the receiver. The acoustic phenomenon governing the barrier attenuation is known as the Fresnel diffraction. This analytically defines the amount of acoustic energy loss encountered when sound rays are required to travel over and around a barrier- see Figure 2.1 (Cohn & McVoy 1982). The noise at the receiver is reduced to that portion which arrives via diffraction over the barrier top or around its ends, and via reflection from other buildings and scattering refraction in the atmosphere.

For a single point source, and an infinitely long barrier, the path length difference is found using the following equation, which is illustrated below in Figure 2.1:

$$\delta = \mathrm{A} + \mathrm{B} - \mathrm{C} \qquad (2.1)$$

where δ is the path difference between the direct ray and diffracted ray due to screening of the source line (Department of Transport 1988;). The extra attenuation of a barrier is closely related to the Fresnel number, N, defined as

$$N = 2\frac{\delta}{\lambda} \qquad (2.2)$$

For, -0.2<N<12.5 the insertion loss (IL), namely the SPL difference between the noise level measured, with and without the barrier, can be calculated by (Kurze and Anderson (1971;):

$$IL = 20\log\frac{(2\pi N)^{\frac{1}{2}}}{\tanh(2\pi N)^{\frac{1}{2}}} + 5 \qquad (2.3)$$

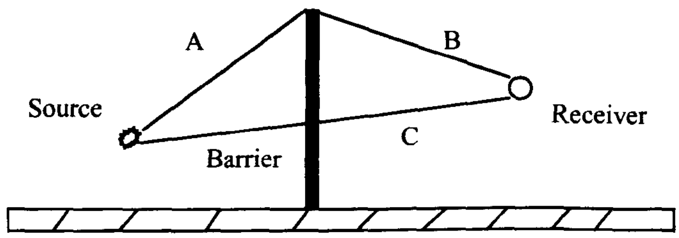

Figure 2.1. Configuration of a noise barrier

2.3.4 Reflections

Reflections of sound occur whenever there is a situation where complete absorption is not achieved, i.e. where the absorption coefficient α of a surface is equal to 0. Sound can be reflected in a similar way to light, with the angle of incidence equalling the angle of reflection when the reflecting object is at least the same size as the wavelength concerned. It is usual for the first and second reflection to be considered only in geometrical analysis (Smith, S. et al. 1996). Theoretically, however, with the development of computer packages, the number of reflections considered can be infinite, although calculation times restrict this.

In noise barrier design reflections are integral to the functionality of the barrier. Reflective barriers are the most widely used barrier type in the UK and can be very effective in situations where there are no sensitive properties opposite the barrier, which may receive increased noise levels. Figure 2.2 below illustrates the principle of a reflective noise barrier and shows the pitfalls of inappropriate use, and a method of reducing this effect.

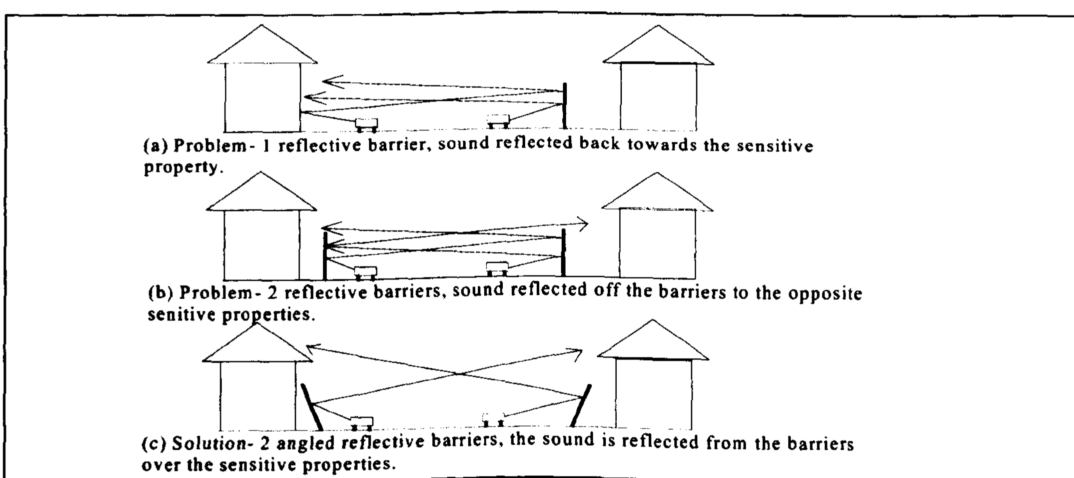

Figure 2.2 Diagrams of how reflection barriers behave the problems and a solution.

2.3.5 Absorption

Noise barriers are categorised mainly into reflective and absorptive. The principle of an absorbent barrier is that noise penetrates the outside material through perforations, and absorbed by the internal porous lining. Different materials have different absorption coefficients and generally the more porous the materials surface the better absorber it is.

For materials without a high absorption coefficient, an option can be to integrate a highly absorptive material, such as mineral wool, into the barrier structure. This is described in greater detail below. The performance of an absorbent is usually expressed by its absorption coefficient α, which ranges from 0.0 for a perfect reflector to 1.0 for a totally absorbent material. The absorption coefficient is not a constant for a given material or composite since it will vary with both frequency and with the angle of the incident wave (Morse & Ingard 1968).

A single number, the Noise Reduction Coefficient (NRC), often describes the absorptive properties of materials. This is an arithmetic average of the normal incidence absorption coefficients for 250, 500, 1000 and 2000 Hz. Normal incidence NRC values can be obtained from various sources in the literature for different roadside locations. Table 2.1 lists values of (NRC) obtained principally from the National Physical Laboratories as reported by Tobutt & Nelson (1990). Absorption coefficients of efficient commercial absorbers remain fairly constant and close to 0.9 for frequencies above approximately 800Hz, although at lower frequencies the absorption falls rapidly.

Table 2.2 (NRC) values for different surfaces and Ground Cover Conditions.

Surface or Material	(NRC) Value
Concrete, brickwork	0.02
Asphalt (sealed surface)	0.05
Timber barriers, without absorbent	0.12
Chalk or rock faced cuttings and embankments	0.2 to 0.3
Grassland: Short grass	0.48
Long grass	0.6
Agricultural land (ploughed fields, growing crops etc.)	0.75
Woodland	0.83
Absorbent faces of barriers and walls	0.73 to 0.95

(Source: National Physical Laboratory in Tobutt & Nelson 1990:14)

The type of situation in which a barrier is used dictates to a large extent which materials are used (as discussed in section 2.3.4 and 2.3.5). If sensitive receivers are only located on one side of a carriageway, then the most appropriate means of mitigation is through the use of a reflective barrier. However, if there were sensitive receivers on either side of a carriageway, then the most appropriate solution would be an absorptive barrier (See Figure 2.2).

2.3.6 A brief review of noise barrier form, properties and practical applications

Noise barriers can be made from many different materials and take many different forms. The most commonly used barriers are generally constructed of one of the following; concrete, earth, wood, brick or masonry units, metal, vegetation, mineral aggregates, plastic, glass or composites of these materials. Using these materials barriers can be produced in a variety of shapes and sizes, and each material has specific characteristics that make it suitable for particular noise situations (Transafety 1997). The literature on different barrier systems has been reviewed by Watts, where he grouped the barriers as reflective, absorptive, capped, double, longitudinal profile, angled, dispersive, vegetative, covers, embankments and earth mounds (Watts 1992).

Considerable research has been carried out to refine the design of barrier tops to maximise the attenuation through diffraction. The beneficial effects of additional diffracting edges have been demonstrated with fir tree profiles, tubular profiles T-profiles, Y-profiles, arrow-profiles, branched barriers and U-sections which involve extra panels connected to the main screen by brackets. These methods are extensively reviewed in Kang (In Press). In addition, the impact of 'fancy' barrier tops has been investigated by, Ishizuka & Fujiwara (2002) and Horoshenkov et al (2003). Their findings on the insertion loss of a noise barrier adjacent to a high-speed railway showed that although the insertion loss can be beneficially affected during some parts of the pass-by, the fluctuations of insertion loss during the pass-by could actually create a perceived negative effect (Horoshenkov, et al. 2003). Therefore, caution was advised when deciding on their use. The subjective impact of barrier types could be further analysed with regard to the aesthetic appeal and visual fusion with the surroundings of unusual barrier tops. Although this is beyond the context of this research, it nonetheless raises interesting questions.

2.3.7 Noise barriers: An overview of their application in the UK

The principle has long since been adopted in the UK when constructing new highways, to increase bank sides close to residences and to use traditional timber fences. These two solutions although appropriate in terms of cost, land take and availability for many schemes, are chosen more out of habit rather than for their superior benefits.

The actual industry of noise barrier production has only relatively recently developed into a specific science. The growth in the use of noise barriers across Europe, the USA, Australia and the Far East, reflects the growing concern of the general public about noise pollution caused by infrastructure projects, in particular roads and railways. Compared with the UK, noise barriers in countries such as Germany, the Netherlands and France, form a greater part of the urban and semi rural landscape, and have done so for several decades (Kotzen & English 1999).

There are several different reasons why the development of noise barriers in the UK has been less ambitious and extensive than in other European Countries. Some of the main reasons have been:

- The effects of the Land Compensation Act, as endorsed with the Noise Insulation Regulations, which encourages the use of noise mitigation in the form largely of double-glazing on affected properties.
- The varying targets for community noise levels between nations within the EU.
- The lack of programs to reduce noise on existing roads in the UK (Kotzen and English 1999)

Although the last point is still largely true with respect to legislatively driven programs, some more voluntary based methods are emerging as the Highways Agency are now committed under the ten-year plan to role out a program of improvements (DETR 2000:10). This has been organised using a method of prioritisation known as 'sift studies'. This is a rudimentary method of assessing large sections of the trunk road network using simplistic methodology, which highlights potential hot spots. These are then put forward for further detailed studies, from which viable remediation measures can be instigated including the use of noise barriers and low noise surfacing.

Unfortunately, despite these moves to improve the acoustic environment of many more people, without a legally binding maximum environmental noise level, the opportunity to introduce mitigation measures, such as barriers that also improve the aesthetic quality of an area, are being lost. This can only be attributed to financial constraints and lack of aspiration and vision to think more creatively.

2.3.8 A comparison of the UK situation with Europe

The use of noise barriers across Europe has not only been more extensive than that in the UK, but also with more emphasis on the architectural qualities that a noise barrier can bring. In most large conurbations throughout Europe a vast array of barrier types and forms can be observed. In fact, many European barriers are near 'works of art'. The use of colour, creative design, and a variety of materials makes European noise barriers artistic and 'aesthetically exciting components of their transportation system' (Transafety 1997:4), with their use being seen as a means by which to give identity to an area and aesthetic value to the unitary landscape of motorways and large trunk roads (Bendsten and Schou 1991; Highways Agency 1995a; Highways Agency 1995b; Highways Agency 1999; Kotzen and English 1999).

In the UK it is rare that an alternative to either an earth bund or a close board timber noise fence is considered when the need for a noise barrier is identified on a major public highway. This is largely due to economic constraints of such major projects. This is in contrast with the situation in Europe, where the opportunity to erect a noise barrier is often taken as a chance to create a piece of aesthetically pleasing street furniture, giving identity and visual context to an area, or even to design a module which is multifaceted, such as those incorporating photovoltaic technology (Bellucci, et al. 2003; Bote, et al. 2003; Erge, et al. 2003).

The problem with the UK's lack of imagination when it comes to noise barrier design is confounded by the population dispersion in and around cities in the UK. It is an unfortunate fact that, whereas in most mainland European cities generally there is a spread of the population within the urban centres and close to the main transportation networks, in the UK it is largely the economically, and socially deprived that live in such locations. Although they are protected by the same laws as the rest of society, they are often less likely to be vociferous in planning matters (Joynt 2002). However, the tide is turning with more concentration on development of inner-city areas and an increased awareness of the importance of both public health and the aesthetics of public space to ensure the success of an area (Environmental Protection Department 2001).

2.3.9 Environmental properties of materials used in noise barriers their source, properties and impacts

The type of materials used can also be influenced by the location of the barrier. Ideally, the use of local materials will keep transportation costs down. However, with respect to environmental costs, this is not widely recognised as a deciding factor. Moreover, as the drive for sustainable practices in construction is pushed forward, it is felt that the importance of embodied energy and environmental impacts of noise barriers will increase. To illustrate this, some of the main materials used in noise barriers are explored below, in terms of their application and environmental impact.

2.3.9.1 Timber barriers

Timber is the most commonly used noise barrier material in the UK. The barriers are designed as either reflective or absorbent. Absorbency is achieved through the addition of an internal absorbent core. Despite the material's popularity, the design of timber barriers has never progressed much beyond the 'garden fence stage' (Kotzen and English 1999:106), which can lead to a mundane roadside landscape for motorists and adjacent residents alike.

Apart from the favourable cost implications of using timber, it is also relatively low maintenance, which adds to its desirability. Timbers lifespan with the application of preservatives on the wood prior to assembly can allow the barriers to last for between 20-40 years[1].

Despite timber's organic source, it does still have significant environmental impacts associated with its transformation into noise barriers. In the UK timber production measures some 4,301,956m3 or 3,519,000 green tonnes, which equates to about 70% of total use (BRE 2000). The remainder is sourced from North America, Canada and Northern Europe, where the greatest contribution to its embodied energy levels occur during transportation from the forest to the timber mills, with transporting materials being responsible for around 25% of the acid deposition and toxicity to air and 50% of eutrophication (BRE 2000:14).

However, the main source of environmentally degrading materials used in the processing of softwoods is the essential preservation treatments. These range from least to worst damaging as follows; borates, quaternary ammonium compounds, zinc soaps, azoles, chromium copper boron (CCB), zinc copper fluoride (ZCF) chromium copper arsenic (CCA), improsol (bifluoride), creosote oil (Thermie Program 1999:115).

Beneficially, the Forest Stewardship Council (FSC) has raised awareness of sustainable forestry and consequently the UK timber importers now insist on deriving their timber from FSC accredited forests. Thereby, if the actual aesthetic design of timber barriers was improved, the relative benefits of this material including its end of life recycling potential, would make it a desirable product.

[1] Source- literature from the following UK registered companies (2003); Burn Fencing Ltd, Buffalo Structures, Gramm Barrier Systems and Charles Ransfords Ltd.

Figure 2.3 (a): Timber noise barrier

(b) Horizontal noise barrier

2.3.9.2 Concrete barriers

Concrete barriers can be either reflective or absorptive. Unlike timber, the absorptive element is applied on the face of the barrier by cementing materials, such as wood fibre, to the solid structure. Concrete can be both precast and delivered to site assembled or partially assembled, or it can be developed 'in-situ' (Kotzen and English 1999). It offers good structural and insulation qualities and good durability.

Most concrete barriers utilise I-column posts set within or bolted onto concrete foundations. To ensure the most effective noise mitigation, rubber seals are often placed between any separate panels to stop leakage of noise. Of all the barrier materials, concrete offers the least maintenance solution due to its structural strength and stability. Most concrete barriers are given a minimum lifespan of 40 years[1].

The environmental impact of using concrete is, however, considerable. The concrete blocks consume large amounts of energy; accounting for 2.6% of UK carbon dioxide emissions in production and being a major user of aggregates and cement (Parrott 2002).

Concrete's aesthetic appeal is questionable if it is used as basic solid blocks, which can create a hard and intrusive corridor next to a main road. However, concrete is versatile and can be produced in a variety of colours and cast into a variety of shapes, which can improve its aesthetic appeal. An even more effective means of softening a hard concrete structure is through the addition of planters to grow low maintenance shrubs. This is a popular option in many European cities (Kotzen and English 1999).

[1] Source- literature from the following UK registered companies (2003); Gramm Barrier Systems, ARC Concrete Ltd and Borall Edenhall Concrete Products.

Figure 2.4 (a) Concrete barrier

(Source: Fenco Australia)

(b) Precast concrete barrier

(Source: FHWA)

2.3.9.3 Metal barriers

Metal barriers are becoming increasingly popular in the UK, particularly over bridges and in areas where wind loading and weight pose considerable problems. The two main metals used are aluminium and steel and both come as reflective or absorbent barriers.

The absorptive element works on a similar principle to that of timber and plastics, with the roadside face of the barrier containing small perforations allowing sound energy into the absorbent core. The minimum replacement period for metal barriers are 30 years and 20-25 years for aluminium and steel, respectively, although the ongoing maintenance of such barriers, especially non-galvanised steel, is considerably more than that for concrete barriers as they require re-painting, (especially when they are positioned close to the coast).

The environmental impacts of the use of metal in noise barriers are considerable, for example, aluminium production uses 26 times as much energy as timber production. Both steel and aluminium production are highly energy intensive and with the latter only 10 per cent of the extracted material is used. However, whilst steel and aluminium do take a great deal of energy to produce, they are rarely used as a mass material and are instead used in carefully sized sections. The impacts of these metals is further reduced by the ease and opportunities to recycle them, illustrating how materials cannot be judged on one criterion alone.

Figure 2.5(a) Steel noise barrier

(Source: FHWA).

(b) Aluminium noise barrier

(Source: FHWA).

<u>*2.3.9.4 Glass barriers*</u>

The use of glass as a reflective noise barrier material is relatively rare in the UK. However, there have been some examples, especially on new infrastructure projects such as the London Docklands Light Railway, where it has been incorporated effectively (Kotzen and English 1999).

Its benefits are its flexibility and its transparency, giving an alternative to the impenetrable effects of most barrier materials. Its use in motorway corridors, to stop feelings of enclosure by motorists and to prevent visual severance for residents, can be very effective. The maintenance of glass, however, is quite high, with financial and practical implications imposed from the need to keep the glass clean. However, self cleaning varieties are now emerging on the market which stop the attraction of dirt and grit and wash clean after rainfall (Edwards 1999). The risk of frequent replacement is accelerated due its susceptibility to accidental damage and vandals, and so toughened glass is a minimum requirement for its use.

The embodied energy and environmental impacts of glass manufacture are also high, not least for the extraction of the composite materials and high production temperatures, but also due to the limited number of UK suppliers producing glass on the scale for noise barrier development, with one company site holding an 85% market share in the UK. Glass has many benefits, in particular, passive solar energy gain that can be utilised in a noise barrier. Efforts are now being made to harness this asset through the development of transparent photovoltaic panels (Bellucci, et al. 2003; Bote, et al. 2003; Erge, et al. 2003; Schirone and Bellucci 2003). The use of transparent materials will remain appropriate in some situations, and increasingly glass is being incorporated with other materials to break up the solid block of a noise barrier.

Figure 2.6(a) Danish Glass Barrier
(Source: Danish Design Access) [1]

(b) Toughened Glass Barrier
(Source: Fenco, Australia.) [2]

1 http://www.ddc.dk
2 http://www.fenco.com.au/

2.3.9.5 Alternative transparent materials for barriers

An alternative to glass, which has been widely developed in Europe and the Far East, is transparent plastic. This can take the form of Acrylic, Polycarbonate, Clear Polyvinyl Chloride and Polymethyl Methacrylate (PMMA) (Whittle 2003). The latter (PMMA) is the most popularly used for noise barriers; commercially known as Plexiglas it has the same visual benefits as glass allowing free view out of a transport corridor without encroaching on any adjacent residents' acoustic environment in addition to the preservation of any views (Kotzen & English 1999)

Transparent plastic is also much more vandal resistant than glass and as a consequence its lifetime before replacement is between 20-25 years3. In addition, it does not suffer from the same problem of opacity over time. However, it does need periodic cleaning and this can pose a problem of access similar to that posed using metals.

Although the original production of any plastic, including PMMA, is both energy intensive and hazardous with regard to toxins, its potential for recycling and the integration of recycled products during generation reduces the overall environmental impact.

In addition, the main producers providing PMMA to the barrier market facilitate a full end of life collection and recycling program, which it is claimed, can be carried out with almost 100% recovery, which makes this material unique in the barrier market.

2.3.9.6 Plastic barriers

Plastic can be used in both reflective and absorptive noise barriers, using the same principle as the metal/ timber noise barriers of having an internal absorbent core, such as mineral wool. They are not as common throughout the UK, despite their high strength to weight ratios, good chemical and thermal resistance and low toxicity.

Plastic has relatively low maintenance needs throughout its life-cycle, with the exception of occasional cleaning. Its lifetime, however, is shorter than that of other barrier materials, lasting from between 20-25 years before needing full replacement. The impact and most prominent feature of plastic is usually the unusual forms and colours it can take. This can lead to its use as an architectural feature, examples of which can be seen widely in European cities and cities of

[3] Source- literature from the following UK/ German registered companies (2003); Gramm Barrier Systems, UK, and Parachemie, Germany.

the Far East (Kotzen and English 1999). However, with exposure to the elements and direct sunlight plastics can fade, consequently loosing some of the intended impact.

The environmental impacts and embodied energy caused by plastic production are relatively high, as they are generally produced from non-renewable materials (mainly oil products). In addition, plastics are difficult to dispose of, except by landfill site (Edwards 1999). Recycling of plastics is possible and its use in noise barriers is beginning to become more widespread. Examples of these can be seen in Australia. However, as plastic recycling increases and these materials become more competitively priced, versatile and robust, it is likely they will be more widely used (Kotzen and English 1999:119).

Figure 2.7 Plastic Noise Barrier
(Source: Federal Highways Agency; FHWA).

<u>*2.3.9.7 Brick barriers*</u>

Bricks are often used to construct masonry barriers, as they fit in with vernacular architecture. Solid bricks are used to construct reflective barriers, whereas perforated bricks are used for sound absorptive barriers. Either solution generally creates the impression of a conventional brick wall (Kotzen and English 1999:117). However, they offer advantages having an attractive and durable low maintenance finish, which can outlast all other noise barrier materials in terms of lifespan (Edwards 1999;).

Bricks have major environmental impacts; the raw material for production involves large land losses from agriculture (though the used clay pits are often utilised for leisure purposes and provide useful wildlife habitats). The baking of bricks consumes large amounts of energy, and transportation to the site takes further fossil fuels (Rigg 2000:43-46).

Increasingly, however, bricks are being recycled. This is not only possible with bricks that were previously bonded together with a soft lime mortar, however it remains very difficult with bricks joined with stronger modern cement mortars as they tend to crack when deconstructed (Vale and Vale 1991:42).

Figure 2.8 (a) Brick Noise Barrier. *(Source: FHWA).*

(b) Brick Noise Barrier *(Source: FHWA).*

<u>*2.3.9.8 Alternative bio- materials*</u>

Alternative biomaterials are now increasingly being developed in particular by incorporating planting; or as a complete plant structure used as a noise barrier. The use of willow both as a living barrier and through the weaving of dead willow branches has grown in popularity as a green alternative.

An example of this new concept in green barriers is that of a soil bank held together with a framework of willow cuttings, which sprout to form a hedge. Obviously these sorts of barriers are invariably absorptive. However, there are two general ways of giving the barrier its absorptive properties. A description of the construction of these barriers is stated below.

For a living willow barrier the wall is erected in stages with willow uprights supporting a basket weave of willow on the outside and soil inside. Cross members hold the two sides together. A second layer is established on top and so on until the desired height is achieved. An irrigation system is buried within the soil to ensure a growth of willow, which is usually achieved within three months of planting[1].

The noise attenuation of such a design can achieve nearly twice the protection of that of a simple earth bund of similar height. Where noise levels are high frequency and emitted from a

[1] http://www.etsluk.com/index.htm.

point source rather than a line source then the effects can be even more dramatic (Johnston and Newton 1993).

The other forms of willow barriers are those with an inner core of mineral wool. In the UK there are two varieties of these types of barriers. These use weaved (dead) willow, and living willow, (as explained previously) with the substitution of the soil bank for mineral wool.

The maintenance of these barrier types is however very high. The living barriers will need regular trimming and protection against disease, as well as servicing of the irrigation system. The dead willow barriers take slightly less maintenance than their live counterparts, but relative to the main noise barrier materials, this is still very high. The lifespan of these barrier types however is comparatively similar to some of the inorganic types above, lasting up to 25 years before needing replacement.

Again, the level of the material's sustainability must also be judged by its durability and its use after its lifetime is complete. Willow is increasingly seen as an alternative crop by farmers to subsidise their income. Thus, in that respect it is replanted and therefore renewed and sustainable. The transportation, which would incur the release of CO_2, can be justified in that the willow will remain a living crop, actively harnessing CO_2 from the atmosphere. As for the dead willow the amount of CO_2 sequestered during it's lifetime can justify that released after it is decommissioned. When soil is used as the inner core of the barrier, the actual negative environmental impacts are negligible. However, with the use of mineral wool these impacts increase significantly.

Despite their obvious benefits it is widely accepted that a noise barrier should blend into its surroundings as effectively as possible. Although greening of cities is desirable, in some quarters it would look out of place. Here designers tend towards more abstract designs or the use of harder, more industrial materials.

Figure 2.9 (a) Woven willow barrier. *(b) Living willow barrier.*

(Source: ETS Environmental Technology and Sustainability)

2.4. Sustainability in the noise barrier planning & design process

2.4.1. The concept of sustainability and sustainable architecture

A brief overview of the relative sustainability of some common barrier materials is discussed above. This section of the literature review explores the growing importance of sustainable development through the exploration of the current situation in the wider architectural and construction fields, as well as related to the more specific field of the environmentally sensitive design of noise barriers. This area is currently relatively small by comparison to the wider architectural and construction fields. However, there are specific examples of new developments, which use sustainable construction as the most important factor in noise barrier design.

The central link of this review is related to the wider thesis aim of devising 'a sustainable approach to noise barrier design'. This covers a multi-disciplinary spectrum, which must include sustainable development. Sustainable development is increasingly becoming a concept that is being integrated as cost-effective, environmentally-sound and socially acceptable means of developing. Some see this term as an oxymoron in that 'development' by its nature uses more than it returns, and can therefore never be sustainable (Gray 1993:280-283; Ulrich Von 1994:8-9; Eckersley 1997:37). However, sustainable development gives us the opportunity to explore the means of having a minimum impact on the wider environment whilst, still growing in economic and social terms.

One of the greatest influences on the desirability of using sustainable architectural techniques in noise barrier design is that the noise barriers are there to protect specific residents from noise pollution. Which raises the problem, that despite the importance of providing localised protection to the public, it would be an unsustainable solution if the wider impacts of pollution stemming from unsustainable practices in barrier design should afflict the rest of society. This reflects the ethos of the whole sustainability concept defined in the Bruntland Report (1987).

The Bruntland Report (1987), although largely criticised due its various and often conflicting interpretations, still remains the blue print for sustainable development worldwide (Ulrich Von 1994). It is defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' Bruntland Report (1987:1). Therefore, any development undertaken today should enlist the best available techniques to increase energy efficiency, use renewable resources, and recycle non renewable resources where an alternative cannot be found to protect the atmosphere and environment that human life and wider biodiversity depend upon.

Western architects, in more recent years, have increasingly realised that they are not immune or separate from the environment, and that they are dependant and responsible for the resources they build with (Vale and Vale 1991). In the creation and management of buildings and other structures structural engineers can participate in reducing global impacts through:

- Understanding the effects of structural engineering decisions on global warming, acid rain, ozone generation and resource depletion
- Choosing a built form and orientation that contribute to environmental economies and future adaptability, flexibility of use and reuse
- Selecting structural materials and systems with low embodied energy and easy reuse
- Selecting construction methods that minimise the effects of construction and deconstruction in terms of land take, waste and pollution (The Institute of Structural Engineers 1999:10)

Consequently, moves to more traditional and passive methods of construction, as seen in many Eastern and less economically developed regions of the world, are being explored. No construction is ever benign in its effects on the environment, as extraction, processing and transportation are still inevitable. However, by insisting on sustainable development the consideration of ecological costs as equal to economic ones can ensure that these effects are minimised.

2.4.2 Measures for the development of sustainable architecture in the UK

Although it is difficult to legislate for environmentally benign actions on the grounds of some ill-defined objective like 'the good of mankind', attempts have been made in the UK using the following strategy, known as 'A Better Quality of Life, A Strategy for Sustainable Development for the UK'(1999). This encapsulates the principles of the Bruntland report and emphasises the importance of acknowledgement of all humanity's basic human rights with the following objectives:

Social progress, which recognises the needs of everyone. Effective protection, prudent use of natural resources and maintenance of high and stable levels of economic growth and development (DETR 1999:1). To achieve these goals, however, more specific pieces of legislation ensure the objectives are attainable. An example of some of the European legislation currently encouraging this is the Eco-labelling (Directive 94/2/EEC), Construction Products (Directive 93/5068/EEC) or the banning of chlorofluorocarbons (CFCs) (594/91/R). Hence, practice in the UK and Europe is highly regulated from an environmental perspective. However, is not always at the level required for sustainable construction.

In Britain, buildings and construction have a major impact upon the use of vital resources, being responsible for 50% of energy use and 50% of consumption of all resources across the planet, 50% of ozone-layer depleting chemicals (CFC's, HFC's etc), 50% of raw materials used by industry and water, in addition to 80% of land lost to agricultural production (The Institute of Structural Engineers 1999:44) These statistics helps to establish the framework for action, and the immediacy of the problem within the UK construction industry, and the political or intuitional sensitivity to solutions (Edwards 1999; Edwards and Hyett 2002).

2.4.3 The method of calculating the sustainability of a product

Evaluating the true environmental impact and sustainable character of a process, takes an holistic approach. This is known as the 'Life-cycle Assessment'. The definition of this is 'the method of assessing the total 'environmental aspect' of that product, from design to disposal'(The Royal Society of Chemistry 1998:3). The term "environmental aspect" is used in order to cover both beneficial and adverse impacts on the environment. Figure 2.10 below illustrates the process of life-cycle assessment using a flow diagram.

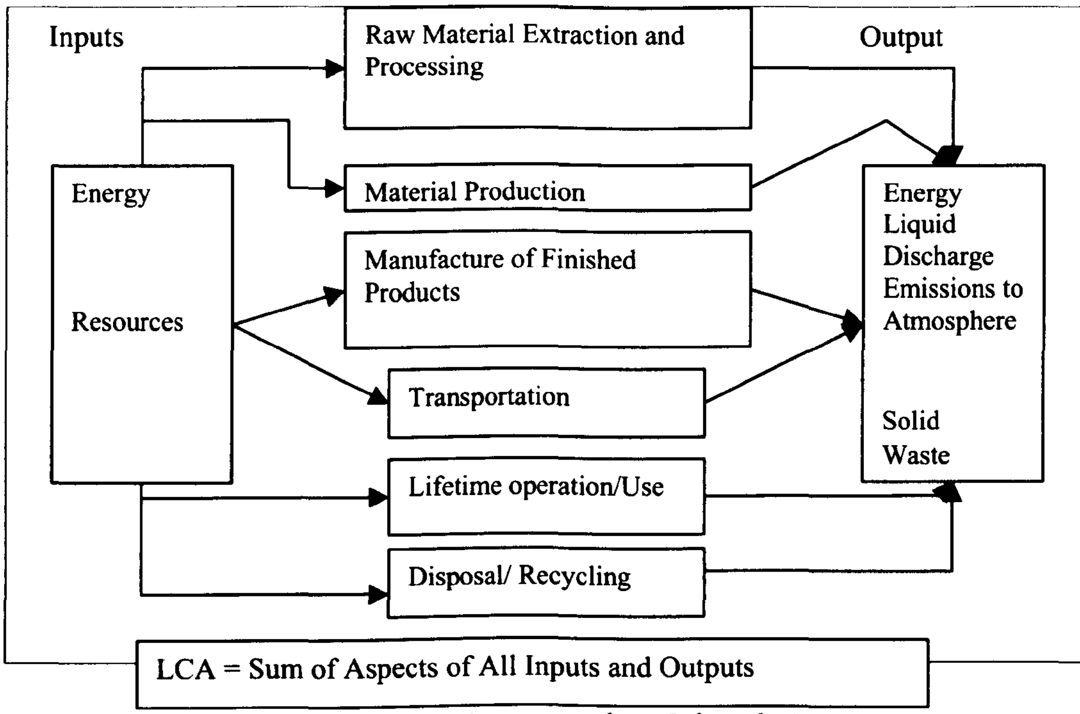

Figure 2.10.Flow Chart for the processes incorporated in a Life-cycle Assessment.
(The Royal Society of Chemistry 1998:2

As Figure 2.10 illustrates, the embodied energy and environmental impacts are those 'built in' to a structure over the complete life-cycle. There is no definition for embodied energy in the ISO Standards. However, the generally accepted definition is one that was produced by the International Federation of Institutes of Advanced Studies (IFIAS) in 1974: 'the total primary energy that has to be sequestered from a stock within the earth in order to produce a product or service'(Chapman and Roberts 1983 cited in Howard, et al. 1999:24).

Thereby, the embodied energy of a material would briefly entail the energy it took to extract it in its raw form, to process the raw material into a useable material, to transport that material to the construction site, to construct the material in to a structure, to maintain the structure and repair it during its life time, and then to dispose of it at the end of the life-cycle. At each stage of the processing, energy is used. Therefore, the calculation of life-cycle or embodied energy figures for construction cannot be carried out without knowing the background to energy production and use in the UK.

If these environmental costs were, in fact, financial costs then the value of the total cost from beginning to end of its production could be calculated relatively easily, as financial costs are tangible. With environmental embodied costs this calculation is more profound, as with each part of the process it can be presumed that energy will have to be used, usually in the form of the burning of fossil fuels. With every tonne of oil equivalent of energy used, there is an associated release of carbon dioxide, and with this an associated risk of global warming. Any recycling or recovery operations built into the life-cycle should lead to a proportionate reduction in the adverse environmental impact (The Royal Society of Chemistry 1998).

However, the price of global warming has no agreed quantifiable amount. In addition, many processes release pollutants, or use finite resources. Some have greater transportation related pollutants and this may vary from material to material. Consequently, another subjective judgement has to be considered in the final life-cycle assessment, that of which detrimental effect is more acceptable than the next.

2.4.4 Basic methods for assessing environmental impacts

As a rough guide, the energy intensiveness of a construction material will act as a guide to its 'greenness'. The energy content of a material is clearly connected to its closeness to the earth; the more it is refined, the more energy it contains. To judge the energy content of any construction would require the detailed calculation of the weights of materials used in conjunction with their energy contents (Vale and Vale 1991:41).

Another concept used within the literature is 'environmental footprints', Wackernagel and Rees (1996) whom coined the term, argue that the sustainability of one individual country can be viewed in terms of the aggregate (global) land area required to meet the needs of its population. These needs can be expressed in a number of ways, such as the land area required to satisfy nutritional requirements, or by converting fossil energy into the land area required to grow the equivalent bio-fuel (or some amalgam of the two). Thus, 'ecological footprint' analysis reflects biophysical reality; by revealing how much land is required to support any specified lifestyle indefinitely, the ecological footprint concept demonstrates the continuing material dependency of human beings on nature (Wackernagel & Rees1996: 223–248).

Within the smaller context of noise barrier development, the 'environmental footprint' would look at the geographical distances between the area materials originate from, and their location of use, and beyond that the continued environmental impacts until the material no longer caused a detrimental effect on the earth. A larger 'environmental footprint' can generally be considered to be less environmentally friendly, since it implies greater transportation costs.

At the opposite end of the impact scale, lies the concept of carbon neutrality. This idea does not account for other environmental pollutants other than carbon, which are produced during manufacturing. However, as currently the majority of embodied energy calculations consider only fossil fuel consumption, this seems an appropriate element to include. However, this should be done with some caution, as a material that does not use a large amount of energy in production may be deemed environmentally sustainable, despite its release of other pollutants during its processing.

The concept of carbon neutrality is developed on the theory that if vegetation is planted, this will absorb carbon as carbon dioxide from the atmosphere in equivalence to the amount produced in production, and then it can claim that it is carbon neutral. This is an interesting concept in the area of noise barrier production, as the planting of vegetation and the incorporation of vegetation in designs is seen as an aesthetic benefit to those the barrier is there to protect. It works well when breaking up the hard lines and often-dominating character of a noise barrier. An example of how planting can be incorporated into a noise barrier is illustrated in Figure 2.11.

Figure 2.11 Plywood barrier with planting (Source: FHWA)

2.4.5 Advanced methods for assessing environmental impacts using life-cycle models

The most effective means of assessing the impacts of a material from 'cradle to grave' is arguably to use a life-cycle assessment model. There are a variety of models that have been developed to calculate the impacts on the environment of manufacturing materials. These include Envest, which was the first UK software tool for estimating the life-cycle environmental impacts of a building from the early design stage. The first version of this was for office buildings, developed by the British Research Establishment (BRE). Other models include BEES (Building for Environmental and Economic Sustainability version 2:0 USA), FORNITEK (Forintek Canadian Corporation) and the Building Research Establishment Environmental Assessment Method (BREEAM). These provide guidance on ways of minimising the adverse effects of buildings on the local and global environments. Each of these models has a similar format, which includes a full life-cycle assessment of construction materials from 'cradle to grave'.

The outcome of the assessment is a certificate or label that enables owners or occupants to gain recognition for their building's environmental performance. However, the problem with the models available and presented here is that they are not appropriate for the use for structures other than buildings.

2.4.6 The use of models for the calculation of embodied energy in noise barriers

Through the review of the literature, it became apparent that with regard to quantifying the sustainability of materials used within the construction industry, all models were developed to assess the impacts of completed buildings. This makes the commercially available models irrelevant with respect to the development of noise barriers, as many of the issues faced by architects in the design of buildings are gone. This is due to the relative simplicity of a noise barrier design, and the lack of direct human contact that will occur with the construction once assembled.

Some aspects of building architecture that justify the use of materials which entail large environmental costs to produce, but once constructed have an element of 'pay back' in terms of energy gain through insulation, cannot be justified in the design of noise barriers. However, some basic needs of the materials such as strength, durability and attenuating properties are more keenly emphasised. Therefore, some of the principles of sustainable architecture used in buildings are relevant to noise barrier design whilst others are not.

With respect to noise barriers, the overall life-cycle is less than usual construction requirements. Most buildings are given an average life span of 60 years, whereas, a noise barrier of any material is required to remain serviceable for 40 years and require no maintenance for 20 years (Kotzen and English 1999:98). This factor must be accounted for when calculating the embodied financial and energy costs, as restoring and replacing damaged barriers has added inherent burdens.

Therefore, a material's durability and lifespan is as important in calculating the overall embodied energy and potential pollution output as its original energy consumption during development. In addition to this, the material's environmental sustainability can be improved if it is able to be further re-used or recycled at the end of its working life-cycle as a noise barrier. With the oncoming of legislation regarding the 'end of life' disposal of materials this will become an even greater factor than at present, especially as the barrier's life should span forty years, in which time it can be predicted with some confidence that disposal laws will be of even greater value. Therefore, many barrier manufacturers are pre-empting this global shift towards even greater environmental awareness and including this as part of the design criteria.

The importance of sustainability in the construction of noise barriers is further confounded by the wider desire to attain a good standard of living without compromising the environment. This mindset is not just the preserve of the academic and construction world, as the public are also becoming more environmentally conscious. The next section of this review investigates the importance of public participation and perception in many contexts related to noise barrier development.

2.5 Planning and public participation

2.5.1 The origin and application of public participation

The implications of excessive noise are clear, making the need for mitigation solutions even more desirable. However, often the subjective impacts of noise can be even more influential than the objective. Consequently, to ensure that people are not exposed to the risk of noise both objective (i.e. defined as detrimental to human well-being) and perceived (noise is a subjective opinion of an unwanted sound), the mitigation measures must be the most appropriate that they can be. Precision planning of the solutions and the integration of the affected public into the design process is the only means by which this can be achieved.

Participation in building and planning can be traced to pre-literate societies i.e. before design professionals existed. However, community participation is of more recent origin. It is commonly associated with the idea of involving local people in social development. The most important influences derive from the third-world community development movement of the 1950s and 1960s, Western social work, and community radicalism (Midgley 1986, Cited in Sanoff 1999:1)

As a policy issue in political debate, participation gained prominence in the 1960s in Britain and in other Western Democracies. Two factors are often identified as underlying the rise of participation to the status of political slogan. First, the post-war increase in material standards had, it was argued, created the conditions for a new political activism based on post-materialist values. Second, the expansion of the activities of the state had created a wider context for a range of citizen demands and protests. As a result, local government became caught up in these general trends (Hill 1970).

In the 1980s, a decline in public participation was due to a reliance on market forces to determine outcomes of consumer choice rather than citizen involvement and decision-making. The 1990s heralded the rise of a global public, which challenged traditional notions of sovereignty and the boundaries of politics. Curtice et al (1995:67), (cited in Stoker, 2000:158) concluded 'British people have clearly become less trusting of their politicians and political institutions in the last two decades. They are also more sceptical about the ability of the system to respond to the demands of the citizenry'.

Current community participation theory, suggests that politicians and bureaucrats have exploited ordinary people and that such people have been excluded from the community development process. The emergence of the community participation theory as an approach to social development is an outgrowth of the United Nations popular participation program that required the creation of opportunities for all people to be politically involved and share in the development process (Sanoff 2000:1).

In 1979, Richard Gutch stated that; 'Local Authorities are required by statute to undertake planning participation, and are required to provide the Secretary of State for the Environment with a full statement of the steps they have taken to involve the public and the manner in which the publics' views have been taken into account in preparing the plan. At no point are local authorities required to say why they have involved the public' (Gutch 1979:3).

In Britain, public protest to road construction and housing demolition played an important role in securing the Housing Act, 1969. This took a tentative step towards participation, demanding that 'people be consulted before rather than after final plans' (Hamdi 1995, Cited in Day. & Parnell, 2003:4)

Over twenty years later the purpose of public participation is still a contentious issue. However, clearer goals have been developed through the introduction of concepts such as Local Agenda 21, the subdivision of the Agenda 21 initiative, established in 1992, at the UN Conference on Environment and Development ('the Earth Summit') in Rio. The key to Local Agenda 21- and what makes it more than a collection of environmental initiatives at local level - is the ideal of local authorities actively involving the local community in working together towards sustainable development.

The Local Agenda 21 Initiative has been consolidated in the UK under the guidance developed in 1999; 'A better quality of life: a strategy for sustainable development for the UK' (DETR, May 1999). As superseded with the new UK Government Strategy, 'Securing the future - delivering UK sustainable development strategy' (DEFRA, March 2005).

The initial and subsequent Strategy looked at the objectives and priorities for sustainable development and tools to bring it about. The former highlighted the need for a themed approach, identifying challenges and priorities in terms of a sustainable economy, sustainable community, and managing the environment and resources. In particular, emphasising the need to involve local communities in the decisions that will progress and benefit their surroundings. The subsequent report was issued to address shortfalls in the 1999 Strategy, and emphasised 5 key areas as critical to the achievement of sustainability targets. These 5 areas included-

1. Living within environmental limits
2. Ensuring a strong, healthy and just society
3. Achieving a sustainable economy
4. Promoting good governance
5. Using sound science responsibly (DEFRA, 2005: 4-5)

Both reports however, recognise the fact that public participation promotes social inclusion and cohesion in communities, which bring benefits to society as a whole. The strategies emphasise, that effective engagement by local authorities with local people should include opportunities to develop a strategic approach to delivering information to people, listening to them and entering into debate. The aim of the consultation will determine its nature, but could include public meetings, citizens' panels, focus groups and interactive websites.

Participation helps local residents to learn about and contribute to the management of their own communities. Participation assists in the identification of indigenous solutions, which may be the most immediate and effective way to address a problem.

The general reasoning behind the theory of public participation, as endorsed by leading proponents such as the World Health Organisation, UN International Children's Emergency Fund (UNICEF) and the United Nations, is a result of experience that has shown that without early involvement of the local community in planning, support for the resulting action recommendation is weak (Sanoff 1999:1). In addition, participation helps local residents to learn about and contribute to the management of their own communities. Participation assists in the identification of indigenous solutions, which may be the most effective way to address a problem.

Worldwide, popular theories of public participation have evolved from a consensus borne of governments, funding agencies, donors, and civil society actors including NGOs and multi-lateral agencies like the World Bank and the International Monetary Fund. These have realised that development cannot be sustainable and long lasting unless participation is made central to the development process. The two methods most widely related are, Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA). RRA was the first method to appear in third-world development actions and was devised as an answer to the disillusionment caused by the use of questionnaire surveys. These constituted the predominant way of conducting rural research. The disillusionment came due to their cumbersome and often ineffectual nature and the problems posed by their undertaking by largely illiterate societies.

Participatory methods were consequently ceased upon as they offered a means of involvement for all through the use of maps and diagrams for the illiterate and less articulate in society, which in addition to the usual tools of participation enabled them to depict their situations and devise methods for changing them. A number of participatory approaches with varying terminologies have since come into practice over a period of time. The RRA soon evolved into the Participatory Rural Appraisal (PRA), which started as a rural based solution as the name implies, but was also used in urban situations and other fields such as adult education, policy influencing and advocacy, along with organisation development (Kumar 2002).

Despite these different acronyms the underlying model remains the same, and although borne of rural appraisal often in countries with very deprived populations, has spread and is relevant to almost all societies.

2.5.2 Public participation and the environment

The origin of public participation in planning, arguably came from small rural communities, often reliant directly on the environment through subsistence farming, integrating with official bodies and gaining ownership in practice and policies directly impacting upon them (Drijver 1991). With the basic premise being, that the poor and marginalised people are capable of analysing their own realities and that they should be enabled to do so (Zanen and Groot. 1991).

These theories have however, also been rooted in the work of a prominent British academic, Dr Tony Gibson, formerly of the Neighbourhood Initiative Foundation. He is reported to have conceived the idea of using models and diagrams to aid planning involvement through the Planning for Real Technique, developed and piloted in the East End of Glasgow in 1977 (The Highland Council 2001:1). Therefore, the use of diagrams and models as a means for community interaction is questionable is now widely adopted and adapted to scenarios worldwide.

The undertaking of participatory methods since their conception in the UK, have largely been grassroots led, rather than from central government. Participatory 'planning for real' techniques have been adopted by bodies such as individual National Parks (Tewdwr-Jones and Thomas 1995), and more recently in the form of participatory actions on-line using the internet.
The University of Leeds has reported on a collaboration with the local authority of Kirklees, who used the internet for the village of Slaithwaite as a means of involving the public in a local planning issue (Carver 2002; Tress and Gunther 2002).

The move of public participation into the realms of local authority and government-backed programmes has been enabled largely through the development of schemes such as the Sure Start Scheme, introduced by the present government. Although not a specifically environmental motive, these schemes aim to benefit and improve the local environment of deprived areas by providing local services and improving social networks. They have also illustrated the depth of desire of people to become involved and gain ownership of both their environment and their future, which should encourage central government to take public participation seriously (Bixby and Horton 2004).

By far the most influential piece of legislation with regard to allowing public participation in environmental matters has stemmed from the UN Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters. This document was adopted on 25 June 1998 in the Danish city of Aarhus (Århus) at the Fourth Ministerial Conference in the "Environment for Europe" process. It entered into force on 30 October 2001, and was presented as Directive 2003/35/EC (European Parliament and of the Council 2003). The directive is split into three pillars as follows: The first, on public access to information, was implemented at Community level by the Directive on public access to environmental information. The second pillar, transposed by Directive 2003/35/EC, deals with public participation in environmental procedures. Finally, the third pillar relates to public access to justice in environmental matters.

The Århus Convention established a number of rights of the public (citizens and their associations) with regard to the environment. Public authorities (at national, regional or local level) are obliged to contribute to allowing these rights to become effective. The Convention provides for:
The right of everyone to receive environmental information that is held by public authorities ("access to environmental information"); including information on the state of the environment, policies or measures taken, or on the state of human health and safety where this can be affected by the state of the environment (European Council 2003:26).

Citizens are entitled to obtain this information within one month of the request and without having to say why they require it. In addition, public authorities are obliged, under the Convention, to actively disseminate environmental information in their possession (European Council 2003:27).

One of the key themes is the right to participate from an early stage in environmental decision-making, with the Directive stating that arrangements are to be made by public authorities to enable citizens and environmental organisations to comment on. For example, proposals for projects affecting the environment, or plans and programmes relating to the environment. With these comments to be taken into due account in decision-making, and information to be provided on the final decisions and the reasons for it ("public participation in environmental decision-making") (European Council 2003:28).

The Directive enables the public to enforce these rights with the option to challenge, in a court of law, public decisions that have been made without respecting the two aforementioned rights or environmental law in general ("access to justice"). For the sake of consistency, the European Community proposes to apply the provisions of the Convention on the access to information, public participation in decision-making and access to justice in environmental matters, to its own institutions and bodies (European Council 2003:28).

The Community signed the Convention in 1998 and recently proposed that it be applied, in the UK. The deadline for the implementation of this directive is 25 June 2005 and the current government have reportedly said, "The government wants to encourage more public participation in environmental decision-making, to increase accountability and transparency and to help raise awareness of environmental issues". Government, local councils and other public bodies regularly take decisions which can have a significant effect on the environment and on people's health and well-being, decision makers need to let the public express opinions and concerns, and take account of those" (DEFRA 2004:4).

These are all encouraging steps in the goal of greater public involvement in decision-making and design and the relevance of this directive to the current climate of greater environmental awareness and accountability is admirable. The challenge, however, is to implement these ideas into real world scenarios, dictated by budgets and timescales and ensuring that such measures are not just paid lip service to, but actually fully involve all interested parties.

2.5.3 Sustainability and the importance of social inclusion in public participation

There are two main potential barriers to effective public participation, one that is directly related to the 'experts' (or any official body required to undertake public participation as a result of good practise guidance). Whereby, the repercussions of using a participation process as a patriarchal one-way flow of information, from the 'experts' to the 'lay persons', or the dominant to the subordinate, interested parties in a development is not fully recognised. Whilst the second potential barrier stems from the non-expert persons themselves (Glicken, J. 2001).

The fundamental aspects of sustainable development in the context of participation are described below. In addition to an explanation of the reasons why firstly a lack of full consideration for participation can lead to the reduction in a projects sustainability and secondly the reasons why 'lay' persons may be restricted by barriers to participation. These barriers can both lead to social exclusion and also be as a result of being socially excluded.

The need to balance environmental, social and economic objectives is a prominent and recurring challenge across all areas of government policy. Equally challenging however is the need to balance the competing priorities and practical dilemmas that arise from the simultaneous pursuit of economic growth, environmental protection and social progress. The concept of sustainable development is founded on themes of public participation and access to information. It is therefore a fundamental contradiction to the principles of sustainable development to believe that it can be achieved without improved social equity and social progress (Eames and Adebowale 2002: 4).

Despite the acknowledgement of this factor by many public bodies the reality of economic constraints still determine the level to which public participation can be fully inclusive. This 'environment-economy' framing is still all too often evident in both decision-making processes and sustainable development issues, leaving multiple gaps in our understanding of the conflicts and synergies between social inclusion and the environmental and economic components of sustainable development (Eames and Adebowale 2002: 5).

Therefore, for a project to be sustainable, the pertinent policies must recognise that more facets than the pure environmental protection versus economic growth argument need to be considered and that social inclusion is a fundamental factor in this.

It is important to recognise at the outset that those who do not participate in the political life of their communities are not a homogenous group. Within this wider group there are (at least) four categories of people. First those who are formally excluded from citizenship rights and who are therefore debarred from having any kind of political voice. Examples of which include asylum seekers. Second, there are those people who would participate but who are effectively excluded as a result of their personal characteristics or situation. People with disabilities who are unable to attend meetings or read communications or those with caring responsibilities who may be said to be excluded from participating by external factors(Percy-smith 2000:150-1; Turok 1999).

There are two other categories of people who exclude themselves. In the first of these two cases are those people who do not participate as a conscious choice; for whom, in other words non-participation is a political act. This might be for a number of reasons such as a belief that they do not have an effective voice or that there is no real choice. The other group who exclude themselves are those who do not participate, not as a result of a conscious decision, but because of one or more of a range of factors such as; lack of information, knowledge and understanding of the issues and the opportunities to participate or not feeling that have a stake in society and therefore the way decisions are made in it (Percy-smith 2000:150-1).

Recognising both why and who is socially excluded should therefore be a priority for public bodies. Social exclusion must not be accepted as an un-changeable reality, but should be addressed as a matter of incremental importance to ensure that a project is sustainable. Therefore, it is necessary in order that projects achieve sustainability that sufficient resources are allocated not just for tokenistic participation, whereby public bodies see their role purely as one of a provider but not accepter of information, but also to address the reasons why some members of the public may be excluded from participation procedures, and facilitate measures to address this problem.

2.5.4 Public participation in the design of noise barriers

Public participation was conceptualised into a 'ladder of participation' by Arnstein (1969). The ladder illustrated the varying levels to which the public are able to become involved in a planning process. The highest rung of the ladder (as illustrated in Figure 2.12), is that of 'Citizen Control', this implies that all of the power balance is shifted into the hands of the general public, who then inform the 'official bodies' on the best means of development.

Citizen Control	
Delegated Power	*Degrees of citizen power*
Partnership	
Placation	
Consultation	*Degrees of tokenism*
Informing	
Therapy	
Manipulation	*Non-participation*

Figure 2.12 Based Arnstein's 'Ladder of Participation' (1969)

In the context of noise barrier design full citizen control would neither be practical, nor beneficial to the end result due to the loss of specialist knowledge. However, at the other extreme both Non-participation and Tokenism in noise barrier design projects have been proved to hinder the eventual perceived benefits of a noise barrier as revealed in many studies including those undertaken by Hall (1980); Cohn (1981; 1982); Pendakur and Pyplacz, (1984) and Golding (1986).

In particular, public participation has been identified as an essential contributor by Kotzen & English (1999) who stated, ' A barrier should reduce noise to required levels, and be acceptable to the planning authorities, but to be truly successful, it must merit the approval of local inhabitants'. The approval of local inhabitants is based on many factors, including the perception of the aesthetic quality of a barrier. As if the wrong type of barrier is constructed for an area, it can degrade the landscape character and diminish landscape quality. It will inspire local animosity and social surveys have proven that where this is allowed to happen, the public perception on any acoustic benefit is noticeably reduced (Kotzen and English 1999:6).

These studies have shown that if there is some involvement, or using methods of involvement which could be described as 'tokenism', is undertaken, but the public are not fully incorporated into any decision-making and their participation is minimal, dissatisfaction may still result either on an acoustic or aesthetic basis, or both (Scire 1992). In the worst scenario, delays can occur or more costly solutions may have to be introduced. These can lead to public meetings and pressure groups and perhaps political involvement forcing projects to be delayed or even abandoned. This has been especially prevalent in the United States where objections to the development of a noise barrier in Oregon resulted in its removal at a substantial financial cost (Cohn 1981).

The largest problem with this phenomenon is the subjective opinion of noise. A noise barrier may be deemed effective with respect to its acoustic performance, but if the public it is designed to protect do not perceive this benefit, then the barrier is not only ineffective, but it will also cause even greater financial and environmental implications.

Two unresolved issues to this effect have happened recently in the UK and in New Zealand. The former was a barrier built and designed by the Highways Agency to protect residents in Yorkshire. Since its construction it has generated complaints that the noise has increased (RPS Plc 2005). Also a metal barrier constructed in Auckland, NZ has been strongly criticised by the residents it was built to protect (Orsman 2003). Findings of a recent report on the noise barrier in Yorkshire confirmed that the complaints were based purely on a perceived increase as the barrier itself was proven to reduce noise from the adjacent carriageway. With the substantial evidence in circulation with regard to the impact of ineffectual public participation on barrier acceptance, the possibility that this was a contributing factor cannot be overlooked.

In addition, there are other influencing factors, for example regional variations between rural and urban settings and also between different cultures. Askew (1998) and Md-Taha (1999) found that variations are not confined to preferences for rural against urban setting, but also varied between urban settings in one country to the next. Md-Taha (1999) reported that differences in culture, standard of living and climatic factors in Wales and Malaysia led to very different opinions on the satisfaction of different types of noise barriers.

It was in the 1980s that studies on effectiveness of noise barriers began to emerge. Effectiveness was shown to depend both on acoustics and aesthetic performance. It has also been established that community participation in the decision making processes for barriers is an important element in their aesthetic performance, confirmed by Hall (1980), Cohn (1981; 1982), Pendakur and Pyplacz (1984) and Golding (1986).

In a report to the UK Highways Agency, community participation was highlighted as being widely practiced in the Netherlands for selecting the most preferred type of barrier for a particular area (DOT, 1987). This participation by the public was also shown to be fundamental to selecting the very specific types of absorptive treatment for a noise barrier (Jae-Seek, 1992). Hall (1980) (another advocate of the benefits of participation) stressed the importance of public participation, especially during the project inception stage. This statement is supported by Cohn (1981a) who indicated that public involvement has to be initiated as early as possible in the design phase or at least during studies for the Environmental Impact Assessment – EIA to be effective.

The public should therefore participate at all stages to ensure the best possible result with the importance of the visual effects of a noise barrier. The role of the landscape architect, therefore, is equally as important as many other sectors. In fact, the overall approach to a noise barrier design should be multi-disciplinary and include other related personnel, such as, architects, planners, structural engineers and, of course, the public.

Herman et al (1993) endorsed this method, noting that this would help to ensure continuity in the development process. In addition, he proposed that attitude surveys should not be limited to the protected residents but should extend to the motorists as well. Indeed, motorists sometimes complain of loss of view or scenic vistas and a feeling of being "walled in" when travelling adjacent to barriers (FHWA 1995), in other words, they view the barrier as a backdrop to the road.

The nature of noise however, is that, it is those closest to its source that would benefit most from, not only mitigation measures, but also from an opportunity to influence those measures.
An option for identifying the most affected areas is that of noise mapping. Noise mapping is now being undertaken on a wide scale throughout Europe in line with DAMEN (Directive of the European Parliament 2000), the results of which will be used to identify specific receiving areas for consultation. This could be adopted to facilitate public participation by highlighting hot spots, and concentrating resources for public participation on specific areas. This release of resources could in turn lead to more specific solutions to the problems incurred when planning noise barriers, through participation. Areas of participation that need to be addressed include that of restrictions in language, which can prevent the incorporation of some community members and the restrictions that some potential participants face due to their disabilities, all of which could be overcome with careful planning of effective and inclusive participatory measures.

It is clear that a noise barrier, which does not provide any perceived reduction in noise to those directly, impacted upon by RTN, is worthless. Therefore, it must be accepted, that if influence on integration directly impacts upon perception of reduction, then for a barrier to work to its fullest capabilities, this issue should be treated as fundamental to noise barrier design and development. Therefore, as required in the Arthus convention public participation should be adopted at an early stage in the development of the project, and preferably be reported in an EIA. The results of any outcome of the participation should then be designed into the barrier and there should be a continual flow of information to and from the public, with regard to progress and for review and amendment.

2.6 Noise prediction through noise mapping as a tool for aiding planning

2.6.1 Micro and macro simulation

Noise prediction is the preferred method of calculating the severity of noise levels. This is achieved through the use of mathematical modelling tools and more recently computer technology. The physical act of noise measurement is still an invaluable tool to validate calculated and predicted levels. However, by using prediction methods, it is possible to achieve more extensive data on the noise environment, as it is more efficient than prolonged monitoring in the field.

The process of predicting noise can be separated into two categories, micro and macro simulation. The former, often using simulation techniques, is used largely in room acoustics and in small-scale areas, for example calculating accurately the sound field in a street where buildings densely flank the roads (Bullen and Fricke 1976; Davies 1978; Sergeev 1979; Oldham and Radwan 1994; Heutschi 1995; Wu and Kittinger 1995; Hothersall, et al. 1996; Kang 2000; Kang 2000c; Kang 2001). The simulation methods utilise a number of different modelling techniques, including image source methods, ray tracing, radiosity method, finite element (FEM) and the boundary element method (BEM).

The image source method and ray/beam-tracing are usually used if the building façades and the ground are acoustically smooth and thus geometrically reflective (Sergeev 1979; Oldham and Radwan 1994; Kang 1996). As the characteristics of street boundaries are important for acoustic simulation, and any existence of uneven surfaces increases the amount of diffusion reflections, an advanced technique for considering diffuse boundaries is necessary. Radiosity simulation is an advanced technique for considering diffuse boundaries. It was developed originally for the study of radiant heat transfer in simple configurations. With the rapid development of computing resources, the techniques have been developed continuously and used widely in computer graphics, lighting simulations, and then in both room and urban acoustics (Kang 2001).

Although these methods are not utilised within the context of broad environmental noise predictions for large infrastructure, their ability to predict noise levels is very useful in the context of urban planning of road canyons and urban squares.

2.6.2 Macro simulation- road traffic noise prediction methods

The macro-scale method is founded on commonly agreed empirical or semi-empirical principles, and depends on up to date software technology as well as hardware development. Based on this method, and with the fast development of computer technology, a number of noise mapping programmes have been developed, including Soundplan, CadnaA, IMMI and LIMA (from Germany), WS Atkins (from the UK), Mithra (from France). The advantage of the macro-scale method is its ability to calculate noise levels in relatively large areas with acceptable time and cost (Huang 2003).

The method used by the Department of Transport for the prediction of road traffic noise levels, and that preferred in this thesis, is that contained in the technical memorandum, 'Calculation of Road Traffic Noise Index (CRTN: 1988)'. The method was first published in 1976 and revised in 1988. It was formulated with the specific objective of providing a method of calculating entitlement of residential properties for sound insulation treatment as part of the Land Compensation Act 1973. Since its introduction, it has also been used to provide guidance on the prediction of noise in connection with the design and location of highways and other aspects of environmental planning. The method of calculation provides a series of charts and simple correction formulae, and was designed to be available to a wide range of users. Its aim was to provide accurate prediction in as many cases as possible, for both free-flowing and non-free flowing traffic (Tobutt & Nelson 1990).

With the development of new noise mapping software, the CRTN is now incorporated into computer programmes to give a visual map, which includes topographical data, as well as traffic flow data and building heights. Consequently, these techniques are now being developed extensively to predict impacts prior to the development of both highway infrastructure and proposals for new developments such as shopping complexes. The arguments for and against noise mapping are investigated more fully in section 2.6.2 below.

2.6.3 A critical review of the validity of noise mapping

The use of noise mapping is becoming more prevalent, with the whole of the UK currently being noise mapped in order to comply with recommendations made in the Governments adoption of the European Green Paper on 'Future Noise Policy' (1996) and the subsequent Rural White Paper; 'Our Countryside: the Future' (DEFRA 2000). This implementation has been done through the guidance entitled 'Towards a National Ambient Noise Strategy' (DEFRA 2001). Which is to be followed by the noise mapping of all transportation networks, and agglomerations with populations of above 250,000 and 100,000 respectively, through the ratification of the EU Directive on the Assessment of Environmental Noise (2000).

The main purpose of noise mapping is to predict and indicate the public response to long-term exposure to ambient noise levels. Thus, the long-term levels (source specific) are actually required that can then be used to estimate citizen reaction. For practical and economic reasons, noise maps are developed using calculations of noise emissions based in turn on a model of reality with various input data.

Noise mapping, by its very nature, cannot be relied upon independently from other noise prediction and calculation measures, but can be used as a constructive tool to gauge a situation. Indeed, debate has been raised in the 'acoustics community' over the increasing reliance on noise mapping for calculation purposes.

A letter published in the Acoustics Bulletin from Shield (2002) prompted a series of debates between opponents of the software (generally those who had no experience in using it) and supporters (mostly developers and users). In her letter, Shield expressed her concern at the way in which 'noise mapping has been accepted, apparently without question, by the acoustics community in the country'. She stated, that currently, the users of noise mapping software's were very unconcerned about accuracy, and provided no proof for claims that 'the predictions were accurate to within 2 or 3dB of measured levels (Huang 2003:18).

She suggested that a transparent method of quality control be established as a matter of urgency, and suggested that with relation to the necessity of noise mapping, the maps only mapped traffic on major urban roads, and that 'most experienced noise consultants could produce an accurate noise map if given a street map and a red pen'. With regard to the relationship between noise mapping and policymaking, she claimed that policy is currently being driven by noise mapping and that this was very evident in the recent consultation document 'Towards a National

Ambient Noise Policy' (DEFRA 2001), and claimed that a national strategy to deal with all sources of environmental noise should be developed independently of noise mapping, although accurate noise mapping could well contribute to the implementation of the strategy (Huang 2003:18).

Jopson (2002), from the Environmental Research and Consultancy, thought the points Shield made were 'particularly salient' and fully shared her concern at the absence of validation of the accuracy of noise mapping. He also questioned that 'if noise contours have been produced using a particular noise model/database, and new, (and inconsistent) contours are produced using a different modelling system. Which maps would be correct and which set of conditions or policies should take precedence?' (Huang 2003:18).

Manning (2002) endorsed Shields comments about the time required for acquisition and input of data, and criticised the tight government budget for producing the noise maps given the size of the task. He thought that efforts of experienced noise consultants with street maps and red pens could be further enhanced if consultation took place with the people who lived and worked in the vicinity, as well as the local planning and environmental officers who knew very well where the noise hot spots on their patch were. He also suggested that a 'transportation noise strategy' would be more practical than a national strategy to deal with all sources of environmental noise, which 'may be too wild a dream'(Huang 2003:19)..

However, some developers and users had totally different opinions on this issue. Tompsett (2002) from Atkins argued that software developers were always 'intensely' interested in accuracy and had spent much time on it. Furthermore, since the calculation is usually compared with a measurement rather than the 'real answer', 'a clear definition of accuracy is not obvious'. Responding to Shield's letter, he made the following points: in relation to accuracy, 'noise levels were pretty much as predicted and often stated the accuracy as a standard error of ±2dB (A) on façades exposed to traffic noise or a properly constructed noise model used within its design limits'. In relation to cost, £13m for a national noise map seems very modest compared with some typical budgets for Highways Agency, and 'for most of our design work covering scheme-sized areas, we expect a turnaround of minutes'; in relation to the necessity of noise mapping, 'Bridget's image of noise maps being conjured by experts with red pens did nothing to dispel the image of noise as a black art not susceptible to the laws of physics or capable of mathematical description' whereas the presentation of noise mapping can make politicians and the public better understand and treat the noise as a serious issue. He believed that noise mapping would provide a rational basis to policymaking and make solutions workable and affordable (Huang 2003:18).

Turner from Casella Stanger and Hinton from EC Working Group (Turner & Hinton 2002) argued that Bridget Shield made several valid points and highlighted the need for the profession to understand what contribution noise mapping can make, and its limitations. However, they insisted that noise mapping exercises were important and the relevant applications should be carried on in the UK.

They made the following points: noise mapping should be undertaken in the UK to comply with the requirements (2002/49/EC) of the Environmental Noise Directive (DAMEN). DEFRA is carrying out a wide-ranging study regarding the modelling process covering reproducibility, repeatability, verification and validation, which not only aimed to meet DAMEN requirements both technically and procedurally, but also to maximise the benefits for all. More importantly, the strategic noise maps would also provide a platform for further refinement and development through which investigations into the noise impact in specific areas might be undertaken (Huang 2003).

Due to the considerable argument and question about the validity of noise maps as discussed above. It is important that in order to answer the question of how accurate a noise map is, accuracy (or more "accurately", and overall uncertainty) must be defined (Manvell 2002). Consequently, it should be noted that noise mapping, or more specifically the noise contours defined by noise maps, should be taken as a range, rather than a specific value at a specific point. It should be noted that depending on the purpose for which a noise map is going to be used, it is not always necessary for actual measurements to agree with calculated data, but it can be generally useful if they are in the same range (Harsham and BP 2003:67).

Measurements, as can actual sound levels, tend to vary over a wide range, such that short-term measurements could be quite unrepresentative of long-term trends. At increasing distances from the source, there is additional variation over an increasingly wide range, attributable to changes in acoustic propagation conditions associated with diurnal (e.g. hour-by-hour) and daily differences in the local temperature and vector wind velocity profiles. Actual measurements are never more than samples of the long-term situation that is arguably more representative for planning purposes (Harsham and BP 2003:67).

Therefore, it is evident that, in both predictive modelling and actual measurements that significant error can influence the validity of the results. Thus, it is imperative in order to prevent the questioning of the validity of noise maps, that the data inputted into the noise mapping software is as free from error as is possible, and that calibration and validation are used as a means of standardising the results. It is agreed that the data entered into the software must be of an equal complexity and accuracy as the results are meant to represent. There are, however, limitations to complexity, in terms that calculation run times and costs can considerably increase if a more complex map is required (Wetzel and Meßsysteme 2001).

Moreover, as there is no current standardisation of the level of both, complexity and over simplification. The danger of not only less accurate results, but also inconsistency of results when incorporated with several maps on a large scale, for example that of the whole UK noise mapping proposal, is apparent. This need for standardisation is recognised by the Director General of Environment for the European Commission, who prepared the aforementioned Directive on Environmental Noise. Who proposes that the results originating from different member states can only be combined if all members use the same indicators for noise exposure and the same methods to calculate these noise exposure levels. However, currently, this is not the case. With comparative studies showing that there are dramatic differences between the outcomes of these methods (Wolde 1999).

Thereby the aforementioned Directive will include indicators for noise exposure assessment in methods of noise mapping (Kluijver and Stoter 2003). This lack of consistency makes the need for a validatory method to compare real and simulated noise levels even more highly desirable.

As stated above, the goal must be to get the actual long-term levels (source specific). Results can be compared to estimates of these levels to ensure that the noise map reflects the actual situation. This can be achieved through the local correction of noise levels. By measuring close to the source under investigation, the source levels can be estimated. An evaluation of the uncertainties in the source model can be used to determine which factor (e.g. % of heavy vehicles or road surface) to adjust to best improve the overall uncertainty. For this, the choice of the monitoring location is critical to reduce residual noise from other sources and to prevent erroneous factors such as reflections. A method for this is outlined in section III- 'The Measurement Method' of the CRTN (Department of Transport 1988).

As is apparent from the review, noise mapping is a tool of immense importance in the field of both environmental acoustics, and more widely in the context of strategic planning. However, it is a tool that is open to error, and consequently the importance of validating and calibrating the results is imperative. Especially in light of is its use in the context of noise insulation for residents affected by road infrastructure changes.

The use of noise mapping within the context of this research is to enlighten on new methods of integrating affected residents into the planning of any noise mitigation strategies, opening up even more potential benefits of this increasingly invaluable resource. The final part of this review discloses the last of the identified essential non-acoustic parameters to be included in the sustainable development of noise barriers, illustrating further, the importance of subjective impacts of noise relative to those of an objective nature.

2.7 The influence of perception on all aspects of noise barrier development

2.7.1 Influencing factors on people's perception of noise barriers effectiveness

As alluded to above, the greatest test of a noise barrier's effectiveness, is not in its objective noise reduction but in the subjective opinion of those a barrier is created to protect. Many things, including public participation in its design, sustainable practices in its processing and the use of multi-disciplinary professionals in its development influence the overall results.

However, there is one other major factor in a noise barrier's appeal, and that is how the end results are perceived. Through the following review of the literature, it is shown, that the influence of barriers are not as simply predicted as previously thought, and that the mere presence of a barrier structure blocking the line of site is not always that effective. As reported by Magrab et al (1975), there is much evidence that the visual shielding of the noise source by a noise barrier has a considerable psychological effect. However, this does not necessarily mean that the effects are positive, as illustrated below (Magrab 1975).

One of the first teams of researchers to uncover the influence of noise barriers on peoples' perception of noise was Aylor et al (1976), whom devised an experiment to measure perceived loudness of noise transmitted through barriers by human observers outdoors. This experiment used a selection of four noise barriers positioned around the circumference of a circle with a swivel chair in the centre for the respondent to sit in. The experiment was under free-field conditions, and used a sound source projected from speakers behind each of the barriers as a stimulus. The respondents were required to note down the perceived level of noise reaching them through each of the barriers, by allocating a value proportional to the perceived value and in association to the other noise incidence heard.

The findings of this experiment revealed, that visual shielding by a barrier dramatically affects the perception of sound transmitted through the barrier, but the direction of this effect was not simply related to shielding. This was defined as 'as long as the source of sound can be seen, reduced visibility of the source is accompanied by a reduction in apparent loudness' (Aylor and Marks 1976:400). However, when the sight of the source was completely obscured by the barrier, this effect completely reversed, i.e. the apparent loudness increased.

They related this to a phenomenon uncovered by Kryter (1976 cited in Aylor & Marks 1976), whereby, noises heard indoors are judged slightly more acceptable than noises heard outdoors, but not nearly as much as would be expected from sound attenuation produced by a building. They believed that the effect of a solid barrier on perceived loudness might hinge on people's expectations of the barrier's effectiveness. They presented the phenomenon as an analogy between their findings and the 'size-weight illusion'; where by a pound of lead feels heavier than a pound of feathers' (Stevens & Rubin 1970, cited in Aylor & Marks 1976:400). Thus, if this sort of reasoning is correct for the size-weight illusion, it may also apply to the loudness-barrier effect: 'when a sound source is occluded visually, one expects its loudness to be diminished, sounds coming from behind barriers appear surprisingly loud, and hence are overestimated relatively to sounds coming from open space' (Aylor and Marks 1976:400).

Aylor and Marks found that magnitude estimates of loudness were greatest when visibility of the source was totally obscured. They attributed these findings to listeners' expectations regarding the apparent sound-attenuating properties of the visual barrier. For example, a visually solid sound barrier might appear to attenuate sound by less than a barrier, which sound travels through, and the listeners can see. In this case, listeners receiving equal-intensity sounds from totally and partially blocked sources, presumably would judge the sound from the invisible source as louder, due to an overestimation due to the expected attenuation.

However, it is unclear why differences in expected attenuation, should result in an underestimation of loudness of sounds from partially blocked sources, relative to loudness of sounds from clearly visible sources. Whatever the correct explanation of this phenomenon might be, Aylor and Marks' findings suggest that expectory features of familiar environments may influence auditory perceptions.

2.7.2 The effect of vegetation on noise reduction perception

One of the most commonly used methods of attenuating noise by the public is to plant vegetation. Huddart (1990) reported, through a literature survey and field study, which measured traffic noise attenuation through five vegetation types, that foliage plays an important role in reducing high frequencies, (above 2kHz). Whilst low frequencies (250 to 500Hz) are predominantly attenuated by the absorbing qualities of the ground, enhanced by the plant root system and leaf litter. The maximum attenuation in the field study, was measured through a 30m dense spruce plantations. This gave a reduction of 6dBLA10 greater than the same depth of grassland (Huddart 1990). Although this noise reduction is reasonable, the reality of planting a 30m dense or even a 10m dense wood adjacent to a major trunk road and residential properties, is likely to be unfeasible (Kragh 1981).

The question of obscuring the traffic source by vegetation was further investigated by Watts et al (1991), who decided to test the use of vegetation further to try and ascertain the precise manner in which vegetation affects the perception of sound. To test this phenomenon, Watts et al (1999) devised a study, commissioned by the Traffic Safety and Environment Division of the Highways Agency part of the UK Department of the Environment, Transport and the Regions, to investigate the effects of the visual screening provided by vegetation on the perception of sound, using both real traffic sources and reproduced traffic noise. The basic approach was to obtain ratings of noisiness of traffic, whilst simultaneously measuring the noise level during the assessment period.

The experiment was undertaken in two stages. The first in-situ experiment was performed with different densities of vegetation between the listeners and the source of the noise. Consequently, it was then possible to test whether sensitivity to traffic noise increased or decreased as a result of the degree of vegetation present and hence the amount of visual screening of the source.

The second stage experiment was undertaken under controlled conditions at the TRL's research facility, the NBTF. As with the assessments alongside the roads, each listener made individual ratings, which were coded with the corresponding noise levels, which were obtained by analysing the relevant sections of noise recordings. Linear regression was used to determine the dose-response relationship between ratings and noise measurements for each screen in turn, and for the no screen condition.

Using the regression lines at the sites where significant effects were indicated, it was shown that there were differences in the sensitivity to noise depending on the degree of visual screening, which was largely independent of the noise exposure level, i.e. the dose-response trend lines had similar slopes, but were displaced vertically. In the case of the dual carriageway site, the difference in the noise exposure level needed to produce the same level of subjective noisiness with a low (30%) and high (>90%) level of vegetative screening was approximately 4dB(A) and the listeners were more sensitive to noise where the screening was highest.

Results at the NBTF confirmed the effect obtained at the dual carriageway site in that, on average, listeners were more sensitive to noise, i.e. gave higher noisiness ratings under the same noise exposure, when the source was obscured by vegetation. The results of the test indicated that it is visual screening of the source that is the important factor and not other factors connected with the presence of vegetation (Watts et al. 1999).

These findings are in agreement with the results by Aylor and Marks (1976) and Mulligan et al (1987). A possible explanation for the effect being presented as that of false expectations. When a sound source is visually screened a listener expects its loudness to be significantly diminished, perhaps in the same manner that light from a source is diminished when the observer moves into the shadow cast by a fixed source. However, due to sound transmission directly through the foliage of vegetation screens or significant diffraction of the sound waves around a solid screen, the reduction in noise could be less than expected by the listeners making the assessments. This would result in the sound source being overestimated in terms of loudness when visually screened.

A secondary, but fascinating, area, in which the association of vegetation and acoustics has stimulated research interest, concerns the visual effects of vegetation on the human response to sound (Anderson, et al. 1983). This is especially curious by the influence that visible vegetation appears to have on the reactions of humans to the types of sounds they hear in outdoor environments (Anderson, et al. 1983).

These findings suggest that, perception of the visual and auditory features of our environment may not occur independently. Instead, these two sources of information may interact in our perception of the environment, a key element of which is vegetation.

2.7.3 Relationships between visual and auditory stimuli

This intersensory relationship between visual and audio stimuli was further investigated by Viollon (2003), who identified that there are two main clusters of relations:

1) Congruence relations, expressing if it is more or less congruent to hear such an auditory environment in such a visual setting (example: it is more usual to hear a traffic noise in a street than in a wood), and

2) Compatibility relations, expressing if it is more or less coherent to hear such an auditory environment in such a visual setting (example: it is unlikely to see a car moving in front of oneself without hearing it) (Viollon 2003:2).

The experiment that identified this showed that perceptions of road traffic noise transmitted through barriers vary according to visual degrees of pleasantness and efficiency. The audio-visual experimental conditions created an artificial urban situation. The simulation technique was developed and validated through a first experiment in a dark and soundproofed room, where subjects were exposed to various audio-visual situations, involving simultaneously projected visual and auditory signals using diffusing stereo sound tracks and projecting large colour slides to create the visual settings.

The various auditory environments were crossed with the various visual settings, leading to audio-visual combinations, the respondents were requested to judge exclusively the auditory environments, along two auditory scales: Noisy/ Quiet, Stressful/ Relaxing.

It was found that visual information exercised a significant impact on the perception of soundscapes, the more urban the visual setting, the more unpleasant/ stressful the perceived soundscapes. The more pleasant the noise barrier, the less stressful the road traffic noises. These situations can be explained as intersensory interaction where by intersensory interaction has not occurred if the addition of a second-sensory modality does not change the nature of the perception by the first modality (Warren, et al. 1983).

The overall conclusion was that visual information is not neutral, but indeed influences the auditory impression. In the experiments, it was concluded possible to reduce the stress felt when listening to road traffic noises, by exploiting the visual appearance of the barrier or to enhance the auditory impressions by reducing the visual degree of urbanization/ unpleasantness.

The visual parameter was found to be the predominant variable with regard to audio-visual interactions. The visual pleasantness of a landscape and of a noise barrier, enhanced by the presence of vegetation, is an important visual parameter, with a strong impact on perception of soundscapes. For the overall urban sound scenes, the more pleasant the visual setting, the less contaminated the auditory judgement and the more acceptable the noise barrier. Consequently, benefiting the effect on the auditory judgement of stress (Viollon 2003).

As noted in section 2.7.1 the two previous studies by Aylor and Marks (1976) and Watts et al (1999) examined the perception of noise transmitted through barriers. For both of these studies, the influence of visual information on auditory perception was dependent on auditory expectations. Aylor and Marks, examined the impact of masking the sound source by a noise barrier, and identified that as long as the sound source is visible, an increase in the masking degree gives rise to a fall in the perceived sound level. However, as soon as the sound source is not visible at all, the inverse phenomenon is observed; this phenomenon can be explained by auditory expectations (Aylor and Marks 1976; Watts 1992).

Through the review of all of these experiments it has been observed that a controlled method within a laboratory with realistic audio and visual stimuli has yet to be tested. There have been various attempts through tests outdoors using real in-situ barriers and traffic sources, which are unable to be experimentally controlled and there have been experimentally controlled scenarios that have had to forfeit realistic visual stimuli in place of still projections. Therefore, it would be interesting to determine whether the phenomenon remains with a controlled but realistic audio/ visual environment.

2.7.4 A practical application for the findings of this phenomenon

The reason that sociological and psychological aspects of noise barriers have such an influence is that, where there is noise pollution at high enough levels to warrant a barrier, there will inevitably be a large body of local non-expert concern. The issues salience to the local residents, it is designed to protect, is further increased by the fact that very often these structures can dominate the landscape, and can be up to 20 meters high (Kotzen and English 1999:5).

Often blocking out any view of the area next to the motorway or trunk road, and leading to a reduction in natural light exposure and creating a feeling of enclosure or severance for those living next to it. In addition, it must be accepted that the expectation of a noise barrier's performance is often unrealistic on the part of the residents. For example, if a barrier reduces noise from 75 dB to 70 dB, from an acoustic engineering perspective, the barrier is a great success. However, for the residents the barrier is there to protect, 70 dB is still very loud, and the perception of noise reduction is often much less than the actual physical reduction (Highways Agency 2002).

The identification of auditory expectations as a crucial part of noise barrier development should influence both the planning and public participation of the barrier design as noted in section 2.5.2, but also in the choice of materials.

A survey undertaken in the USA by the Texas Department of Transportation uncovered that the visual quality of noise barriers is a critical factor, since 'they become a major line element (in the highway corridor) second only to the road itself' (Transafety 1997:3). The survey highlighted that, like a 1981 predecessor, that transportation agencies did not have enough information on the public's perception of aesthetically pleasing barriers, and, as the literature has illustrated perceived aesthetic appeal can influence a barrier greatly (Anderson, et al. 1983; Transafety 1997).

This in turn was related to the findings of Storey and Godfrey cited in (Transafety 1997) who concluded that transportation agencies could improve the perception and acceptance of noise control efforts, if the public were given both more knowledge about noise barriers and a more active role in their design.

Consequently it is now widely accepted that the success of a noise barrier, must be measured on much more than its ability to attenuate noise. It must be cost-effective, aesthetically pleasing, comply with safety regulations, be accepted by the local residents, whilst not being a distraction for motorists, along with a multitude of other criteria which must be adhered to, for a noise barrier to be regarded as a successful project.

2.8 A brief summary of the findings

This review covers a wide range of disciplines, as the aim of the research is to emphasise the importance of a multidisciplinary approach to the design of noise barriers. As a consequence, the literature referred to in this review is not exhaustive. However, a wide range of work has been reviewed which illustrates the multifaceted nature of the problem of noise barrier design.

The review has unearthed the current and existing research on many levels of noise barrier development, and draws together the existing gaps in knowledge and possibilities for research. The aim, therefore, of this thesis is to develop an approach that defines and qualifies both the importance and practical application of sustainable measures into the design of noise barriers, with the emphasis on the non-acoustic parameters including, public participation, the impact of perception of noise through noise barriers and methods to assess this, prior to barrier development. In addition to the development of a methodology to undertake sustainable development along with a review of the existing means of calculating the sustainability of a project. The application of which will be necessary, with the increasing demands by consumers and suppliers alike, to undertake sustainable development in both a voluntary and mandatory capacity.

Chapter 3 Methodology: An Overview

3.1 An introduction to the basis of the research methodologies utilised

As noted in the review, the context of this thesis is wide reaching and its aims are broad, in that unlike most objective acoustical research, there is no clear theory to test and no clear position to adopt. The basis for the thesis has arisen, from an understanding through the literature review, that current methods of noise barrier development are falling short in many of the non-acoustic respects that determine their successful development. A reason for this trend could be attributed to the current patriarchal approach to noise barrier design and development. From the evidence found in the literature, the current preferred methodology is to plan, design and assemble noise barriers, with a minimum amount of public involvement. Ignoring the opinions of those the barrier is meant to protect.

Therefore, the method assessed within the context of this research, attempts to illustrate how a more holistic, inclusive and generally more accepted barrier project can be undertaken. The main means of realising these aims is to develop sub-objectives using quantitative, qualitative, and mixed methods of analysis. Furthermore, the manipulation of technological resources is presented, to enable a comparison of objective facts to subjective opinions. As well as providing a method for lifecycle assessment of noise barrier material, which will help to guide the design and incorporation of the important non-acoustic parameters. Figure 3 illustrates an overview of aims of the research and the methodology adopted to achieve a sustainable approach to environmental noise barrier design.

This inclusive epistemological stance falls short of what could be described as a purist feminist approach. In that on a basic level the structuring of the thesis is in the third, rather than the preferred first person, and on a more profound level, includes a multi-strategy approach utilising both qualitative and quantitative methodologies (Reinharz 1992:14 & 204-206).

However, the overall epistemological orientation for the research can still be described as feminist, in that it is based fundamentally, on the belief of social inclusion, participation, and the belief in the ontological theories of constructivism (Bryman 2001: 17). This can be described as a social reality of communities defining their own order, rather than being subjected to an external coordinator, by accepting the potential for communities to order their own realities, rather than having them ordered for them (Kumar 2002:31). This ideology also promotes the belief, that this is a natural reality of communities that are successful, as they respect the intrinsic value of environmental protection and sustainable development. Accepting that successful projects are created with a move away from the traditional patriarchcal approach, of enforcing beliefs of 'what's best on a community', to that of listening to communities, and using their input as the blue print for development (Bryman 2001; Kumar 2002).

In this context therefore, the overall methodological approach, and the more defined methodologies used within the proceeding chapters are discussed below, along with a description of some of the basis and arguments for the theories.

3.2 The phenomenological research methodology

The basis for the research came from an investigation in to a real world case study, in a South Yorkshire area, including the small communities of Tinsley, Brinsworth and Catcliffe. The theories of this thesis were derived from the realities of the affected communities, which were exposed to adverse noise pollution emanating from the M1. This issue was addressed in the spring of 2001, through the construction of a noise barrier. The existing literature had revealed that noise barriers can often fall short of expectations, and therefore the result of this case study was used as a basis to evaluate how a project such as this could be improved.

The means of doing this was through a semi-structured interview technique, which enabled respondents from one of the affected communities, to reveal in their own words with the aid of a series of predetermined prompts, how they perceived the success of the barrier. These results were in turn compared to the results of two further semi-structured interviews, undertaken with representatives of the Highways Agency, the commissioners and coordinators of the noise barrier's development.

The semi- structured interview or unstructured interview, is a qualitative data-gathering technique. Australian scholar Dale Spender defined feminist research with the following statement.

"At the core of feminist ideas is the crucial insight that there is no one truth, no one authority, no one objective method which leads to the production of pure knowledge. This insight is as applicable to feminist knowledge, as it is to patriarchal knowledge, but there is a significant difference between the two: Feminist knowledge is based on the premise, that the experience of all human beings is valid, and must not be excluded from our understandings. Whereas patriarchal knowledge is based on the premise that, the experience of only half the human population needs to be taken into account, and the resulting version can be imposed on the other half. This is why patriarchal knowledge and the methods of producing it are a fundamental part of women's oppression, and why patriarchal knowledge must be challenged- and overruled" (Reinharz 1992:7).

Drawing on these ideals, a cross section of the community was interviewed, and through this a feel for the reality of the case study emerged. To transpose these thoughts into a theory, Glaser and Strauss' 'Grounded Theory Approach' (1967) was utilised, which using a series of codes, induced a theory from the results, rather than testing a theory with the results; the full description of the method is in Chapter 4. The result of this method was a testable group of theories, informing knowledge on why the noise barrier project failed/ succeeded, through the eyes of the local population and the professionals.

3.3 The positivist methodology

Adopting a triangulation methodology, which tested the theory developed through the qualitative method, using quantitative techniques then developed the outcome of the qualitative investigation (Bryman 2001; Kumar 2002). The sampling technique used, was a multi-stage cluster sample method (Bryman 2001), which captured the responses of 108 people, from a cross section of the community. These respondents were accessed using techniques of inclusion, which incorporated questionnaires translated into Urdu, Bengali and Somali, large print, and assisted completion to aid the elderly, and partially sighted. A full description of the sample population and method used is described in Chapter 5.

To ensure that the members of the household most affected by noise were captured in the sample, the household member whom remained in the home the longest over an average 24-hour period filled in the questionnaire. The reason for this was to ensure that those likely to have the greatest sense of change as a result of the noise barrier were questioned, as opposed to the main householder, who could possibly be out at work for a larger proportion of the day. This approach also endeavoured to capture the main guardian of any children in the house, as it was felt they would be more likely to have noticed any changes in the children's behaviour, that may be attributed to the noise barrier, for example, more restful sleep and increased concentration.

The statistical package SPSS11 was used throughout the investigation, to determine correlations and statistical inferences within the data, allowing the findings to be concluded with a degree of certainty to the wider population.

3.4 The multi-strategy approach to inclusive noise barrier design using noise-mapping technology

In order to identify the sectors of the community that should be targeted for public participation, the possibility of utilising noise maps was investigated. The software utilised was the CadnaA version 3.0, which ran on an ordinarily configured windows operating PC. The choice of software was based purely on the basis of availability, as subsequent use of the alternative packages including Noise Map 2000 and Soundplan have revealed that CadnaA provides a user-friendly package, comparable with other available products and capable of producing the same results.

The full details of the method used in this work, is defined in Chapter 6. In brief, the method was devised to illustrate, and test the effectiveness of noise-mapping as a tool for identifying those for whom public participation would benefit the most, and to illustrate how participation methods could be tailored to individual communities.

The reason for attempting this was two fold. Firstly to involve only those who would truly see benefit from integration in a noise barrier's development, as opposed to concentrating efforts on the highly vociferous members of society who attend public meetings, could enable the redirection of funds allocated for public participation. Thus, by focussing the efforts of participation on a smaller community, the cost of identifying smaller affected groups could be offset.

Secondly, it was felt that in light of the prevalence of noise-mapping, resultant of both the UK proposal, 'Towards a National Ambient Noise Strategy' (DEFRA 2001) and the EC Directive, on the Assessment of Environmental Noise. That this huge resource base could be adopted for an alternative use, so that the outcomes not only inform policy but also aid in its successful application (Wetzel 2002).

This was achieved through the comparison of subjective public opinions, regarding the effectiveness of the noise barrier, collected during the quantitative investigation in Chapter 4, to a selection of modelled maps of the case study area's noise.

In addition, noise maps with and without the noise barrier, and with varying heights of the barrier were modelled. This allowed both for a comparison of subjective opinions and objective measurement's and enabled an assessment of the extent to which public attitude's resultant from extraneous variables, such as the level of participation, impacted upon the perception of the barriers performance.

3.5 A life cycle assessment to determine the sustainability of noise barriers

Developing a database of relevant values, and providing a framework within which to undertake life cycle assessment addressed the current lack of models available for assessing the environmental implications of noise barrier throughout its life cycle. The model developed enabled the impacts of noise barriers to be assessed from 'cradle to grave'.

The reason for this being incorporated into the thesis was firstly due to the increased prevalence of environmental accountability in design, which is leading towards a stage where all projects and developments must show a commitment to environmental sustainability.

Secondly, as an acknowledgement to the increased desirability of a comprehensive approach to development, that benefits wider society, as opposed solely, to those directly affected by a project. The method illustrates how a micro environmental problem can be resolved, without a macro environmental problem emerging. To determine this, a life cycle assessment of several commonly used noise barrier materials was devised, which addressed the current lack of a suitable methodology, which currently hinders barrier providers from choosing the most environmentally benign solution.

The full account of the method is detailed in Chapter 7. The approach undertaken here is described in brief below:

- Impacts associated with raw materials up to the point of delivery from the factory, - 'cradle to gate analysis'
- The above impacts plus those associated with delivery to site, - 'cradle to site', analysis;
- The impacts associated with the maintenance, replacement and operation on site, together with recycling potential, and final disposal, - 'gate to grave' analysis.

The LCA model designed was used to collate appropriate data from many secondary sources to illustrate the potential life cycle impacts of each chosen barrier material type, including embodied energy, embodied CO_2, released pollutants to air and water, reuse and recycling potential and final disposal. This method was similar to that used by Woolley et al (2000), who devised a LCA model based on the general principles of existing commercially available models.

3.6 Laboratory experiments, investigating the impact of barrier materials on the perception of noise reduction

The final section of methodology used in the thesis, brought together the points identified as fundamental in noise barrier development. The first element being the influence of subjective responses to noise barriers that are largely influenced by non-acoustic factors. The second element being the choice of various barrier materials, which impact the least on the society. The link between these two elements is that the choice of aesthetic finish, was found in the literature to influence the perception of the acoustic benefit of the barrier.

Some researchers have carried out previous investigations into the influence of material and form of barriers on the perception of noise attenuation, (as reviewed in Chapter 2). However, it was discovered that to date the development of a method of testing responses, in a controlled laboratory environment, had been limited to static images being projected in front of participants with accompanying sound (Aylor and Marks 1976; Watts and Nelson 1993; Watts, et al. 1999; Viollon, et al. 2002; Viollon 2003) In previous experiments attention to realism had not been adequately achieved. Therefore, a method was devised using a virtual reality suite to counter this problem; a full description of the methodology is described in Chapter 8.

A brief synopsis of the procedure is presented below; the purpose of this investigation was to test the respondent's perceptions of noise attenuation by noise barriers, based purely on subjective assessment, by utilising the RAVE- Reconfigurable Advanced Virtual Environment suite, at the University of Sheffield. A sample of several respondents was randomly selected from the University population, representing varying ages, academic departments and ethnic backgrounds. The sample was subjected to three tests; devised using projected images of in-situ noise barriers, with heavy traffic passing behind them, and a dubbed sound recording of vehicles.

The first test was developed to identify any correlations between the preconceptions of the sample, on how they predicted each of five noise barriers to work, including a concrete, metal, timber, transparent and line of deciduous vegetation. Therefore, for this test the visual sequence was played without an auditory stimulus, and the respondents were asked to rank each of the barriers, in order of their predicted effectiveness at attenuating noise.

Test 2, introduced the auditory stimulus, and the respondents were requested to evaluate how well each barrier was attenuating noise, by rating them in relation to a base value. This tested intersensory interaction, with the introduction of the second modality of noise. The test was however controlled, with the noise levels remaining the same for all barriers throughout the test.

This was achieved by replaying sounds during the listening periods, which were originally obtained from a sound sample of noise recorded 10m from the nearside carriageway of the M1. The noise was produced by a sample containing a fairly constant level of free flowing motorway traffic noise. This sample was then replayed through an equalizer with digital output control, that enabled further samples at different levels to be obtained; this process did not affect the frequency balance of the resulting sounds.

These four sounds were then arranged in different orders, so that listeners would not be able to anticipate the level of noise that was replayed. An 8-second quiet period was left between each sound, in order to allow sufficient time for listeners to make an assessment. All the orders were balanced according to a Latin Square Experimental Design (Dénes 1991), to reduce any ordering effects. Consequently any judgement of variation, between the barriers abilities to attenuate noise, was based purely on perception.

The final test again removed the auditory stimulus, in order that the respondents could judge the barriers on their aesthetic qualities alone. The results of which were correlated, to the two previous tests, to determine any relationship between aesthetics and perceived noise reduction.

3.7 Overview of the methodology

In summary, the methodologies adopted in this thesis span a wide area of research, all of which were devised, on the basis of developing a methodology for a sustainable approach to noise barrier design, which moves away from the current patriarchal and ineffective methods of noise barrier development. Replacing them with, innovative methods that are based on the findings and outcomes of real investigations, which include, the opinions and proposals by ordinary laypersons, whose opinions would ordinarily be held in low esteem. The methodology used, can be interpreted as a methodology for use in future noise barrier projects, when considering the non-acoustic parameters incremental to their success, a diagram is presented in Figure 3, which illustrates the inter-linkages of the methods and aims.

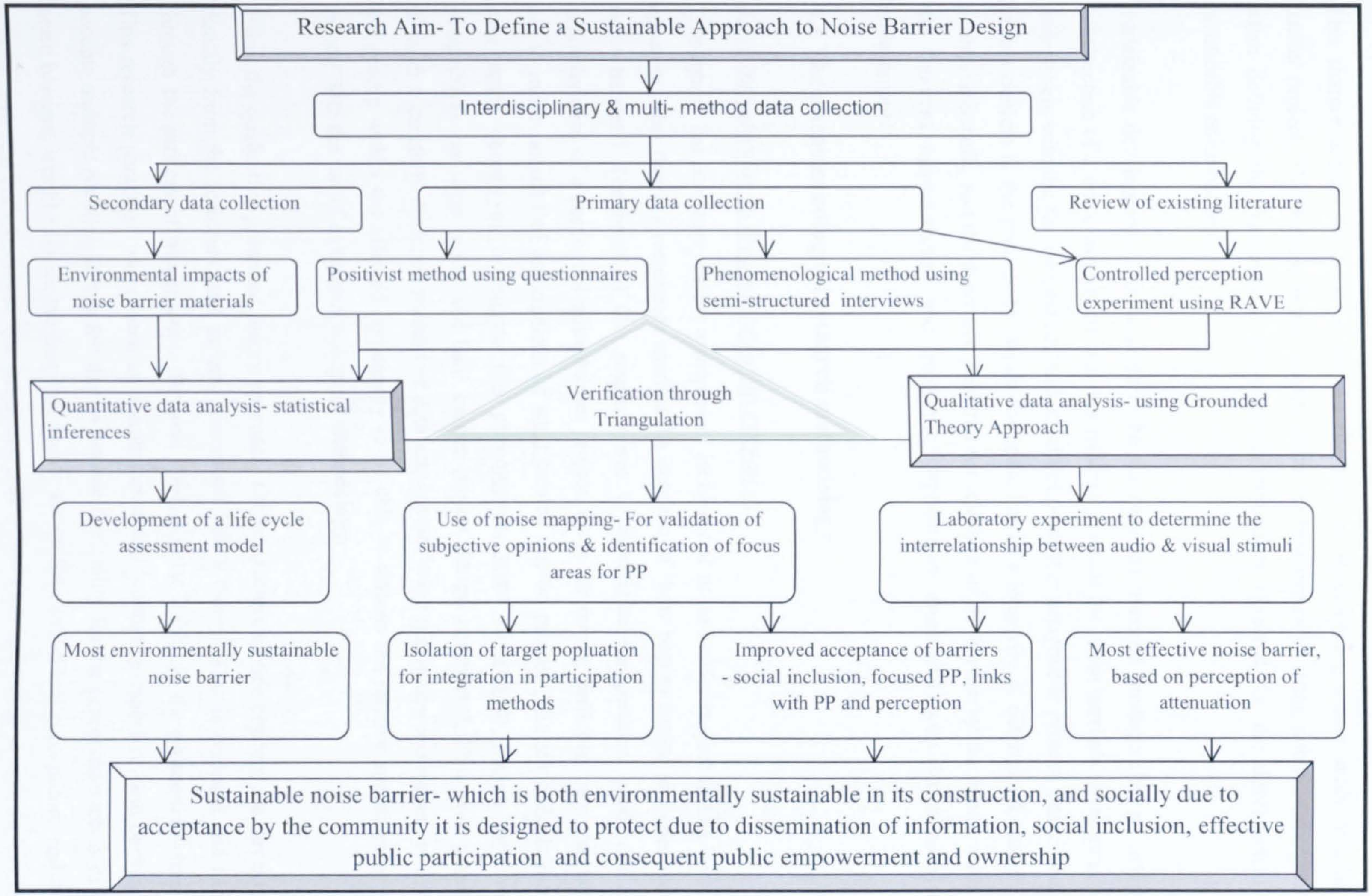

Figure 3: An illustration of the methodology and theoretical basis of the work approach

Chapter 4 Qualitative Investigation: Grounded Theory Approach

This chapter defines the basis of the overall thesis by investigating a case study of a noise barrier project. The purpose being, to determine the best means of using public participation, when defining the fundamental non-acoustic parameters essential for the development of sustainable noise barriers.

Sustainable development is understood to be not only the material products that go into the construction of a noise barrier, but also the means by which the noise barrier's development is undertaken, with the full cooperation and insight of those it is designed to protect. Sustainability in this context is the process by which the noise barrier's longevity is determined, due to its perceived benefit, and the decreased potential for rejection of the barrier by the public, with all the inherent environmental and economic implications associated with its removal or replacement.

4.1 The phenomenological research methodology

4.1.1 Introduction to the qualitative investigation

Throughout the literature review examples of incidents of noise barrier project failure became apparent. This theme's recurrence sparked the question of 'how best to design and construct a noise barrier'? The basis of this research was to investigate the pertinent properties and characteristics of a successful noise barrier project. From the outset, particular care was taken not to make unqualified assumptions of what created a good project. The respondents in the case study chosen to investigate this phenomenon, were allowed to impart their own perspectives on what 'good and bad' barrier project design constituted. This was possible through a carefully designed method of data acquisition, using qualitative techniques, to allow the people within the affected community to be able to discuss the relative successes of the project with the use of a phenomenological methodology.

Using the qualitative grounded theory approach, the key factors of this concept are developed directly from the residents, and experts' comments into a theory. This is widened and tested through the process of triangulation (Bryman 2001; Kumar 2002), in the proceeding chapter. This research paradigm was chosen as it embraces a multicultural perspective, and because it accepts multiple realities. It was felt that to assume one reality for the perceived success of the noise barriers, would exclude the fact that people act on their individual perceptions, and their actions have real consequences. The subjective reality that each individual sees is no less than an objectively defined and measured reality. They make few explicit assumptions about sets of relationships, such an approach is the basis of grounded theory (Glaser and Strauss 1967).

As noted above, the literature revealed several incidences of failed barrier projects. The failures of these projects had been examined to some extent, and lead the focus of this study towards the question of the necessity for public participation, in the design of successful noise barriers. This was taken as the preliminary theme. However, further themes and focuses were unearthed and developed as the investigation progressed.

Consequently, the first stage of this wider investigation, into the definition of 'a sustainable approach to the development of successful noise barriers', was to uncover the components of 'good' and 'bad' projects, by interviewing in an area that had recently received a noise barrier. This was achieved, through the use of semi-structured interviews, of ten carefully selected individuals, which were analysed using the grounded theory approach. A grounded theory is one that is inductively derived from the study of the phenomenon it represents. This means it is discovered, developed and provisionally verified, through systematic data collection and analysis of data pertaining to that phenomenon. Data collection, analysis and theory, therefore, stand in a reciprocal relationship with each other. One does not begin with a theory and then prove it. Instead, one begins with an area of study and what is relevant to that area is allowed to emerge (Strauss and Corbin 1990).

Deeper analysis, therefore, provided a good descriptive stage to widen the investigation. These features were inherent in the grounded theory approach. Therefore, adopting this approach enabled the integration of a feminist epistemology. This then grounded the research in its principles, and was ultimately used to illustrate the best available technique for noise barrier design, that would directly benefit those it was intended to protect.

4.1.2 The grounded theory approach

As noted in the literature review, the importance of 'social aspects of acoustics' is growing in stature. The theories and ideologies of which, sit well with this holistic approach to data acquisition, thereby defining and validating a noise barrier's effectiveness through the subjective eyes of those it is designed to protect. The background contributing to the development of grounded theory, was partly derived as a result of the desire to use a method that required the following attributes: 'a) the need to get out into the field, to understand what is going on; b) the importance of theory, grounded in reality, to the development of a discipline; c) the nature of experience and undergoing as continually evolving; d) the active role of persons in shaping the world they live in; e) an emphasis on change and process, and the variability and complexity of life; and f) the interrelationships among conditions, meaning, and action' (Strauss and Corbin 1990:24-25). Grounded theory was chosen over analytic induction, because despite some similarities, the differences made grounded theory more appropriate. The main difference is that analytic induction, is concerned with developing rather complex theories. In addition, grounded theory differs from analytic induction, in its adoption of a constant comparative method, involving the comparison of multiple data segments judged to belong to the same category, in such a way as to identify the central features of that category. As the analysis develops, the categories become the central organizers of the material (Hammersley 1989).

A final difference is the issue of theoretical sampling, whereby cases or groups are strategically selected in order to maximise theoretical differences or similarities[1]. This approach fitted the criteria of the researcher, both to undertake an investigation on a case that could be developed further into a theory to be adopted in future cases, and within this case through triangulation. The approach also allowed the research to be conducted from a feminist epistemology, which reduced the risk of imparting aspersions on to the case study, and allowed a voice to those directly affected by the salient issues.

The grounded theory approach is devised in a systematic order to derive as much from the qualitative data as is possible, and form it through its own direction into a theory. This is opposed to the usual qualitative methods, which generally describe the scenarios being investigated.

For clarification the difference between theory and description are as follows: *Theory uses concepts;* similar data are grouped and given conceptual labels, this means placing interpretations on the data. The concepts are then related by means of statements of relationships. *In description*, the data may be organised according to themes. These themes may be conceptualisations of the data, but are more likely to be a précis or summaries of words taken directly from the data. There is little if any interpretation of the data. Nor is there any attempt to relate the themes to form a conceptual scheme.

Grounded theory is a scientific method, as its procedures are designed so that if they are carefully carried out, the methods meet the criteria for doing "good" science, by including the following: significance, theory-observation, compatibility, generalisability, reproducibility, precision, rigor and verification (Strauss and Corbin 1990). The methodology is described, as

[1] Theoretical Sampling; 'is the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses the data and decides what data to collect next and where to find them in order to develop the theory as it emerges' Bryman, A. (2001). Social Research Methods. Oxford, Oxford University Press.

the data is processed below, it was felt that this was the most effective means of describing and giving explanations of the methodology where appropriate. The process can, however, be summarised into three stages of coding; open, axial and selective, which processes the data derived from long semi-structured interviews, into a theory to explain a phenomenon.

4.1.3 An introduction to the case study

The origin of the research was derived from the development of a noise barrier parallel to the M1, on the North East Side of Sheffield. Built to benefit the residents of three communities, namely Tinsley, Brinsworth and Catcliffe. A description of these areas is given below, which helps to frame the context of the study. However, the actual origin of the project was sparked by the unusual origin of the noise barrier. The noise barrier constructed along this five-mile stretch does not look out of the ordinary from observation (Figure 4.1). However, its creation stemmed from an entirely different approach to the design of noise barriers, as it was designed as part of an open competition. This move away from the traditional patriarchal approach to such design and construction issues, raises the questions, of how much further this decentralised approach to design could be taken? Indeed could the whole process of design be given to those people that noise barriers are intended to help, and how would this influence the success of the project?

Figure 4.1 Tinsley noise barrier, as seen from M1.

The M1 motorway runs parallel to the area of residential housing under investigation, and as a consequence, the residents suffer from the increasing and disruptive intrusion of noise pollution emitted from the traffic. This is evident from the fact that the motorway is known locally as the Berlin Wall (Sheffield First Partnership 2000). Tinsley, the only area studied in the initial qualitative investigation, has a mixed ethnic community and has many families living on low-incomes. It is characterised by high unemployment, severe environmental pollution and some social disquiet between local White and Asian youths. Despite this, the community has a predominantly good integrated community feeling and the area has many social and educational development schemes.

Another key factor relevant to the discussion of this case study is the role of the local forum. Tinsley Forum was established in 1984, as an independent body to represent the local community and give an outlet for residents to air their opinions on local issues. The Forum is now held in such high esteem by the local government, that many projects are piloted in the area, as feedback is so effective. In this respect, Tinsley Forum is a very important platform for local debate, its utility as the sole means of engaging the public is explored later in this investigation.

The noise barrier competition was launched in the autumn of 2000, by the Highways Agency (HA) in collaboration with Design Yorkshire. The competition criteria, was to design an innovative noise barrier, to protect the 5-mile stretch from junction 33 to 34 of the M1 motorway. The funding for this came from the £5m set aside by the Government in the year 2000, for noise reduction measures on motorways around the country (Child 2001). A major influence on this investigation is that the residents local to the motorway had been lobbying their local council and government representatives for a noise barrier since 1997. In fact the area has been earmarked for other noise mitigation procedures, including the application of low noise road surfacing. However, for the purpose of this study only noise barriers will be explored, as this was the only noise reduction implemented at the Tinsley site at the time of the investigation.

A main feature of this research was the level of reliance on the Tinsley Forum for information distribution, and the potential shortfall this lead to with regard to providing information for both those unaware of the forum, and the other affected areas of Brinsworth and Catcliffe. Consequently, Tinsley Forum was the first port of call for the researcher to establish the foundation of the investigation. A lengthy discussion with the Forum's president and representatives from the East End Quality of Life Initiative[1] resulted in the acquisition of local knowledge on salient issues. This included a background on the noise barrier's development from the aspect of the local residents, as well as further names and suggestions for more interviews.

[1] East End Quality of Life Initiative, 31 Montgomery Terrace, Sheffield; This body are responsible for surveying on all aspects of social, political and environmental regeneration projects in the whole of the east side of Sheffield.

Additionally, the researcher was able to gauge a general feeling for the project, as those available at this time were incremental to the lobbying and party to the public participation offered by the Highways Agency. A general impression of dissatisfaction at the resulting barrier was made apparent. As although a feeling of relief could be sensed with regard to finally seeing their efforts of lobbying seeing fruition, it was also evident from this conversation that neither the problem of excessive noise pollution had been fully addressed to their requirements nor that their thoughts given during the public participation process had fully influenced the outcome.

With the use of the names provided by the forum the qualitative investigation was commenced. The Snowballing Approach is a widely recognised technique in qualitative research (Bryman 2001:324). It is synonymous with accessing stigmatised groups, and uses word of mouth, for transferral of information about other possible respondents falling into a similar group (Ribbens and Edwards 1998). This enabled access to a sample of people known by the Tinsley Forum for various reasons. Some were internal members of the organising and lobbying committee, others were on the mailing list, following attendance at a meeting in the past and others were known through other community groups and advice centres, but not directly linked to the forum.

4.1.4 The semi-structured interview

On advice from both the Tinsley Forum and the East End Quality of Life - Regeneration Project it was decided, due to the fact that the Tinsley area had become saturated with surveys, and in the light of the large population of ethnic minorities, that a semi-structured interview would receive a better response as an initial survey. In order to ensure the outline methodology and issues would be understood, and would achieve the objectives of the study, the semi-structured interview and key aims were reviewed by representatives of the Tinsley Forum, The East End Quality of Life Project, and staff of the sociology department of the University of Sheffield. There was no set format to pilot, as the process was evolutionary. If a pilot 'per se' had been carried out, it would not have altered the structure anymore than the structure is changed throughout the theory development process, thereby making a traditional pilot study irrelevant. In effect it is not therefore a case of 'how many people think such a way'? More, 'what do the people think'?

An initial list of 20 names was acquired. The potential respondents spanned all possible age groups, genders and ethnic backgrounds, and from this list, the respondents were chosen one by one and approached to participate (see Table 4.1.a). Not all the participants were chosen at the outset, due to the evolving nature of a grounded theory approach. Following the completion of an interview, the data was transcribed and analysed for concepts that needed further investigation and for gaps of knowledge. As a consequence to this fluid approach, new questions evolved throughout the course of the investigation.

By using the preliminary information held on the respondents, the next participant was chosen, with the aim of the next respondent, being able to answer the missing questions and gaps in knowledge. To ensure that key groups were not ostracised from the sample, a translator's assistance was sought for help with the interviews of the non- English-speaking participants. This was very important as it enabled the opportunity for opinions to be raised from different cultures, particularly in light of the fact that 34.5% of the population of Tinsley were from ethnic minorities (Sheffield First Partnership 2000:2).

The inclusion of any respondents with potential information and a perspective adhered this study to the pursued feminist epistemology. In addition to this, interviews were held with representatives of both the Highways Agency and the professional consultants to the Highways Agency responsible for the organisation, fund allocation and supervision of the noise barrier project. This gave the data a rounded facet with both lay and professional opinions, which enabled a comparison of views on all aspects of the noise barrier's development and further developed the theory.

The semi-structured interview or long interview is distinguished from the unstructured 'ethnographic' interview, insofar as it adopts a deliberately more efficient and less obtrusive format (McCracken 1998:7). To indulge in a full ethnographic interview involves immersing oneself within a culture, in some cases for months or even years, and observing the idiosyncrasies of a group of people, about whom there is a desire to understand better. This is an especially useful tool in the case of cultures very different from the researcher's, as to fully achieve a qualitative approach the researcher must have a greater ontological perception of the world of those they are researching. In the case of very different cultures it would be easy to enforce our own opinions of what we perceive their life to be from assumption, should we not fully understand the nature of their lives.

The use of the semi-structured interview does not abandon this approach completely, but it fits better into a smaller case study, on a sample which the researcher had an existing understanding and empathy through personal experience. Despite some of those being interviewed having different ethnic backgrounds, or having lived within different countries and cultures in the past, at the time of the research, they were all living in a community the researcher could relate to, having lived within the area for several years, and witnessing in general the increase of traffic and consequent noise pollution, additionally the researcher could empathise with the loss of value in the respondents home, relative to the rising values within the surrounding area, rendering many of them without an option to move out of the area. This does not mean that the researcher would automatically understand the situation, but removes the necessity for the complete long-term immersion, necessary when using the ethnographic approach (Ribbens and Edwards 1998:3).

Feminist researchers generally consider personal experiences to be a valuable asset for research, as the use of personal experience is a distinguishing feature of this particular ilk of research. Personal experience typically is irrelevant in mainstream research, or is thought to contaminate a project's objectivity. By contrast, in the context of a qualitative investigation it is relevant and repairs the project's pseudo-objectivity (Reinharz 1992:258).

In the case of qualitative research it is the concepts and categories, not their incidence and frequency, that are said to matter. In other words, qualitative work does not survey the terrain, it mines it (McCracken 1998:16-17). This means that qualitative research enables a small case study to be investigated unto its own, rather than to find trends that fit into a wider genre. This was necessary at the outset of this research, to enable the building of a theory, insofar as qualitative work is theoretical in its aims rather than descriptive. This is especially so with case studies that use qualitative methods- it is the testing of a theory that is important, rather than the issue of inference or generalisability (Yin 1989). According to Strauss and Corbin (1990), the purpose of grounded theory, is to specify the conditions that give rise to a specific set of actions/interactions pertaining to a phenomenon; it is generalisable to those specific situations only.

The interview was, therefore, organised in a preliminary format (see *Appendix 1A* for an example), which was adapted to encourage the answering of knowledge gaps, whilst preserving the idea of developing a theory and finding similar concepts within the data. The interviews all took between forty-five minutes to an hour, and were undertaken for convenience within the homes or the work places of the respondents. Despite the adaptability of the process from interview to interview, some aspects were constant, these included the 'grand tour questions', which were covered at the start and simply allowed the respondent to describe themselves and their place within the community in their own words. The 'main questions' then followed which were guided but allowed the respondents to wander verbally through the subject area to allow any salient thoughts and issues to emerge. These were analysed to form the theory. In addition to the 'prompt questions', several photographs of noise barriers were presented to the respondents to aid them in visualising and conceptualising the questions regarding the noise barrier, these can be seen in *Appendix 1D*.

4.1.5 Grounded theory in practise

Table 4.1 below is adapted from the initial list of names provided by the Tinsley Forum, the identities of the individuals are protected but the variety of ethnic backgrounds, family types, age groups and genders are revealed. Evidently not everyone on the original list was willing or in some cases was available to cooperate in the study. In the instances where an individual filled a category that needed to be approached for better understanding, and they were unavailable, an alternative individual from a similar category was approached.

Table 4.1.Original Information on potential respondents Tinsley and order of interviews.

Interview order.	Employment Status	Gender	Ethnic Origin	English Speaking	Marital Status	Parent	Age
1	Part time	Female	British	Yes	Married	Yes	Middle aged (59)
2	Part time + training	Female	Asian	Yes	Married	Yes	Young (36)
3	Part time	Female	British	Yes	Divorce	Yes	Middle aged (56)
4	Housewife	Female	Asian	No	Married	Yes	Young (35)
5	Housewife	Female	Asian	No	Married	Yes	Young (32)
6	Cleric [1]	Female	British	Yes	Married	Yes	Middle aged (54)
7	Full time	Male	British	Yes	Married	No	Middle aged (54)
8	Part Time	Male	Asian	Yes	Divorce	Yes	Middle aged (50)
9	Employed by H.A [2]	Male	British	Yes	N/Relevant	N/Relevant	N/Relevant
10	Employed by WSP [3]	Male	British	Yes	N/Relevant	N/Relevant	N/Relevant
	Fulltime	Male	Asian	Yes	Married	Not Known	Not Known
	Retired	Female	British	Yes	Married	Not Known	Elderly
	Retired	Female	British	Yes	Married	Not Known	Elderly
	Retired	Female	Asian	No	Married	Not Known	Elderly
	Retired	Man/Wife	British	Yes	Married	Not Known	Elderly
	Retired	Male	British	Yes	Not Known	Not Known	Elderly (90)
	Fulltime	Male	Asian	Yes	Married	Yes	Not Known
	Cleric [4]	Male	British	Yes	Married	Not Known	Not Known
	Unemployed	Female	Asian	Yes	Single	Yes	Young (25)

(Grey boxes indicate those willing and able to participate in the study).

[1] Reverend of local church not resident in Tinsley.
[2] Representative of the Highways Agency responsible for the Tinsley Project
[3] Project Manager of Tinsley Project representative of WSP Engineering Consultants.
[4] Reverend of local church not resident in Tinsley.

The first respondent chosen was a female member of the Tinsley Forum, a parent, and a long term resident in the area. These characteristics were deemed the most appropriate to start the theoretical sampling procedure, for a number of reasons. The first 'being female', was identified because of the fact that previous research into the area of 'noise barrier development and the perception of success', had specifically targeted males as they were deemed to be the 'heads of the house', and therefore the most important people to approach (Md-Taha 1999:52). This was not only a rather narrow and misguided way of looking at a population, due to the fact that many women now own their own properties, or see themselves as an equal partner in a shared household; but also because this ostracised half of the potential sample, and their accompanying views at the outset.

In addition to the obvious statements above regarding a woman's place within both a household and a community, it is also a fact that generally but not exclusively women are more likely to both remain within a household for longer periods[1], and are more likely to be the principle guardians of any children[2]. With respect to these two criteria, it can be assumed that a person firstly remaining close to the source of noise for longer periods, would be more attuned both to the problem and the effectiveness of the solution, but also as chief supervisor of any children they would be more aware of any impacts attributed to noise, that is affecting their children. This is not to say that male opinions were not actively sought, as to alienate them from the project would undermine the purpose of full representation (Reinharz 1992).

The final two considerations were that the first respondent had lived in Tinsley for over 40 years[3], and also had close ties to the Tinsley Forum, having been a founder member. Although for contrast it was desirable to have respondents of various backgrounds, to give breadth and to direct the theory this respondent was predicted to hold the most information at the outset and so was successfully approached for interview.

Following the collection of the initial data during a 45-minute interview, the respondent spoke freely and knowledgably about her feelings on the noise barrier, including both her perceptions of its development and successes, and her perceptions of how other members of the community had perceived the noise barrier. At the end of the interview many key questions had been raised and answered, and many new insights into issues and consequent new questions had arisen. The examining of the scripts was a continuous and cyclic process throughout the development of the

1 On average, men spend longer at work and on leisure activities, whilst women spend longer on household chores, childcare and shopping National Statistics (2002).
2 Women also spend more time than men looking after children National Statistics (2001).
3 Resident in the area prior to the M1 construction in the late 1960s

theory, as with each new respondent came new ideas, and reinforcement of existing issues. In addition, there were varying perspectives on existing matters reflecting the fact that grounded theory is often referred to in the literature as 'the constant comparative method of analysis' (Glaser and Strauss 1967:102).

Following the first interview in the grounded theory process the findings were transcribed in full and reviewed. This reviewing stage is known as 'coding' and is a key process in grounded theory. Whereby the data is broken down into component parts, which are given names. There are three types of coding; 1) Open coding; 2) Axial coding and 3) Selective coding, these will all be described in relation to their purpose later on. The coding is the process of identifying concepts, and concepts are the building blocks, first of the categories, which flow through the theory outline, and also as the foundation for the theory of a phenomenon.

As the procedure of coding and identifying concepts occurs with every respondent, rather than having an individual explanation of which and what order the subsequent respondents were chosen, Table 4.1 illustrates which members of the community were approached and in which order. Issues that arose in the previous interviews ordered the respondent's interviews. For example some British respondents perceived there to be an under representation of the Asian community in the local Forum's participation process. These observations in turn led to the researcher interviewing Asians both working within the community with fluent English and those not working within the community without any English language skills.

This continuous review process illustrates how questions were raised and then explanations to the phenomenon were investigated. To enrich the content of the theory, two non-resident representatives of bodies charged with the 'professional' development of the barrier were interviewed. They enlightened on the reasoning for actions undertaken that had been queried by the residents, and also explained the limitations of the project that the community members would not be aware of.

The following continuation of the method provides the outline of the procedures necessary to accomplish a grounded theory in general, and the method used to develop the relevant theory. Figure 4.1 below illustrates the processes and outcomes of grounded theory; it illustrates both the various stages and the process of moving forwards and backwards throughout the data to gradually develop the theory. The first three stages have been explained above, stages 4 to 12 are described below with an explanation of how the procedure was tailored to this particular investigation.

Processes	Outcomes
1. Research problem	
2. Theoretical sampling	
3. Collect data	
4. Coding	4.a. Concepts
5. Constant comparison	5.a. Categories
6. Saturate categories	
7. Explore relationships between categories	7. Hypotheses
8. Theoretical sampling	
9. Collect data	
10. Saturate categories	
11. Test hypothesis	8. Substantive theory
12. Collection and analysis of data in other settings	9. Formal theory

Figure 4.1 Processes and outcomes in Grounded Theory (Adapted from: (Bryman 2001:63)

4.2 Analysis of the residents perceptions of the noise barrier development

4.2.1 Open coding

To obtain the first level of results, known as the concepts, a system of open coding was developed. A method was devised that enabled the analysing process to flow, whilst leaving the copies of the transcripts legible using a system of coded symbols and colours ('Concepts and Accompanying Symbols' are in *Appendix 1B*, along with their corresponding definitions). The transcripts from the resident's interviews were studied, and for each new concept that appeared, a new symbol was assigned, where concepts reappeared the existing symbol was input. This was a cyclic process as some concepts in earlier transcripts only gained salience with the emergence of a more in-depth description in later transcripts, therefore as these key themes appeared later and in more detail in further scripts a concept was devised.

As the interviews with the two professional representatives were related but did not contain the same form of questions, two sets of concepts, categories and theories were developed, and the analysis of the expert interviews can be seen in *Appendix 1C*. In effect, two grounded theory approaches were undertaken which resulted in 'lay themes' and 'expert themes'. These were related, and consequently helped to explain each other, but could not be fully integrated due to the nature of the differences. Consequently, the two often-opposing positions enriched the theories and helped to qualify some of the aspersions highlighted from both the lay and expert interviews. The method for open and axial coding of the expert interview transcripts was done using key terms and phrases, as opposed to symbols, as there was less data to analyse and less risk of confusion, with the exception of this outlined difference the methods used were the same.

The data was conceptualised through open coding which was the first step of the analysis. This breaking down process enabled observations, sentences, paragraphs and utterances to be given a name or concept that stood for or represented a phenomenon. These individual concepts were then put together into categories. Some concepts pertained to more than one category and therefore were added to more than one. Each transcript was studied several times with pertinent symbols used to highlight all the salient observations, which were then copied and pasted under each of the categories. This process continued until every symbol relevant to the category had been identified and the sentence it flagged up had been judged for relevance to the category, when all the categories had been 'saturated' then the second process of axial coding was pursued.

The end result of this was the emergence of a group of categories that were salient to the respondents, with regard to the development of the noise barrier and to the wider context of the area's problems and development. This brought about the occurrence of two processes. Firstly the importance of the noise barrier's development was determined in relation to other social, economic and environmental problems in the area. Secondly, but more discreetly, the issues underlying these main categories appeared and a picture of the area, its problems and its positive aspects appeared through the categories.

In total seven categories were developed (see list below) for the creation of a grounded theory of the residents or lay views. These varied from those specifically related to the noise and noise barrier, and wider social and environmental categories which developed themes such as the fear of pollution, related health problems and health problems indicative of an environmental influence but unidentified as such. Although all categories are explained further below, a main category started to evolve through the process of axial coding and this category formed the central point of the theory to which all the other related categories were integrated. (See *Appendix 1B* for all the seven categories and their associated symbols).

List of categories and sub-categories: for the residents; (The Lay Themes).

1. Distrust and disbelief in experts

- Sceptical of how well the barrier works, perceive barrier as bad/ failure, aware of the barrier prior to construction, see environmental problems, noise reduction over aesthetics, lack of belief/ trust in experts professionals, barrier should be natural & blended, cause negative aspects and opportunities for community, bothered, pessimism, barrier looks bad, barrier choices are important, residents have complained (or are prepared to), aesthetics important.

2. Unsatisfied expectations

- Lack of hope, suppressed, disappointment, lack of belief/ trust in experts and professionals, decline, bothered, abandonment & severance, self reliant to get things changed, causes negative aspects and opportunities for the community, act to stop it, problems are as bad as made out, rejection of situation, external exaggeration of problems, suggestions for improvements, defiance, public participation is very important, uninformed, disillusionment, ability to have say, residents have complained (or are prepared to), would like involvement, disenfranchised, lack of trust, aware of forum, pessimism, informed, environmental problems, aesthetics unimportant, noise reduction over aesthetics.

3. Health implications

- Affected by noise, time away from the area is better for me, environment affects the quality of life, M1/ traffic heart of areas problems, dislike living here (would like (will) move away, fearful (perception of silent poisons, high incidence of asthma, and heart disease, and leukaemia), main problem environment, illness, evidence of hearing problems.

4. Passive, unaffected, optimistic and preoccupied

- Not complained (not prepared to), approval, going away makes no difference, no environmental problems, improvements, optimism, no suggestions for improvements, included, hopeful, don't act to stop it, barrier looks good, would not like to be involved, acceptance of situation, not affected by noise, main problem social, wait for external help, un-sceptical of how well the barrier works, trustworthy, unaware of the barrier prior, not bothered, like living here (or would (will) like to move in), inclusion & acknowledgement, barrier is good/ success, unaware of forum, trust and believe experts as they improve and benefit the area, external exaggeration of problems.

5. Noise reduction over aesthetics, but aesthetics has its place

- Noise reduction over aesthetics, affected by noise, barrier is bad/ failure, (barrier natural & blended barrier contemporary & eye catching neither one or the other just reducing noise) aesthetics important, barrier looks good, barrier looks bad, not bothered, trust and believe experts as they improve and benefit the area.

6. Un-utilised public opinions

- Residents have opinions that could have been used in effective PP
- Noise reduction over aesthetics, aesthetics over noise reduction, barrier choices important, suggestions for improvements, aesthetics important, aesthetics unimportant, barrier natural & blended, barrier contemporary & eye catching, public participation is very important, act to stop it, causes positive aspects and opportunities for community, rejection of situation, barrier looks good, sceptical of how well barrier works, barrier looks bad, women's opinions most salient, approval, causes negative aspects and opportunities for community, would like involvement, improvements, barrier is good/ success, barrier is bad/ failure.

7. Rejection of community initiatives

- Communities are both willing and able to organise themselves in to action, but feel this action is unsupported, or even ignored leading to frustration, and rejection of things like the barrier:
- Act to stop it, self-reliant, rejection of situation, disenfranchised, abandonment & severance, causes negative aspects and opportunities for community, lack of hope, sceptical of how well barrier works, external exaggeration of problems, barrier

choices important, decline, bothered, causes positive aspects and opportunities for community, public participation is very important, lack of belief/ trust in experts & professionals, disappointment, pessimism, uninformed, problems are as bad as made out, barrier is bad/ failure

Through the coding of the expert interviews five categories were developed, these are listed below with their subcategories.

List of categories and sub-categories: for the experts (The Expert Themes).

1. *Perceived limitations of the project*
   - Accountability, high expectations due to non-expert involvement of organising committees, reduced control, delegated responsibilities, arena affect should have been explained, Applied V Pure ~ Curvatures of the design lost.
     - ~ Acceptance of failure to some degree.
     - ~ In hindsight would have increased height
2. *Adoption of public participation which equates to 'tokenism' (Arnstein 1969)*
   - Public participation incomplete at Tinsley, situation was explained not determined at the forum.
     - ~ P/P was not an obligation.
     - ~ Fear of consequences of too much control through P/P.
     - ~ Forum deemed only/ best means of engaging the public.
     - ~ Would not change PP method with hindsight
   - The importance of public participation is accepted and acknowledged.
     - ~ Awareness and attempts at alternative means of PP, just not used here.
     - ~ Responsibility of PP lies in the hand of the public.
     - ~ Despite best effort not everyone can be engaged.
     - ~ Damage limitations are practised by spreading the word.
     - ~ Unclear how to engage properly
   - Reactive solutions are the norm not proactive.
3. *Delegation of responsibility to impart meaningful information*
   - Potential for public integration unused, greater P/P at Altoffs (an alternative site) influenced acceptance,
   - Realistic expectations.
     - ~ Should have been imparted
     - ~ Public were unrealistic.

~ Project regarded a success due to realistic expectations by experts.

- Realistic alternatives.
- Misconception of public opinion due to lack of communication.

~ Opposing views, illustrating bad communication.

4. *Negative aspects of integration highlighted rather than opportunities for informed decisions*

- Restrictions of design controlled by official noise barrier design specs, upfront cost is deciding criteria, as all noise specs are conformed with naturally, planning not a consideration when part of existing works (as is inclusive), aesthetics important, maintenance costs were considered.

5. *Evidence of unlearnt lessons, and lack of acceptance of importance of full integration*

- Would not change actual method of design with hindsight, accept for including a before and after survey, other mitigation strategies would have been wider felt, i.e. Low Noise Surface.

4.2.2 Axial coding

Following the compilation of all the concepts, the next stage in the process of the theory development began. This involved axial coding, which developed a relationship between the subcategories and the main categories, and started to form the basis of the theory. The model used to allow this was a paradigm model, using this model did not fully link the individual categories together as this process was undertaken at the next stage of 'selective coding'. It did, however, start to develop themes, which enabled 'core themes and categories' to emerge (Bryman 2001:392-395; Straus and Corbin 1990:99). The paradigm model used linked the subcategories to a category in a set of relationships denoting causal conditions, phenomenon, context, intervening conditions, action/ interactional strategies, and consequences. The model is simplified as an overview in Figure 4.2 with an explanation of each phase. The results of the axial coding process for each of the categories used in the development of the actual grounded theory are detailed below.

Category 1

Causal Conditions: Distrust and Disbelief

Phenomenon

Many residents distrust experts, and disbelieve many of the things that have been said to them, and also disbelieve some of the actions taken.

Context: (Represents the specific set of properties that pertain to a phenomenon)

When the noise barrier was built many rejected it, claiming it had not worked, despite having no proof to the contrary. Their expectations for the barrier had been higher, both for its physical state and for its noise reducing ability's.

Intervening Conditions

This is influenced by previous feelings of rejection whereby ideas put forward have been rejected, or residents have felt excluded. The residents may also feel this way due to previous experience of actual situations where they deem experts to have failed, for example the building of unworkable traffic islands, Meadowhall, Magna, etc, which have had a detrimental effect on the community and residents.

Action/ Interactional Strategies

The residents counter this disbelief in experts, by taking their own action, through attending meetings, contacting councillors, the city council, writing letters, and rallying round to causes such as the closure of the school and the buying of the bridge and the church. However, some feel that this is fruitless, as they have been ignored before, so they accept the situations begrudgingly, and then develop negative attitudes towards the actions taken, without scientific proof of the failure.

Consequences

The consequences are that either people take action to attend meetings, but then feel excluded and believe the barrier doesn't work or people take no action because they feel it will achieve nothing and then still reject the final outcome of the barrier.

Category 2

Causal Conditions: Unsatisfied Expectations

Phenomenon

Many residents made comments that the barrier, in one form or another, was not as expected. However, despite this fact, many felt that they could participate through the forum, and were proud of their ability to 'have their say', the fact that many felt their views went unheeded when they raised their issues led to dissatisfaction both with the process, and with the final product.

Context

There was a lack of information on how high the barrier would be, and no realistic predictions of the improvements it could achieve. This meant that the residents seemed to think the barrier would totally block the noise, and as they could still hear the noise they largely felt that it had either not worked at all, or that it had worked but not as well as expected, or that it had not served its purpose. In addition, many commented on the lay of the land and how the barrier did not undulate with the land, statements that it needed to be higher in places were made, but they also made comments that they did not know whether this was possible A greater understanding could have been achieved with less questioning of its value had better information been provided initially.

Intervening Conditions

The Highways Agency had attended meetings and told them about the form and colour of the intended barrier, but had failed to impart realistic expectations on how the noise could be reduced, and problems incurred through restrictions of height and land undulation. If they in fact had imparted this information, but the residents had not retained it, it could still be considered ineffectual.

Action/ Interactional Strategies

The Highways Agency had reacted to the phenomenon of public participation by attending the meeting, but had not reduced the chance of unsatisfied expectations by not relaying accurate expectations of what the barrier could achieve.

Consequence

Consequently the residents had high expectations that were impossible to satisfy, leading them to believe the barrier had failed, and was ineffectual.
(The importance of realistic expectations being given along with all other information prior to the barrier's construction is illustrated. As all structures have their limitations, and these should be highlighted).

Category 6

Causal Conditions: The residents had/ have opinions that could have been used in effective public participation

Phenomenon

Many of the residents had ideas, and design suggestions that could have been raised and integrated into the noise barrier design. They felt that although many would not have wanted to design the barrier from scratch if they had been given choices on form (winding in and out of trees), finish (more natural and blended), height (higher and in line with the lay of the land), and with better consideration for blending of the barrier over bridges, that they not only would have liked to participate, but would have added valuable ideas.

Context

The fact that the Forum is in place should allow easy access to develop effective communication between the locals and the developers. However, some of the Asian women felt unable to go to the meetings, despite attendees thinking to the contrary. This means that the Forum would be an effective means of engaging the residents but not necessarily all of them.

Intervening Conditions

Many felt the barrier did not reflect their area appropriately and felt as residents of the area they were better placed to develop such a thing.

Choice was another factor raised, which would counter the problem of designing from scratch. (The HA claim choice was given, but as the noise barrier competition was not singularly devised to develop a barrier for Tinsley, but also for another community within Yorkshire. In effect a more integrative participation process was undertaken at the M1 / M62 Junction over 30 miles away in Altoffs. Therefore, in quite insular communities, such as Tinsley, one solution chosen by residents many miles away cannot be expected to fit the criteria and aspirations of the residents in Tinsley).

Other intervening conditions were firstly, the lack of opportunities for some sectors of the population to become involved due to language, time constraints, and other commitments. Tinsley Forum, although accepted as a very positive community asset, seemed to imply individually a 'full and long term commitment' which took up time, 'burned people out' etc. So if people did not want to be 100% involved, but had suggestions and felt they could benefit the design, there was no opportunity to impart this information. Tinsley Forum should not have been seen as the sole option for engaging the locals.

Consequences

There are several consequences of the public participation (PP) not being effective. Firstly, ideas that could have benefited the design were not heard. There was a feeling of frustration at not being allowed to influence their own environment (ownership), which led to rejection of the barrier "it looks like they have just plonked a 6ft fence there". Also, due to lack of imagination in engaging the wider residents. Those unable to attend meetings felt no opportunity to impart their ideas, which presumably ostracised large swathes of the community. The lack of PP, also led to the previous two phenomena, that there was less opportunity to give realistic information about the barrier's potential and distrust and disbelief of the experts.

Category 7

Causal Conditions: Communities are both willing and able to organise themselves into action strategies, but feel this action is unsupported, or even ignored leading to frustration, and rejection of things such as the barrier

Phenomenon

The Tinsley Forum's existence and attendance figures are testimony to the local community's willingness to take action in a defiant manner to better the area. The fact that the majority of those interviewed had at least heard of the forum illustrated its effectiveness at engaging a large proportion of the residents, if not all.

Context

However, the comments made in an almost passive defeatist nature, regarding the fact that the residents ideas were not used or heeded "so what's the point", illustrates the importance of nurturing and respecting the residents ideas and fully involving the residents when they are willing to give their time to it.

Intervening Conditions

The problem is that due to feelings of alienation, and a lack of support for their enthusiasm to be involved, many now do not feel they can change a situation, 'so why bother'. On the other hand, in scenarios where the community feel they have influenced decisions such as with the Tinsley Tree Project, this defiance is rewarded, and the residents feel empowered. This was illustrated by the benefits perceived by the residents from the Tinsley Tree project, where several hundreds of trees had been planted alongside the southbound carriageway of the M1 following pressure from Tinsley Forum and the local residents and businesses. The comments about this project even went so far as to state that the trees had considerably reduced both air and noise pollution despite the trees being quite immature and realistically probably not attenuating any significant noise.

Action/ Interaction Strategy

This is a powerful illustration of the importance of an effective PP process. Negative comments made about the noise barrier were not about it having been built, as the residents felt that their campaigning had given them the barrier, again empowering them. Their complaints were instead all about things they felt they could have made comments about i.e. heights, finish, form. This raises the question, therefore, if they had felt more in control of these aspects would they have perceived the barrier to be more effective? There is no definitive answer as to whether the barrier had worked due to lack of official test results to prove a before and after change, however, ultimately it is the perception that counts. If the barrier has worked to some extent when tested scientifically, if no perceived improvement occurs then it can only be perceived as ineffective.

Category 5

Causal Conditions: Noise reduction over aesthetics, but aesthetics has its place

Phenomenon

The residents unanimously stated that the noise barrier should first and foremost reduce noise, but many comments were given about the barrier's form, as related to category 7. The residents all seemed to have well formed opinions on how they would have wanted the barrier to look.

Context

This raises the question about 'function and form'. Form is evidently important, but more importantly is that its form influences the perception of the barrier's function.

Intervening Conditions

For example, the thoughts that the barrier should have been "more solid", "higher", "more natural like an earth mound". All imply that the form influences the perception of the barrier's effectiveness to reduce noise, regardless of any actual scientific evidence. Therefore, if the effectiveness of the noise barrier was judged on its form, and its form's effectiveness at reducing noise, is guided by integration of the public ideas then a full circle of the importance of effective PP emerges.

Action/ Interactional Strategies

It would, therefore, be beneficial to find out prior to building, by providing a choice, which barrier material is perceived to be more effective: -(This theory is investigated further in Chapter 8). Illustrating the importance of customised participation and fully integrated planning. Regional variations in preference for various barrier forms are discussed by MD-Taha (1999).

Consequences

The consequences of this are that the function and form should not be looked at as two separate issues, but as one, and then the appropriate barrier can be produced for the appropriate area by and for those it's intended to protect. An overview of the process above is presented in an abbreviated form below in Figure 4.2.

Processes		***Outcomes***
Causal Conditions	→	The conditions that give rise to the phenomenon or categories, its specific set of properties in which it is embedded.
Phenomenon	→	An explanation of the predominant characteristics of the phenomenon.
Context	→	A context represents the specific set of properties that pertain to a phenomenon; that is the location of events or incidents pertaining to a phenomenon along a dimensional range.
Intervening Conditions	→	The broad and general conditions bearing upon action/ interactional strategies. These include time, space, culture, economic status, technological status, career, history and individual biography.
Action/ Interactional Strategies	→	The methods by which respondents address issues, or by which external bodies aid the resolution of any problems inherent in the phenomenon.
Consequences	→	The consequences of these actions be it successful or not, and the basis for theory development to explain or resolve issues.

Figure 4.2 The paradigm model: Adapted from Strauss & Corbin (1990: p 99)

4.2.3 Selective coding

The final stage of the coding, 'selective coding', enables the final development of the grounded theory, it is the process of 'making it all come together by integration' (Strauss and Corbin 1990:96). This is not that different from the process of putting the data back together again in 'axial coding', it is just done at a more higher and abstract level. Where as axial coding puts the concepts into categories by working out the salient properties, dimensions, and associated paradigmatic relationships, giving the categories richness and density. Selective coding starts to form relationships between the categories, and the story line starts to emerge. At this stage a core category that seems to define the research emerges, and the way in which the other categories relate to this can be woven into the storyline (Strauss and Corbin 1990:116-120).

The key themes were derived from five of the seven categories produced. The remaining two, were interesting and helped define the outlying position of the theory by describing many issues that impacted on the community under investigation, and also placed the importance of the core themes in context with the perception of other issues in the area. However they were not essential to the description and validation of the core category and were consequently abandoned at this point.

In addition the first two stages of the grounded theory of the expert interviews were undertaken, this further influenced the core themes.
Therefore the remaining categories that supported the core categories were the following:

- Distrust and Disbelief in Experts.
- Unsatisfied Expectations.
- Un-utilised public opinions
- Rejection of community initiatives.
- Noise reduction over aesthetics, but aesthetics has its place.

The core category, (or theme) basically described the storyline of the grounded theory, and was influenced by all of the supporting categories. The main theme and the basis of the grounded theory, was defined as 'The Consequences of Ineffectual Public Participation Processes'. The full definition of which, with accompanying respondent quotes can be found in Section 4.3 below where the overall grounded theory developed from the qualitative investigation is presented.

4.3 The core theme of the grounded theory on the barrier's development

The core concept that emerged from the coding was 'the consequences of ineffectual public participation processes', this is considered and developed into a theory in the following sections, and is the core of the grounded theory.

Figure 4.3 illustrates the main internal and external influences and realities that impacted upon the lay and expert categories. The diagram illustrates that most of the categories are resultant of internal perceptions resultants from extraneous influences such as previous experiences. The diagram also illustrates however, how external realities such as time pressures etc impact upon the categories. Overall the diagram shows that the overall core category is a product of many complex thought processes and perceptions of both the lay and expert persons. The diagram also illustrates how multi-dimensional core category building is, and how less apparently related themes could influence the overall category, despite their initial salience sometimes being difficult to see.

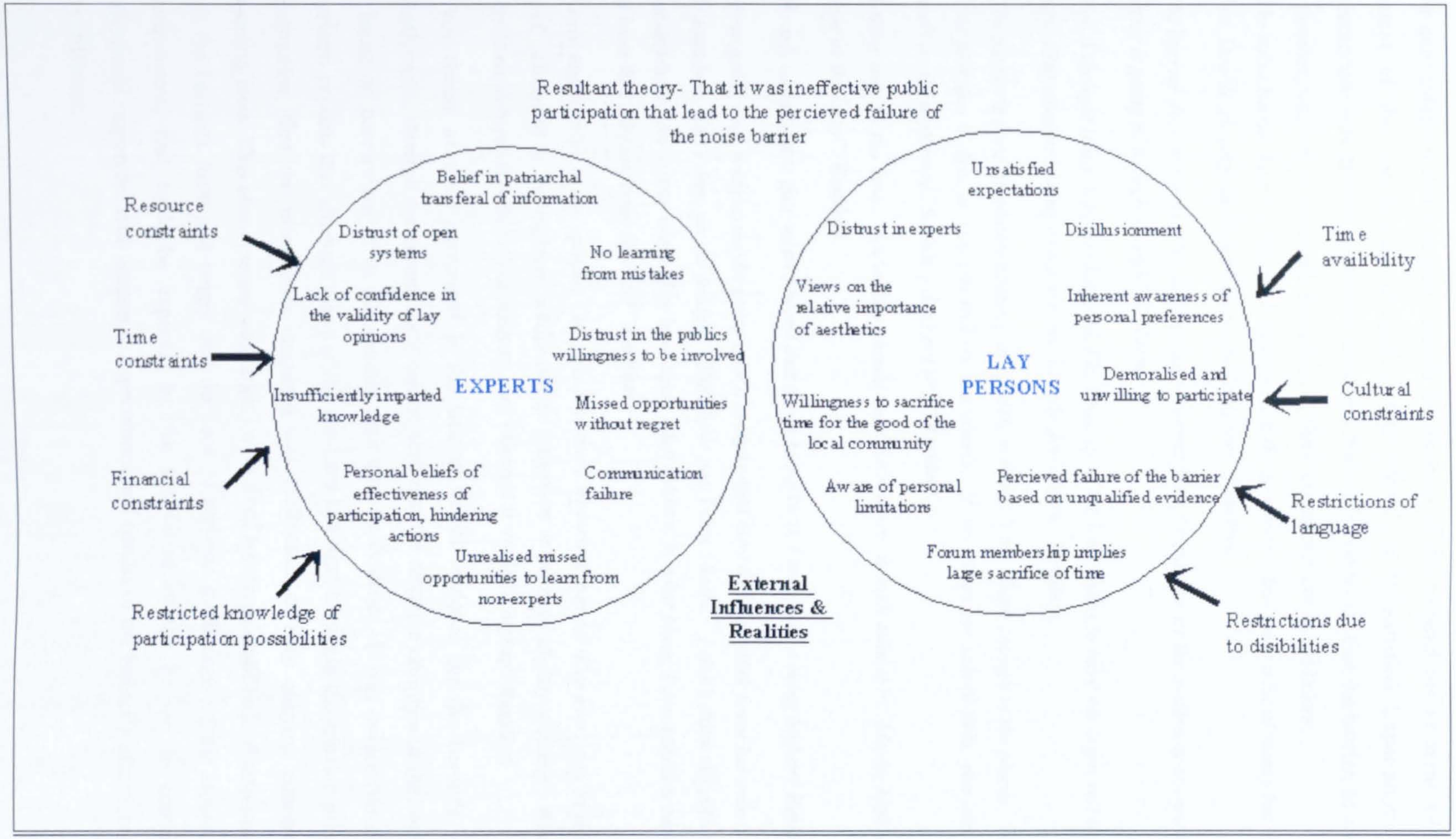

Figure 4.3 A representation of the influences upon the categories and the resultant theory

4.3.1 Evidence of the 'unsatisfied expectations'

The core category that emerged through the analysis of the respondents' answers, within the context of the contributory categories, was related to 'Unsatisfied Expectations'. This phenomenon was derived from those residents that made comments that the barrier, in one form or another, was not as expected. Selections of these comments are noted below.

"The noise barrier hasn't given much improvement the government has spent a lot of money but it has no effect. Double-glazing would have been a better option" ***Resident.***

"The barrier does not work. I've seen no improvement from the barrier as the motorway is raised, so no barrier is going to be high enough" ***Resident.***

"Well, I thought it was a good idea until, like I say, lie of the land seems to have not improved in certain areas. But whether it's improved in some, I really don't know" ***Resident.***

" The barrier's done absolutely nothing, absolutely nothing. It isn't high enough in the places. They can do six foot, but it dips, so you can still see the wheels. If you go on the school field, you can see the wheels on the motorway. So that's done nothing" ***Resident.***

"I think they're too low. Maybe they should have been twice as high than this. Maybe higher, same height as the lorry". ***Resident.***

"My only complaint is that, when I heard that it was being built, I imagined it being higher" ***Resident.***

" Even going over bridges, maybe going over a bridge might have to be a timber fence but even they look odd somehow, don't they, on the bridges. They have not, I don't know. I don't think the colours have done anything. No matter where they have been, what colours, in what place, I don't think it matters. It just looks like a 6 foot fence, don't it?" ***Resident.***

"Fairly nondescript in my opinion. It looks like every motorway barrier I've ever seen in the whole world. Designed by an engineer, whose artistic judgement is perhaps slightly wanting! What does surprise me very much is that it's actually so low. I thought it would be higher" ***Resident.***

A key theme of these comments is the lack of actual evidence for the barrier's lack of effectiveness, through the comments it can be seen that the negative opinions of the barrier are all based on perceptions of its form rather than specific evidence. It was evident through the interview process that although many of the residents had tried to obtain information prior to its construction, that the information acquired was ineffectual at both allaying concerns and imparting facts. This phenomenon was largely a result of a perception of lack of information on both the barrier's form and height and the lack of realistic predictions of the extent of the improvements that could be expected by the imposition of the barrier. In contrast the professional responses, with respect to expectations and results of the barrier's effectiveness are very different:

"It's certainly effective in parts, I think that people's perception is that's it's a noise removal measure, rather than a noise reduction measure, and people have written saying it's not very good we're only getting 3dB reduction, and that's quite a success. If I thought that I had achieved that I would have said I've succeeded. And anything over that is a bonus and I think there are quite a few properties that are still in the shadow. Those properties where the roads high and they're below the level I think we were hopefully looking at 10 dB(A), because they were actually in the shadow obviously those that get 2-300 meters away, by definition are not going to get too much reduction. There are areas where it isn't effective because it needs to be continuous because where the road dips and you've got properties in what they called the arena type effect, if you can see the vehicles you can hear them, because its a direct line to source. So there were some people who were upset because the road dipped at the embankment and the barrier followed it, which again needs to be a continuous barrier. Otherwise the effectiveness is lost upstream and downstream". ***Expert.***

"We haven't gone back and measured it, although someone else has claimed they have, I think that was the school or something. And that's when they said it's only gone down 3 to 5dB, and I said that's pretty good." ***Expert.***

"I think by definition because you put up a noise barrier two meters high although some people wont benefit as much as others some will, we know by definition, especially where the motorway's on an embankment we know that people will have benefited. Because we know how it works, but they may well not have perceived it or appreciated it and that's why we do it". ***Expert.***

The disparities between the views of the experts and the laypeople are pronounced in terms of the barrier's effectiveness, this is clearly due to the key difference between the two parties of unrealistic and realistic expectations. This is not to say that the barrier does work perfectly or that it is a total failure, and without definite proof this is impossible to say. However, it does confirm that either the information was not imparted to the residents, regarding realistic expectations of the barrier's abilities, or the information was not imparted in an effective manner, which the residents retained.

The researcher, when questioning the experts, felt that although the necessity for imparting information was accepted. That the true extent of the importance of the information being understood was not fully acknowledged. In many respects the researcher got the impression that the experts felt they had done all they could, despite the acknowledgement that the information had not been fully digested and retained.

Indeed it was apparent that not only was their view of participation one inline with a one way flow of information, conceptualised as 'tokenism' by Arnstein (1969), but also that the significance of that information being understood was not valued.

4.3.2 The consequences of mutual distrust and disbelief

The second category that was largely attributable to the first category, and of previous experience was a 'Distrust and Disbelief in Experts". Many residents gave strong views as to the rejection of expert opinions for example:

"Well, no, because we've had that much trouble with the experts. I mean, they have put islands in and had to take them out before today, when lorries can't turn round corners and get into factories gates, and things like that, you know, because sometimes it's somebody down in London, down in an office, and they don't know the land. They don't know, all they see is a road map. And it don't work like that" ***Resident.***

"I think I would want to be involved. Experts don't know what we need. I think that's what's been happening. Everything's being decided for you, and people not having their views put forward. It's been mostly whatever's happened." ***Resident.***

"I just felt that yet again, they have not done it right. It's always the case that they do things half cock". ***Resident.***

"The height. People in Tinsley think the barrier is a waste of money and time; authorities ignore Tinsley. It's like an Island" ***Resident.***

The experts who made comments on the validity of the public's comments also reciprocated this distrust to some extent. Implying that a non-expert opinion would be too idealistic and consequently unworkable in a real world scenario.

"Very difficult, if you involve the public they want the earth, they see no reason why we cant have noise barriers 5 meter high the length of the M1. If we'd have just gone in there and put up the bog standard timber fence, I think we would have had complaints. They would have said well, why have you just stuck up a Timber fence could not we have had something a bit more aesthetically pleasing. It's a difficult one, halfway house, do you have full public consultation do you tell the public what's happening it lays somewhere in between" ***Expert.***

"So public consultation is always in the loop but it's the level of that if it's a noise barrier to protect A and B, its very dangerous, we went to Altoffs and we went to Rotherham and they asked for it to be increased in length slightly but that's the problem you get is that, I don't think a barrier will ever be too long there will always be someone on the end of it. It is a case we've got £5 million across the country year on year" ***Expert.***

4.3.3 Evidence of unutilised public knowledge

However, many of the residents felt that they would have not only been able to give a valid contribution to the barrier, but would have also offered examples of their suggestions during the interviews, for example:

*"I would personally go for the natural effect, with greenery, if that worked as well. I think that in some cases the trees on the motorway side of it, like which the DETR planted after pressure from us. When our tree planting project, planted on the other side of the boundary, they saw the light and planted on the other side of it". **Resident***

*"I think it ought to just blend in more altogether. Higher, blend in more. It definitely just looks as though somebody's plonked a fence there and not given it any thought" **Resident***

*"I think it's got to blend in, and obviously the right height. And, obviously the height's going to have to vary in whatever place it's at. And maybe, I mean I don't know enough about noise, maybe it don't want to be just in a bang straight line" **Resident***

*"I think the community's input would have improved the barrier well, the barriers might have been better if the community had been allowed to have a say" **Resident.***

What was striking from these comments was the acceptance of their limitations, due to their lack of expert knowledge on noise. However, they largely felt they could have successfully contributed to attributes of both height and finish.

*"I think I would definitely have it more solid, and also higher than these. Much higher than these. I think a double layer on these" **Resident.***

*"Effectiveness, materials, size and location. Striking from the motorists side and a natural blending for residents, noise reduction is very important" **Resident.***

Many responded to picture card prompts of several barrier types with firm ideas of how well they would perceive each barrier type as being able to attenuate noise (see *Appendix 1D* for copy of the prompt images).

The fact that the residents felt their opinions were un-utilised compounded several problems, the factor of trust in experts, in addition to their unsatisfied expectations, made their perception of the barrier's effectiveness reduce. This in turn, led to feelings of frustration and a loss of ownership of the project. Through the analysis of the expert interviews it became evident that the residents opinions could have been integrated at several stages; for example.

*"They were all as equally effective, if they could conform to the HA document". **Expert***

*"So then it was down to aesthetics". **Researcher***

*"It was down to aesthetics, the market scheme, longevity, maintenance anti-graffiti, to some extent it was a compromise between making it visible and making it attractive, and not causing distraction". **Expert***

Therefore, in effect, if all the barriers designed for the competition were compliant with the legal requirements then the residents could have been integrated to choose the winning design.

The ability to attenuate noise, was sited unanimously as the most important aspect of noise barrier development, but despite some comments to the contrary most did value the aesthetics of the noise barrier quite highly. With many of the residents implying that they had well formed opinions on how the barrier should look.

The striking aspect of this situation was the difference in opinion of how the barrier should have looked between the experts and the residents.
The experts felt that the barrier should have been a bold statement to reflect its gateway stature as the entry to Yorkshire. The residents all however felt that a more natural and integrated barrier would have been more effective, especially in light of the loss of green space in the area, due to both the motorway and recent commercial developments.

*"I think it could have been bolder". **Expert***

*"I think it ought to just blend in more altogether". **Resident.***

4.3.4 The consequences of rejecting community initiatives

The lack of proper communication had led to some grave misconceptions on both parts as to how the barrier worked, and how it should have looked. These misconceptions were illustrated further with the expert's opinion of how the public participation process had worked. The experts felt that they had managed to capture a large proportion of the residents through using the Tinsley Forum, however this method of public participation overlooked those who were unaware of the forum.

Of the residents that were aware of the Forum and had tried to get involved with the noise barrier's design, many felt disillusioned by their experience. The rejection of community initiatives left many of the residents feeling that they had no charge of their area, which according to the experts was true, as the Highways Agency was under no obligation to have a public consultation:

The Highways Agency's approach can be described as patriarchal in its practise, in that despite their technological expertise which evidently restricts the prospect of allowing full 'citizen control', they would still not actively attempt to engage all affected community members, on areas that could easily and without compromising the end result have been decided by the community. It is accepted that there are limitations with regard to financial constraints on how much participation can be undertaken. However, as illustrated with the reliance on one Forum as the main means of engaging the public, that the level and reasoning behind the current methods is neither extensive enough nor does it fully acknowledge the benefit of allowing a two-way flow of ideas.

"Because the barrier goes up in improvement order, we don't have to consult on it, it's a case of improving the highway under our highway land, it's basically an improvement to an existing highway and that included under a general power. But we do engage people purely on this cross load of information" ***Expert.***

The experts did acknowledge the importance of public consultation and participation as illustrated in the following quote:

"If we're doing new works we certainly like to consult with people and again, we consult with groups all the time, you know make them aware of what we're doing, there's environmental group there's lots of partnerships now that are going on, so that people are kept constantly aware, and we used to go out and talk to parish councils on a regular basis and asked them if they had any problems, it is about engaging the public because at the end of the day they are our customers, our customers are not just road users they are also the people that are effected by the route". **Expert.**

At the extreme, the methods used could be described as patronising, in that they 'don't have to involve the public, but do so as a service'. Rather than putting the opinions of those that the barriers are intended to protect as an incremental deciding factor on the success of the barrier.

To conceptualise this within an understandable framework, would be to define an effective approach as that where some power is delegated to the community, and the cross flow of information between all affected residents and the experts results in a barrier that is accepted by the community both for its benefits, and with its limitations. The findings of this work do lead to the theory that a lack of inclusion and integration of all groups and ideas respectively, result in a barrier that falls short of its potential.

Unfortunately despite the acknowledgement of the importance of integrating local communities, in practise, the methods used were more dictatorial than participatory, especially for the residents who attended the Tinsley Forum. This was largely due to the fact that the residents of Altoffs, an alternative section of the project some 35 miles away, were the only residents able to participate and influence the design. They had an influence on the colour, where as the residents of Tinsley were told what was going to happen and had no real influence over the design or finish. The experts did claim that, had there been severe objection to the barrier, they would have reconsidered it, but as was captured in a statement from one of the residents this was not a real prospect for the Tinsley residents;

"And they were doing it in 3 different colours, and one thing and another. And I think, if it's only 6 foot high, or whatever it is, they don't have to have a lot of permissions, planning permissions. And, so from that point of view, like, you say go ahead, because, well they go ahead anyway, but you say go ahead because something's got to be better than nothing. But then when you realise the lie of the land" ***Resident.***

The importance of effective public participation in the design of noise barriers has been highlighted by several investigations in the past as reviewed in the literature. However, it would seem that it is not the will to do the participation, it is the way. For even if the residents who attended the Tinsley Forum had been able to influence the barrier's form and height, the residents of Tinsley who were unaware or felt unable to attend the Forum meetings would still have been ostracised.

4.4. Discussions and conclusions

This research has illustrated clearly that even when public participation approaches are attempted it does not necessarily guarantee a project that is accepted by everyone, and more importantly that is perceived by everyone to work. It is, therefore, 'Ineffectual Public Participation' that creates more problems than no participation at all. This statement is enforced in three different ways by the results of this investigation. Firstly, the acceptance and perceived effectiveness of the barrier reported from the residents of Altoffs, Leeds, who had received the exact same barrier but had influenced its design (Joynt 2002). The second factor is the positive reports about the Tinsley Tree Project, although not related specifically to this project; the trees benefits were perceived greater than that possible, due to their being immature (Magrab 1975; Harris and Cohn 1985).The final factor was that amongst the residents who had a greater awareness of the barrier's construction, those who were unaware of its existence reported more negative comments upon its effectiveness.

The use of the grounded theory approach enabled the residents to have a voice, and through that voice, the underlying facts of firstly how the residents perceived the barrier's effects, and secondly why they had perceived it in that way, were revealed. The use of this method does limit the quantity of respondents able to be interviewed, however, it has many benefits in the depth to which phenomena are both revealed and explained, which combined can inform theories and future decisions of this nature if required. Had a more quantitative approach been utilised at this stage the phenomenon may have been highlighted, but its importance above all other salient factors and the explanation would have been missed. The use of this approach enables the further evaluation, using quantitative methods to be better informed and guided, allowing the extent of the problem to be revealed.

Therefore, through the grounded theory approach, the theory of the negative consequences of ineffectual public participation has been highlighted. Although the experts claimed that it would not be impossible to please and engage everyone, the lack of communication, proper utility of existing resources and distrust on both parties, led to the fact that nobody in this sample of ten respondents felt the benefits, and the barrier in effect failed.

The key themes developed through the analysis of the expert interviews are the perceived limitations of the projects due to several factors. The delegation of responsibilities for engaging the public, and despite accepting that public participation is needed, a true sense of why it is important and the opportunities for improving projects remains unrecognised. The use of the consultation process is seen as an opportunity predominantly, to impart information as opposed to receive it, as well as being an obligation as opposed to an opportunity to inform and enlighten the project. The fundamental themes underlying this are the un-utilised potential and opportunities and also a lack of imagination on how different methods of attempting public participation, particularly to engage disenfranchised minority groups, can be achieved.

The researchers perceptions have been incremental to the analysis of the interviews, and it is accepted that there was a potential bias in favour of the residents due to the comparison of 10 peoples (lay) opinions with 2 peoples (expert) opinions. This was emphasised by the researchers allegiance to the principals of feminist ideology, which value the opinions of all, and sees merit in social inclusion and full participation, this was in contrast to the patriarchal ideology adopted by the Highways Agency. It is accepted that alternative interpretations of the data could have resulted in a differing opinion of the result. However, it has been the researchers aim to develop an opinion based on the facts provided by the respondents interviewed, and not to impart personal opinions upon the respondents, but rather to develop the theories based on issues raised within a free flowing conversation, where the respondents arrived at their own opinions. Therefore, it is felt that the construction of the resulting theory reflects the reality of the situation as seen from the perspective of all the affected parties.

In conclusion the context of the phenomenon, is the isolation of the public or lack of involvement, which reduces the feelings of ownership for the project. With the reduced feeling of ownership, in addition to the perceived outright rejection of salient views, comes a related feeling of alienation and removal of local power. When this is done, despite efforts to become involved, a negative perception of the implemented project occurs. This is compounded by the lack of understandable information about realistic expectations and a lack of awareness as to the extent of the importance of fully integrative public participation by the barrier providers.

With regard to the Highways Agency's policy on public participation it would be seen as a large omission in previous practices that public consultation was not mandatory. However, with the ratification of the Arthus convention, this is likely to change. However, this change should not be seen as a hindering obligation, but an opportunity to improve the final outcome.

Although the researcher does not work as an expert directly for the Highways Agency, her experience with the Highways Agency in a professional capacity and within the constraints of a budget and profit driven environment does give some insight in to why the scenario of ineffective public participation would arise. Therefore, for public participation to be a realistic option with the realisation of the true potential benefits, then a greater emphasis need to be given to training on the importance of public participation with employees and undertakers of design initiatives. In addition it is also fundamental to provide financial support for the provision of resources to undertake effective participation.

As public participation as a result of the EC Directive (2003/35/EC) from 2005 will be a mandatory obligation, it is hoped that the financial resources are put in place to undertake participation to its fullest extent, allowing a partnership between the expert and lay opinions to result in a barrier that not only works in objective terms, but is perceived as effective by those it is aimed to protect.

The key to the theory therefore, for creating and effectively incorporating public participation into the design of a noise barrier, is the willingness and ability to allow a flow of communication and information between all interested parties. In addition, realistic expectations should be imparted to the public in a manner that they understand and accept, together with overall utilisation of the views and opinions of those that the barrier is intended to protect. Without this the ownership of the project is removed leading to frustration and resentment and a consequent rejection of the barrier. The financial considerations of adopting these strategies would likely be ultimately less than the complete failure and replacement of the barrier, as has been illustrated in cases before Hall (1980); Cohn (1981; 1982); Pendakur and Pyplacz, (1984) and Golding (1986)..

The next stage of this investigation therefore is to reveal the extent to which this theory is valid within the wider population of Tinsley, Brinsworth and Catcliffe and also to find any further relationships between the perceptions of the participation process and the perceptions of the noise barrier's effectiveness. In addition, issues, which were raised within the qualitative analysis, such as accessibility and opportunities for minority groups to become involved, and to what extent they are currently excluded, are explored. Also the opportunity for the respondents to impart their thoughts on which method of participation would be best suited to various sectors of the community are revealed and tested. To find out whether the trends revealed would be representative of the population as a whole. These insights are then further compiled to give an overall view of a sustainable approach to the development of a noise barrier.

Chapter 5 Quantitative Investigation: Expanding the Case Study Findings through the Triangulation of Methods

In Chapter 4 a qualitative research approach was used to develop a grounded theory, which described the consequences of ineffectual public participation (PP). In order to test and develop this theory further, it was decided that a large retrospective quantitative study would be carried out, concentrating on the whole area impacted upon by the noise barrier. This process of integrating both qualitative and quantitative methods is known as 'triangulation'.

The interest in the non-acoustic and sustainable aspects of noise barrier development stemmed from a discovery in the literature and research undertaken in Chapter 4, that through the use of effective PP the perception of a noise barrier's worth can be vastly improved. Despite the discovery and acknowledgement of this fact by noise barrier developers and governments around the world, there is still a lack of full commitment to undertake more successful participation and the actual practical means of doing this still remain largely undeveloped (Hall 1980; Cohn 1981 a; Cohn and McVoy 1982; Pendakur and Pyplacz 1984; Golding 1986; Kotzen and English 1999; Md-Taha 1999).

5.1 The positivist research methodology

5.1.1 The origin of the research and the relevance of a quantitative study

During the qualitative investigation the main theories that emerged were that it was not the lack of PP that had led to the barrier's failure, as perceived by the residents, but it was the ineffectual use of the PP process that led to the barrier's failure. As a consequence several new lines of enquiry emerged which included questions related to the following,

- 'How had the wider community perceived the barrier?'
- 'Was the scenario reported in Chapter 4 an anomaly?'
- 'If so were the rest of the residents completely satisfied?'
- 'If the current method of PP had not worked, what were the reasons behind it not working? And how would the residents foresee changing the process to make it more attractive?
- 'Under-representation and alienation of minority groups, was also raised as an issue, who were these minority groups'?
- 'What was the cause of their alienation and why were they unable to participate'?
- 'Which measure would they choose themselves, to integrate more successfully into the planning process, and would this encourage them to get involved'?

- 'Did the minority groups that the participants belonged to effect their perception of their opportunity to become involved?'
- 'And finally did the residents perceive the barrier as effective, and how did the results of their perception relate to all the other factors noted above'?

All of these queries led to the need for a wider ranging study, than that possible using just a qualitative study. The qualitative study was invaluable however in defining the research question and focussing the research and minimising wasted time and expense carrying out an unfocussed quantitative investigation.

The use of the quantitative study may seem to elude from the feminist aspect, which influenced the previously chosen qualitative method. However, whilst the qualitative approach overcame the problem of giving a voice and language to the residents, with which to express their concerns and opinions, the quantitative approach served to indicate the extent and patterns of their inequality. According to Brannen (1992), a feminist stance ought not necessarily imply an allegiance to a particular methodology. With the more important issue being that of theory, it should therefore be possible to conduct statistical studies, which test hypothesis guided by feminist theory as well as qualitative studies that give a voice to the people themselves (Brannen 1992:3-33).

To ensure that the 'giving of a voice' to the population was not restricted, a key point of the research undertaken was that the data captured was from all representative subgroups and minority groups in the study area. The methodology for this is described in section 5.1.3 below, and illustrates the importance of the feminist ideal in understanding the non-acoustic and sustainable aspects of noise barrier development.

The crucial aspect in justifying a mixed methodology research design, is that both single methodology approaches contain both strengths and weaknesses and the effective combination of these methodologies, focused upon these relevant strengths and weaknesses to enhance the investigation (Brannen 1992:3-33). By using qualitative and quantitative methods in tandem a correction was incorporated that reduced the inevitable biases present in each method (Cook and Reichardt 1979).

According to Denzin (1970:310) cited in Brannen (1992:3-33), methods of triangulation may be 'between-methods' or 'within-methods'. A within method approach involves the same method being used on different occasions, while between-methods means using different methods in relation to the same object of study. For this investigation it was a 'between-method' that was utilised, in that there were similar traits between the qualitative and quantitative investigations. The investigation did not merely ask the same questions in the same form to more people, but instead the investigation was widened and developed new theories and themes. This is supported by Cook and Reichardt (1979) who claim that disparate methods which still converge on the same operations, are better than similar ones because the former are likely to share fewer biases than the latter (Cook and Reichardt 1979:21).

5.1.2 The sample areas

During the qualitative investigation, the sample of residents approached for interview all had specific links with Tinsley, either through residing or working there, with the exception of the two expert representatives. As noted previously, the noise barrier was not only built to protect the residents of Tinsley, but also extended approximately five kilometres in length to protect the villages of Brinsworth and Catcliffe. Therefore, as part of the wider quantitative investigation, these other areas were incorporated into the methodology.

Tinsley, Brinsworth, and Catcliffe have many indicators of social deprivation. Although some aspects of the communities give a reasonably encouraging profile of the areas such as the low crime rate, the influence of high unemployment and poor health, in addition to low house values have led the areas into decline. Much of this can be attributed to the M1 motorway with the problems of severance to the city/ town centres of Sheffield and Rotherham, respectively, causing problems for those who need to commute to the business district. In addition, poor public transport links, and the effects of the air and noise pollution from the motorway have contributed to diminishing house prices and poor health (East End Quality of Life Initiative 2001; Greig, et al. 2001). An overview of the social and economic indicators for the wards of Darnall, (which includes Tinsley) on the North East Side of Sheffield and the local authority of Rotherham are contained in *Appendix 2A*.

5.1.3 Multi-stage cluster sampling

In order to obtain a random sample of the population, to investigate further the theories and questions raised in Chapter 4, a method of unbiased sampling was chosen. The area affected by the noise pollution spread over 5 kilometres, therefore, a means of capturing a representative sample was adopted which allowed residents from all three villages within the area to be selected to answer the questionnaire. This was done whilst maintaining a random element of sampling; therefore one of the main clusters used was the already defined boundary of the three villages.

The second cluster was derived after consideration of the work of Pendakur et al (1984), who found that the perceived effect of a noise barrier was considered negligible beyond the third row of houses as judged by the residents. In addition Askew et al (1998) discovered that beyond 300 metres the effects of traffic noise in correlation to the perception of the noise after a barrier's development become less related. A cut off point of 250 metres on either side of the north and southbound carriageways was, therefore, implemented as this then put the most effected residents within the sample, who were more likely to hold stronger and better-informed opinions of how well the barrier worked.

A detailed map of the area was studied at a scale of 1 x 10,000, which illustrated all the houses, along with a random distribution of some of their numbers and the street names along the length of the 5km stretch of motorway and either side of the carriageways spanning 500 metres, this gave a catchment area for the total sample of 2,500,000 metres squared.

This area encompassed the villages of Tinsley, Brinsworth and Catcliffe, and the approximate[1] total number of residencies within the sample area was 1,067 homes. Being spilt into 50 metre bands oscillating out from the motorway further stratified the sample area. This gave a specific distance band of how far the residencies were from the carriageway, these were the second set of clusters to be analysed.

In order to ensure that each resident had an equal chance of being chosen a probability sampling technique was developed, to attempt to keep the sampling error to a minimum (Kinnear and Gray 2000; Bryman and Cramer 2001; Pallant 2001). This was done by first establishing the sampling fraction (Equation 5.1):

$$\frac{n}{N} = \text{Sampling fraction} \qquad (5.1)$$

Where n is the sample size and N is the population size.

In this case with an overall population of 1067, and a sample size of 188, (the total number of properties eventually approached), which translated as a ratio of 18 in 107. In total 188 houses out of the 1067 within the total population were approached. However, as the houses were not equally distributed between the 50m stratum bands, the sampling fraction was used to confirm that the minimum number of houses was approached in each stratum to be representative. Table

[1] The value is approximate as the buildings were viewed from a map, and not all were inhabited, nor were any distinctions made between dwellings, some smaller shops, workshops and businesses.

5.1, therefore, illustrates the total population of houses within each strata and the minimum number that would be required to be representative. From the sample equation for every 100 persons in the population a minimum of 18 had to be picked to be representative.

Table 5.1 Minimum ideal and actual sample in each stratum.

Stratum	Population	Minimum Sample	Actual Sample
0-50 m	40	7	21
50-100 m	230	39	35
100-150 m	268	51	65
150-200 m	303	58	37
200-250 m	226	43	30
Totals		198	188

As can be seen in Table 5.1 the sample chosen was just short of that to be fully representative of each of the populations in each stratum. However, with consideration to the estimation of the overall population initially, due to the absence of an alternative means of calculating the population other than counting the buildings from a map, and in light of the fact that some of these properties included could have been shops, or businesses the sample numbers were accepted as representative of the population.

The individual houses within the stratum were chosen randomly again using the 1 x 10,000 maps, as noted above, the map was used to identify the addresses of the potential respondent. As standard ordnance survey base maps, at this scale have the entire street names illustrated, along with a random selection of house numbers to aid orientation. The houses chosen for the sample were picked if a house number was displayed on the map. This was random in that by looking at a map alone the occupant's age, gender, or ethnic background could not be determined.

In total 188 households were approached to complete the questionnaire, this gave approximately 18% of the population the opportunity to give their views. The residents were approached in a two-step process; firstly a letter was distributed to each property identified as a potential respondent a week prior to the house call. The letter contained details of the date and the time that the researcher would be calling, and an explanation of the background of the study and the requirements to participate. This preliminary letter was sent in four languages, English, Urdu, Bengali and Somali (Sheffield First Partnership 2000), to ensure an understanding of the procedure *(Appendix 2B)*. In addition, telephone numbers for both the researcher and the supervisor were listed to answer any further queries.

Prior to the decision to distribute the questionnaires by hand other methods were considered. These included the use of mailed questionnaires; this is a convenient means of distribution, however, it does have a higher non-response rate. Methods to increase the response rate include the 'Total Design Method', as created by Dillman (1978), which claimed to aid response rates of up to 60%, in samples of the general public. However, this method claimed that without full adherence to the procedure that the chances of such a response rate would be significantly jeopardised. Despite the method being theoretically possible, the additional factors of the area having been extensively surveyed prior to this study and the use of different language questionnaires, plus the opportunity to assist those unable to complete the questionnaire on disability grounds, meant that the use of mailed questionnaires was ruled out.

The alternative to this was to use a labour intensive method of distribution by hand; this method had several pros and cons, which are listed below.

Pros:

- The respondents made contact with the researcher, the questionnaire was not from an anonymous source and so they were less likely to ignore the questionnaire, due to the interrelationship developed from face-to-face contact.
- The arrangement of a time for collection at the respondents convenience, gave a more official verbal agreement to both complete the questionnaire and to return it.
- Any questions about either the research, or answering of privacy concerns could be addressed at the outset, reducing the chance of refusal to respond due to unfounded concerns.
- The amount of potential waste paper and stamps were significantly reduced, consequently reducing the stationary and postage costs. Any refusals could be determined on delivery and an alternative respondent could fill in the questionnaire.
- The researcher could aid the respondents when they were hindered by disabilities such as severe arthritis or visual impairment.
- The researcher could distribute the appropriate language questionnaire at the outset, rather than having to send 4 or more copies to each respondent.
- As the researcher spent significant amounts of time in the area, during the time the respondents were completing the questionnaire, any significant noise events occurring could be noted that could have influenced responses.
- In addition to the time the researcher spent in the area, distributing the questionnaires gave the opportunity for any personal perceptions of the various areas noise problems to be made. This aided understanding of the respondent's views, which was not possible by judging from a map alone.

<u>*Con's:*</u>

- The labour intensity of the method meant the data collection took 6 weeks, and cost significant amounts in transport costs to and from the case-study site.
- This high cost of transportation was further exacerbated when respondents were not at home at arranged times for collection, resulting in some cases in several return visits.
- There was a significant security risk to the researcher from approaching strangers alone.

Despite these cons the method of data collection proved very successful with a 57% response rate, and reduced errors due to misunderstandings. The method utilised could have been an indefinite one, in that for every refusal potentially an alternative respondent could have been found until a 100% response rate was achieved. However, the consequent added costs of transportation to site and further letters of announcement made this an unviable option, and so 57% of the population or 108 respondents of 188 was deemed satisfactory for representation.

The questionnaires were therefore distributed by hand at the pre-stated times. If successful the appropriate questionnaire was given to the respondent and a mutually convenient time for collection of the completed questionnaire was arranged. In the event of there being no-one in to receive the questionnaire a letter announcing a new time was posted. Up to three return calls of this nature were allowed before an alternative property was chosen. Returning to the map used previously and choosing a property either side of the unsuccessful property to select an alternative.

The actual respondent within the households, were chosen to reflect the population most likely to be exposed to the noise pollution and most likely to have noticed any benefits of the noise barrier. This approach differed from previous investigations where the respondents sought were the main homeowners (Md-Taha 1999). Therefore the first qualifying criteria was whether they had been living in the house for 12 months or more, respondents living in the area for less than 12 months were discounted and an alternative respondent was sought (see above).

Secondly, the respondents within the households were selected simply by approaching the person who claimed to remain in the home for the longest period in an average day; there were two reasons behind this:

The investigation aimed to eliminate the problems of under-representation of minorities. To have restricted the sample of respondents to homeowners, risked ostracising many key sectors, who may not have owned their own homes, but have an equally important opinion particularly, women, teenagers, elderly relatives of the homeowner etc. Although this method risked large proportions of similar groups being interviewed, it was assumed that it would be representative of the groups who remained at home for longer periods of time subjected to the traffic noise.

The second reason behind the choice of respondent is touched on above. The effects of noise were likely to be much more profound on people exposed to it for longer, therefore their perception of noise aimed to give a greater insight into the severity of the areas problems.

Included in the sample, which represented 10% of the area's population, was a wide spectrum of respondents in terms of age, gender, ethnic background and economic status. This confirmed the success of the random sampling approach undertaken and details of the respondents can be seen in the results analysis.

The advantage of multi-stage cluster sampling is that it allowed interviews to be far more concentrated; than would be the case if simple random or stratified samples were selected. The advantages of stratification can be capitalised upon because the clusters can be stratified in terms of the 50 metre bands to enable further dissection of the sample population by order of distance removed from the motorway (Bryman 2001:92-3).

The standard error of the mean[1] was calculated for both the clusters of the three villages, as well as for the properties identified within each 50-metre band using Equation (5.2) below. To establish how far the finding of the random sample could be generalised to the wider populations of both groups (Henry 1990:27).

$$\bar{x} = \sum_{k=1}^{K}\sum_{i=1}^{M_k} x_{ki} / \sum_{i=1}^{K} M_i$$

$$s_{\bar{x}} = [(1 - K/A)\sum_{k=1}^{K} \tfrac{(\bar{x}_k - \bar{x})^2}{(K-1)K}]^{1/2} - (1)$$

$$s_{\bar{x}} = [(1 - K/A)\tfrac{1}{\bar{M}^2 K}\sum_{k=1}^{K} M_k^2 s_k^2]^{1/2} - (2) \qquad (5.2)$$

where K: number of clusters selected Mk: cluster size $s\bar{x}$ *is standard error;* a *is number of clusters selected; A is total number of clusters in a population;* $\bar{x}a$ *is a cluster mean, and* $\bar{x}$ *is the overall mean; (1-K/A): finite population correction*

[1] Which is the difference between a sample and the population from which it is selected, even though a probability sample has been selected.

The overall mean equalled 62.7 of the total population and the standard error of the mean using the villages, as the main clusters equalled 35.5. The overall mean for the other cluster sample, with the 50-metre bands regardless of which village they were in equalled 12.46 and the standard error of the mean equalled 2.5 (see *Appendix 2C*). Standard errors increase as the differences between the cluster means and the overall means increase due to the differences being squared. Thus, the more clusters differ, the less the precision they represent (Henry 1990). Therefore it can be seen that the data analysed in terms of the 50-metre bands was a little more precise and representative than that analysed by village. However both clusters are within a level that can be accepted as representative of the population (Bryman and Cramer 2001:99-100). Throughout the analysis the statistical package SPSS11 was utilised to determine levels of significance for all the findings, this enabled the results to be extrapolated to the wider area with a degree of confidence.

5.1.4 The sample: An overview of the objectives

As noted in the methodology, researchers that have previously analysed the importance of PP in noise barrier design have under-represented some members of the community during data acquisition. However, using the methods here for targeting all members of the society and preparing for obstacles such as language barriers re-addressed this balance. This move to gauge the response of all members of the community, especially those who remained in the home for longer periods confirmed the suspicions that had arisen through the reviewing of the literature. These included the fact that females remained in the home for a longer periods during an average day, consequently enduring greater exposure to the effects of the noise pollution and making them better qualified to complete the questionnaire, this was illustrated by the fact that out of the respondents chosen at random 63% were females and 37 % were male.

With respect to ethnic background, data was derived and averaged from the Sheffield First Partnership for Tinsley (2000) and from the National Census data (2001), for the ward of Brinsworth, Catcliffe and Treeton, and was compared to the information recorded in the questionnaires. This enabled an assessment of how representative the sample was with respect to the overall area statistics. Figure 5.1 illustrates that the sample was very representative of the wider population from which it was picked in terms of ethnic background.

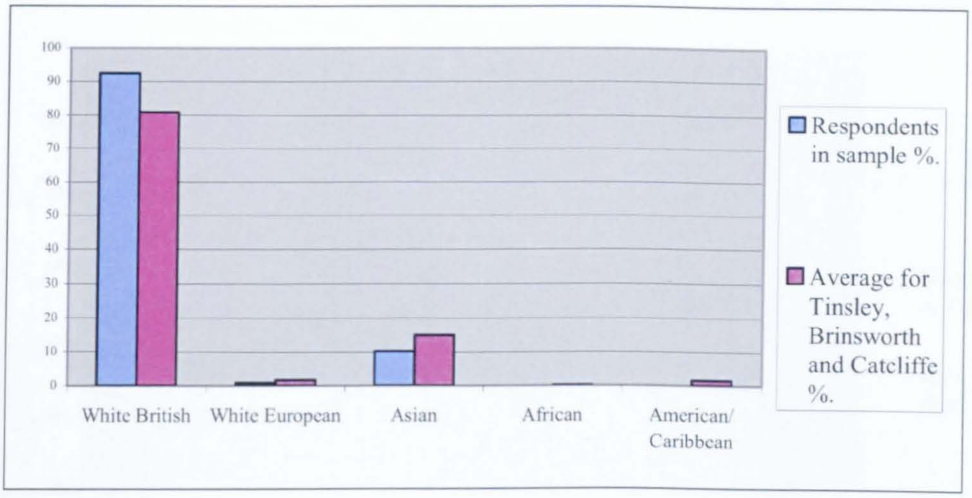

Figure 5.1 Comparisons of census data for the areas ethnic mix and that of the respondents.

The number of respondents from each of the ethnic groups, was representative of the parent population. However, the low numbers available as a result of the limited sample size restricted any statistical inference that could have been calculated. Consequently for the purpose of analysing the impact of ethnic minority status on the other variables, all non-British respondents were counted as of another ethnic minority and were evaluated together. The same principle was applied to the various minority languages, consequently the data for these were condensed into two groups of 'first language English' and 'first language other'. In a larger study with more resources the individual differences between the different ethnic backgrounds and languages would potentially produce very interesting results however this was unfeasible with the limited resources available.

The average ward level data for age and that of the respondents is compared and presented in Figure 5.2. The data was corrected and the cumulative curves illustrate the normal distribution of age group data, compared to the wider population.

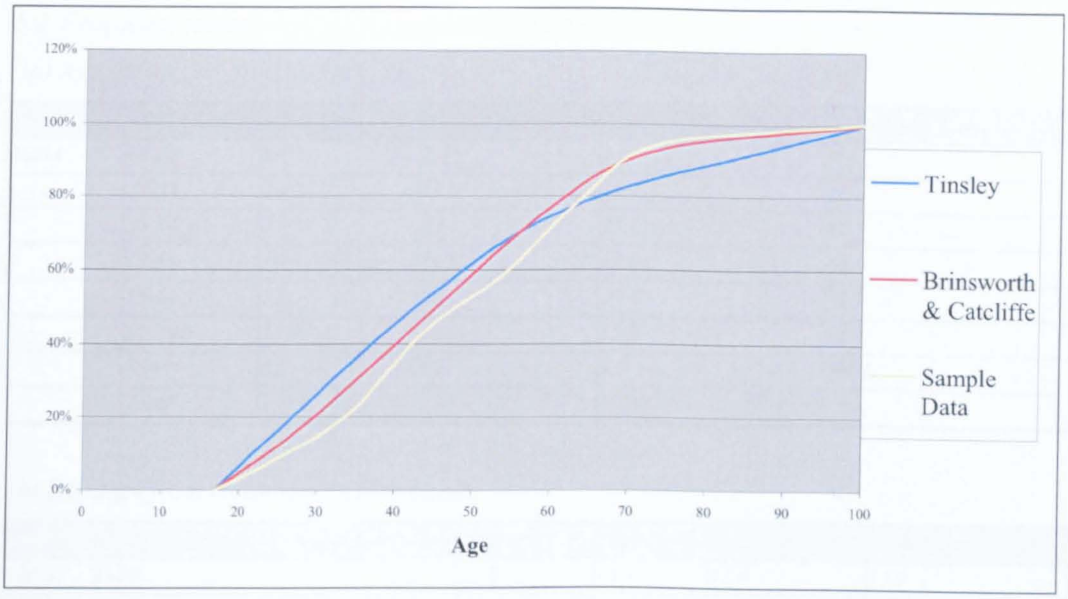

Figure 5.2 Cumulative curves of the age distribution of the sample compared to the wider populations.

Disability was another factor, which restricted the potential for some respondents to be involved in the PP process; therefore respondents were asked whether they were registered disabled. Out of the randomly selected group of respondents 11.2% were registered disabled, this is a higher proportion than the area average of 7.3%. This illustrates that of the respondents sampled, a greater proportional representation of the areas disabled gave their opinions.

The sample of the data was big enough to presume normal distribution, however, for minority groups such as those with disabilities, and those of ethnic minorities it would clearly be unreasonable to think that the population would be equally distributed in a randomly selected sample. Tables 5.2(a-d) demonstrate the data for the variables where normal distribution should be expected. These tables represent the same normal distribution as those presented in Figure 5.2 above and confirm the data is valid for statistical tests, these are referred to throughout the chapter to confirm that assumptions regarding normal distribution required for some parametric tests have not been violated.

5.2 Frequency tables

(a) Age group

	Age group	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-24	8.0	7.4	7.5	7.5
	25-34	14.0	13.0	13.1	20.6
	35-44	25.0	23.1	23.4	43.9
	45-54	16.0	14.8	15.0	58.9
	55-64	22.0	20.4	20.6	79.4
	65-74	16.0	14.8	15.0	94.4
	75+	6.0	5.6	5.6	100.0
	Total	107.0	99.1	100.0	

(b) Distance from motorway in 50m bands

	Distance from motorway in 50m bands	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-50	15.0	13.9	13.9	13.9
	51-100	24.0	22.2	22.2	36.1
	101-150	35.0	32.4	32.4	68.5
	151-200	20.0	18.5	18.5	87.0
	201-250	14.0	13.0	13.0	100.0
	Total	108.0	100.0	100.0	

(c) Village.

	Village	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Tinsley	40.0	37.0	37.0	37.0
	Brinsworth	42.0	38.9	38.9	75.9
	Catcliffe	26.0	24.1	24.1	100.0
	Total	108.0	100.0	100.0	

(d) Gender.

	Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	66.0	61.1	61.7	61.7
	Male	41.0	38.0	38.3	100.0
	Total	107.0	99.1	100.0	

5.1.5 Pilot study

In order to ensure that the questionnaire would gauge the correct level of response, and to remove any areas of ambiguity, five copies of the questionnaire were distributed randomly using the same method as noted above for identifying the respondents. The results of these questionnaires were recorded and as a result five amendments were made to the questionnaire, including the re-phrasing of questions to reduce ambiguity and the revision of a typing error. These question changes were not significant to affect the results output, as they were undertaken to reduce explanation of the questions upon delivery. Therefore the data collated from the other questions within this pilot batch were used as a valid data source in the overall data analysis. In addition to this the questionnaire was shown to a member of the sociology department and the planning department for review, and as a result minor changes were made to some of the phrasing and structuring of the questionnaires, as well as the inclusion of a note regarding the Data Protection Act, these changes were completed prior to the first piloting of the questionnaire.

5.1.6 The questionnaire, and the strategy for increased response rate

The questionnaire was developed to enhance the cross-sectional design approach of the research and had a number of purposes. In the first instance, it was to establish the existing impacts of noise pollution on the population, and to determine the relative importance of noise pollution as an issue of local concern, in relation to other environmental pollutants and social issues. Secondly, it was to gauge the public awareness of the noise barrier, and collate opinions on how its noise mitigation was perceived, in addition to establishing how the residents had perceived the PP process, in order to determine any correlation between the two. Thirdly, the questionnaire gave an opportunity for the respondents to give their opinions on what they believed would be an appropriate way of engaging the public for future environmental planning procedures. Finally, questions regarding the respondent's personal information such as age, gender, ethnic background, and ailments were asked.

The format of the questionnaire was designed to encourage the best response by beginning with open questions, which were about the area and environment in general. Had closed questions been used at the outset, the respondents would have adjusted to using the answer paper by the time they reached the open questions, and would be less likely to answer the questions without being influenced by what they perceived the overall questionnaire theme to be about (Munn and Drever 1996).

The main section of the questionnaire, which held key questions, was developed with a mixture of Likert style questions and simple 'yes', 'no' and 'don't know' question replies. Simplifying the method of response, reduced the chances of confusion, however the integration of questions requiring different response styles, other than Likert questions reduced the temptation to choose one number and circle it all the way through without reading the question. However, this is still an inevitable possibility that cannot be avoided with this style of data collection.

A section of personal information questions were placed at the end, to help gauge the make-up of the sample and whether there were any particular health problems that seemed to be common in the sample. These questions were better placed at the end of the questionnaire as at this point the attention of the respondent had been engaged and they were more likely to complete the questions, as to place them at the beginning would have risked antagonising the respondents by plunging straight into sensitive and personal questions (Munn and Drever 1996).

Finally, an opportunity was given to the respondents to state any further views at the very end of the questionnaire. This final open question allowed for salient points to be made, and reduced the feelings of frustration on the part of the respondents, if a point they thought would have been particularly relevant had been missed; (see *Appendix 2D* for a copy of the questionnaire).

In line with the feminist ideal, questionnaires were translated into the three most widely spoken minority languages Urdu, Bengali and Somali[1], this ensured that a wider demographic of the population was included into the data sample. As the questions were mostly in the form of box ticking or circling, it was possible to analyse the data from the questionnaires completed in foreign languages. In the event of further comments being added in a foreign language the help of the council translation service would have been sought, however this was not necessary.

In addition, other sectors of the community who might ordinarily be excluded from the data sample were encouraged through the production of questionnaires with large print for the partially sighted, and for those who were unable to complete a questionnaire due to disabilities, assistance was offered to fill in the questionnaire.

5.2 Results of quantitative analysis

5.2.1 The salience of noise pollution relative to other environmental and social issues

Although the main hypotheses of this investigation were addressed through more specific questions, it was important to illustrate the salience of the issue of noise pollution to those interviewed. This enables judgements to be made in the event of a comparison of this situation with other noise barrier case studies; in addition the description of the situation enables the reader to comprehend the context of the problem. Therefore below are the results of questions asked to the entire sample with regard to how they perceived both the severity and impact of the noise problem in relation to other environmental and social problems.

[1] Translations were care of the Community Languages Centre, Sheffield Town Hall –Tel: 0114 273 6313

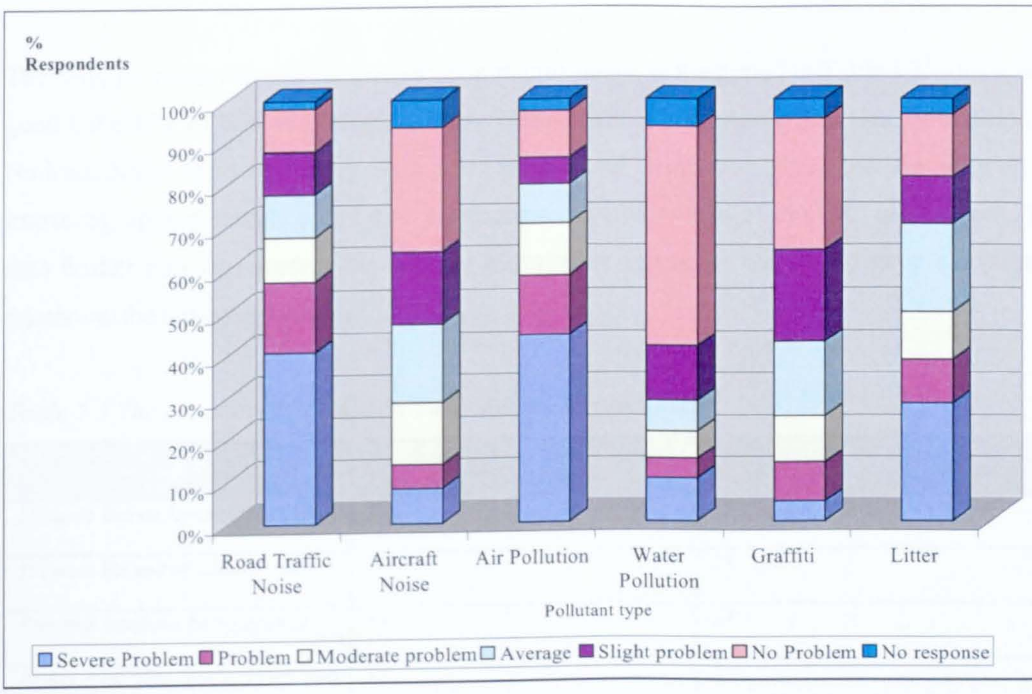

Figure 5.3. Respondent's perceptions of noise pollution in relation to other pollutants by percentage

Figure 5.3 illustrates that noise pollution is of particular concern to the residents, in the sample. The large number of respondents claiming noise was a severe problem was less (5%) than the percentage of respondents who had claimed air pollution was a severe problem. The very similar trend of the values along the air and noise bars illustrates just how important the respondents deemed the issue of noise in relation to air pollution.

The reason noise had gauged such a high percentage of responses with relation to its severity is illustrated by the fact that when asked to answer the question 'does road traffic noise (RTN) affect you, when you're in your house or outside in the garden'. The results showed that '62% of the population said yes' it did affect them. In response to the broader question 'Do you think traffic noise is a problem/ nuisance in this area?' with the alternative 'used to it' as a reply, the results indicated that 57.9% of the respondents said it was a nuisance or problem, with only 15% saying it was not a nuisance, while significantly 25.2% claimed they were used to it.

This can be interpreted as saying that of those people not directly affected by noise themselves; they still saw the salience of the problem in the area and felt that the problem still existed.

The way, in which the noise impacted upon the residents, is illustrated in Table 5.3[1]; this gives a good indication of how imposing the noise climate within the sample area was. In addition the National Noise Incidence Study Statistics[2] (Skinner and Grimwood 2002), for 'the noise effects impacting upon a sample population representative of the whole of the UK' can be seen. This data further puts into context the extreme disturbance that noise had on the sample population relative to the national statistics.

Table 5.3 The impact of the noise on the residents by percentage.

Noise Effects	*Respondents in the Sample: Proportion (%)*	*NNI Statistics: Proportion (%)*
Disturbs indoor leisure activities	*39*	*15*
Prevents the use of outdoor space	*41*	*19*
Prevents windows being opened	*49*	*34*
Makes you feel tense tired and irritated	*34*	*7*
Has contributed to illness	*17*	*3*

This study was retrospective, in that the barrier had already been constructed when it was undertaken; consequently the following response was not unexpected, in light of the extent of the reported disturbance caused by the noise. The questions referred to noise levels, and were asked in two different ways, one at the very beginning of the questionnaire in order to reduce the impact of the respondents being fully aware of the central theme of the study. This question asked 'In your personal opinion, has the level of noise pollution decreased in your area in the last 12 months?' the results gave a very strong indication of how the general public had perceived the noise levels with 12% claiming the noise had decreased, and 87% saying that it had not.

What was more compelling however was that so many of the respondents had noted no change in noise levels, even when reference was made to the noise barrier's completion date. The question was phrased as follows 'Since the barrier's construction in Spring 2001, have you noticed a difference in the noise levels at your house?', with the answer options including, 'decreased noise', 'increased noise', and 'no change'. It is expected that noise reduction may not have been so dramatic as to fall in places to levels that could be described as very quiet, as

[1] Q 3. From this study stated: - How does road traffic noise affect you?
[2] Q 8. From the NNI Survey stated: - Does RTN interferes with any of these aspects of your life?

this would be an unrealistic expectation, however for such a large proportion of the population to not perceive any change post the construction of a 2m fence raises questions. The results are illustrated in Table 5.4.

Table 5.4 The respondents perception of the impact of the noise barrier on the noise levels at their homes.

Perception of noise	*Percentage (%)*
Decreased noise	*13.2*
Increased noise	*10.4*
No change	*76.4*

5.2.2 The Consequences of ineffectual public participation on the projects success

The findings of the survey on the perception of the noise mitigation by the noise barrier reflect the problem of having invested considerably in financial terms in building a noise barrier, which has little perceived improvement for the locals. Noise barrier effectiveness can be assessed in two ways, 'objectively' by using noise models or before and after measurements to give an actual value for the noise reduction. Or with a 'subjective' measure which can often be of equal or greater importance than the former. This was confirmed by Pendakur and Pyplacz (1984) who agreed that the effectiveness of a noise barrier, as perceived by the public, and its acoustic performance were of equal importance.

As documented in the literature review the influence of PP upon the acceptance and perception of the effectiveness of a noise barrier is well established. The question here therefore goes a step further, as according to the barrier's developers in the case study, PP methods were undertaken at the design stage. If this was the case why had so many of the respondents representing the wider community not perceived any noise reduction, and some further still, reported increases in noise?

The immediate conclusion raised by this is that the barrier did not work. Unfortunately, actual before and after measurements were never taken by the developers and so this can be neither proved nor disproved officially. The results of a noise mapping exercise undertaken within this study are reported in Chapter 6, which allows for some conclusions to be drawn on this fact, in addition to further statistical analysis with the respondents' answers.

However, for the purpose of this section of the investigation it is presumed, based on the data compiled in Chapter 6, that the 2-metre fence running the length of the 5-mile stretch and aiming to protect a minimum of 1067 residencies attenuated noise at some of the properties under investigation. Consequently, the question arose, 'why had 89% of those interviewed either noted 'no change' or noted 'increases' in noise levels post construction?' These questions raised three main hypotheses, which utilised the questionnaire data using a variety of appropriate statistical techniques calculated using SPSS 11 (Table 5.9 summarises all the statistical techniques used). The results of each enquiry are presented below in three parts and establish which part of the design process had led to the apparent project failure, and how lessons from this could be taken and reiterated to inform future projects of environmental planning of noise barriers.

The following results are explored bearing in mind that when the respondents were asked whether they had ever attended a meeting of the local forum, 27% had attended a meeting and 72% of the total sampled population had never attended a meeting. This is significant due to the fact that the Tinsley Forum was the only contact between the barrier developers and the public, and all the PP undertaken was through the Forum. This fact in addition to that of when the residents were asked whether they had heard of the Tinsley Forum, 48% claimed that they had not attended because they had never heard of it. This illustrated further the lack of effective procedures. As a consequence three main hypotheses were developed to test the impacts of the PP, and these are presented in sections 5.2.3,5.2.4 & 5.2.5 below.

5.2.3 The influence of public participation on the perception of a noise barrier

Hypothesis 1: 'Neglecting to fully involve the public in the design participation process results in a negative perception of the noise barrier's effectiveness'.

Using a set of Likert style questions, respondents were asked to assign a response to a set of statements regarding the noise barrier's success and their involvement in the PP process. The responses ranged from strongly agree (SA) through, agree (A), uncertain (U), disagree (D) and strongly disagree (SD). The statements are listed below in Table 5.5, with the results of the responses displayed as percentages in Table 5.6.

Table 5.5 Statements used in Likert scales to test public perception of various aspects of the noise barrier project.

Likert Statement No:	**Statements**
1	'Public Participation in the design process was very effective; all the Residents had the opportunity to make their suggestions'.
2	'I felt very involved in the barrier project due to good information availability for the local residents'.
3	'The barrier has reduced the noise significantly'.
4	'The barrier is a success because local residents were allowed to make suggestions over its height and location'.

Table 5.6 Respondents replies as a percentage for each option.

Likert statement number	*Strongly Agree (SA) %*	*Agree (A) %*	*Uncertain (U) %*	*Disagree (D) %*	*Strongly Disagree (SD) %*
1	*3*	*6*	*32*	*19*	*31*
2	*3*	*5*	*15*	*28*	*46*
3	*3*	*9*	*34*	*19*	*33*
4	*1*	*3*	*29*	*19*	*39*

In brief Table 5.6 illustrates that the combined total of those who disagreed and strongly disagreed to statement 1 was 56 % of the sample, giving evidence that over half of those questioned felt that the PP in the design process was ineffective.

The second Likert questions indicated even stronger evidence of the dissatisfaction with the participation process, with 76% of the sample disagreeing and strongly disagreeing. The results of statement 3 showed that 53 % of respondents disagreed and strongly disagreed with the statement about the barriers effectiveness at reducing noise. Finally the statement, which specifically implied that the residents had had an opportunity to influence the design, invoked 58% of the respondents to disagree or strongly disagree[1].

[1] Percentages don't total 100 due to missing data.

When the results of statements (1) and (2) were analysed together to establish a significant relationship between the perceptions of the effectiveness of the PP process and the perception of the barrier's effectiveness using the Spearman's rho Correlation Coefficient 1-tailed at a 99% confidence level, it was found that there was a significant positive relationship (Pallant 2001:266). This is illustrated as a box plot in Figure 5.4. This leads to the confirmation of the findings of the relationship between the perceived effectiveness of the PP process and its influence upon the perceived effectiveness of the noise barrier in this sample, which reconfirms the theories raised by Pendakur and Pyplacz (1984) amongst others.

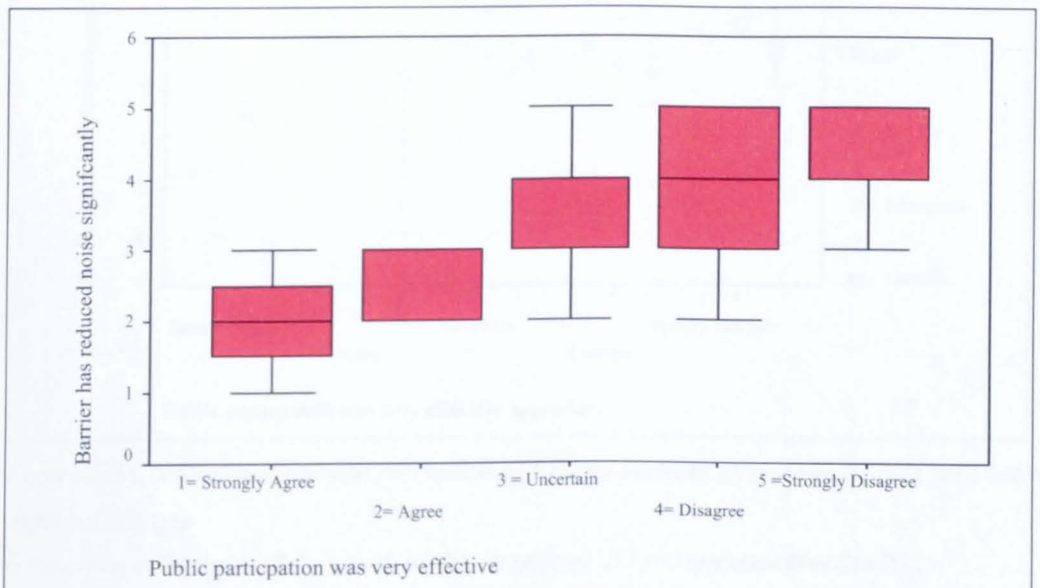

Figure 5.4. Perception of public participation process and perception of the effectiveness of the barrier.

(r (Spearman's)=0.502 P<.0.01(Pallant 2001:266-7).

The box plot above clearly shows the positive correlation with those respondents strongly disagreeing with one statement, largely disagreeing with the other and vice versa. The establishment of a relationship between the PP process and the perceived effectiveness of the noise barrier allowed for the further investigation of the data in relation to the different sub-groups, to evaluate whether this relationship was particularly inherent in one or more groups, over others.

The dataset was spilt into three groups of respondents from different villages, using a Spearman's Rho correlation and presented as an error bar graph in Figure 5.5. The relationship remained significant at the 0.01 significance level, with the residents of Tinsley and Brinsworth showing clear disappointment with both the participation process and the barrier's ability to attenuate noise. The residents of Catcliffe, on the other hand, generally felt much more optimistic about the barrier's ability to reduce noise. This may be indicative of the fact that

Catcliffe although bordering the motorway, is actually much lower in topographical terms from the motorway than the other villages. Figure 5.6 illustrates the relationship between the PP process and the perceived noise mitigation by the barrier; the relationship was not altered and remained strong despite the increase in distance.

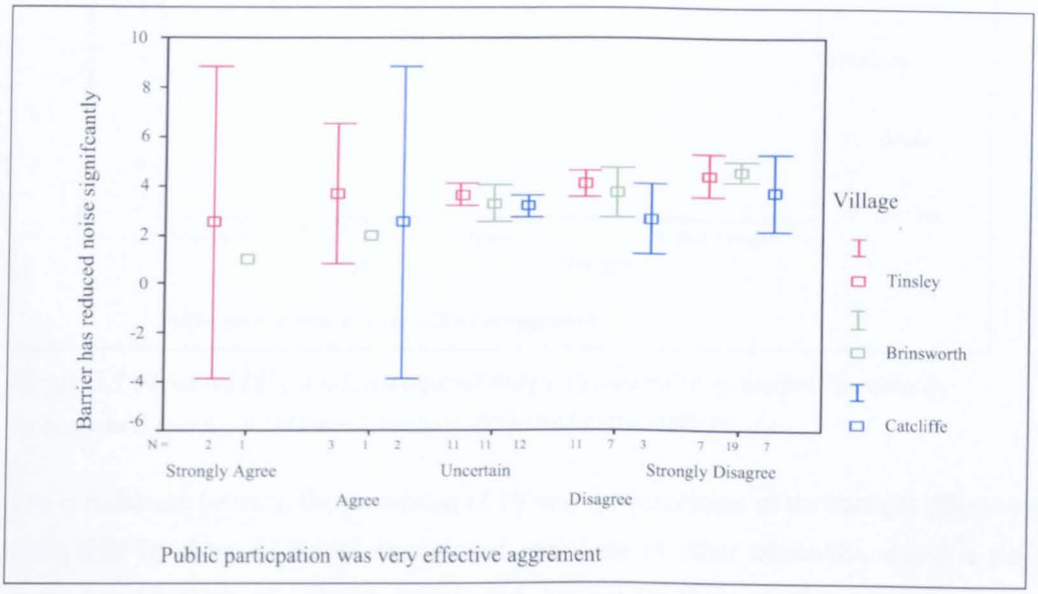

Figure 5.5 Correlations between perception of PP and barriers effectiveness: data split between different villages

(r (Spearman's) Tinsley= .447, Brinsworth =0 .637, Catcliffe =0 .211 p<0.01(Pallant 2001:266-7)).

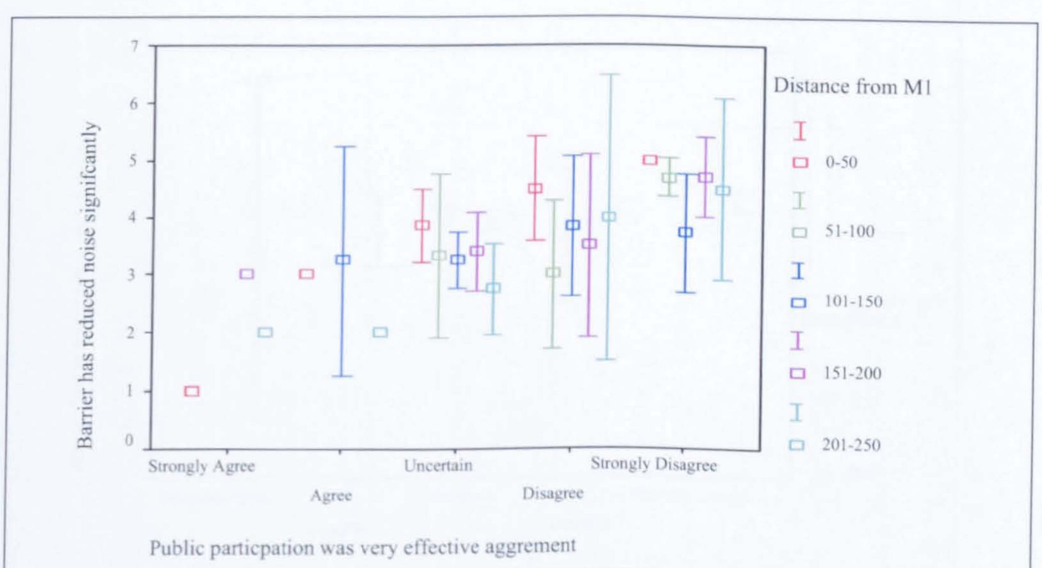

Figure 5.6 Views on PP correlated against the perceived noise reduction by residents in 50 metre bands from the M1

(r (Spearman's) 0-50 =0.732, 51-100 =0.622, 101-150 =0.200, 151-200 =0.656, 201-250 =0.817. P<0.01(Pallant 2001:266-7.).

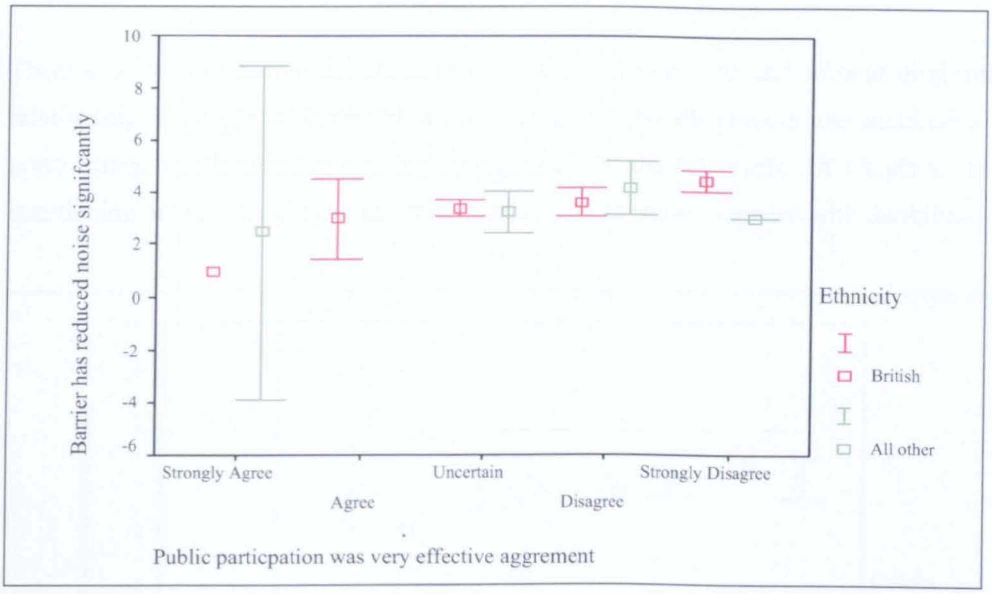

Figure 5.7 Views on PP correlated against the perceived noise reduction by ethnicity

(r (spearman's) British = 0.522 Other Ethnicity = .347 p<0.01(Pallant 2001:266-7)).

The correlations between the perception of PP and the perception of the barrier's effectiveness, when spilt by those of British background and those of other ethnicities, shows a positive correlation for those of a British background, but not for those of other ethnic backgrounds. Figure 5.7 does however illustrate that the trend of disappointment with both indicators was apparent for those of other ethnic backgrounds despite this not showing significance.

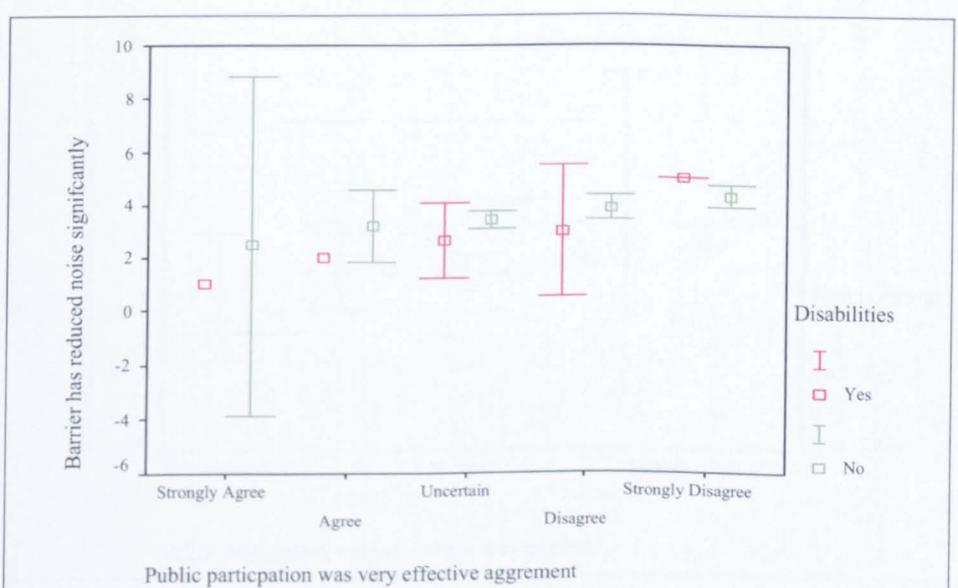

Figure 5.8 Views on pp correlated against the perceived noise reduction by those with and without disabilities

(r (Spearman's) Disabled=0.821, Able Bodied =0 .456 P<0.01(Pallant 2001:266-7.)).

There is a strong positive correlation when split by those with and without disabilities. The relationship of people with disabilities believing that the PP process was ineffective and the noise barrier was ineffective was highly significant at the 0.1 levels. This leads to the further questioning of the suitability of the current procedure for those impeded with disabilities.

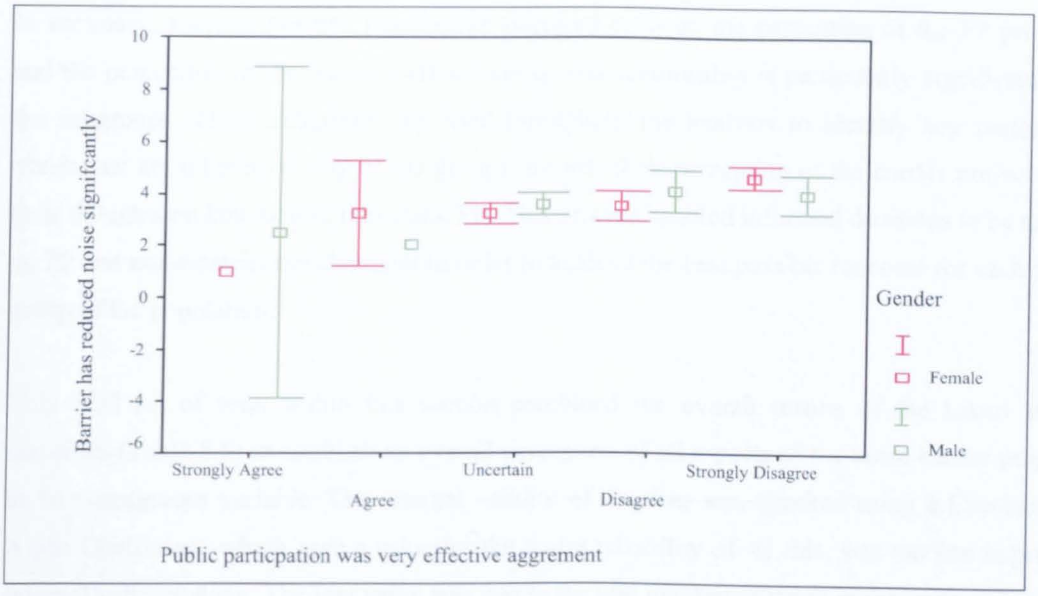

Figure 5.9 Views on pp correlated against the perceived noise reduction by males and females
(r (Spearman's) Male0. 378 P 0.05, Female =0.562p<0.01(Pallant 2001:266-7))

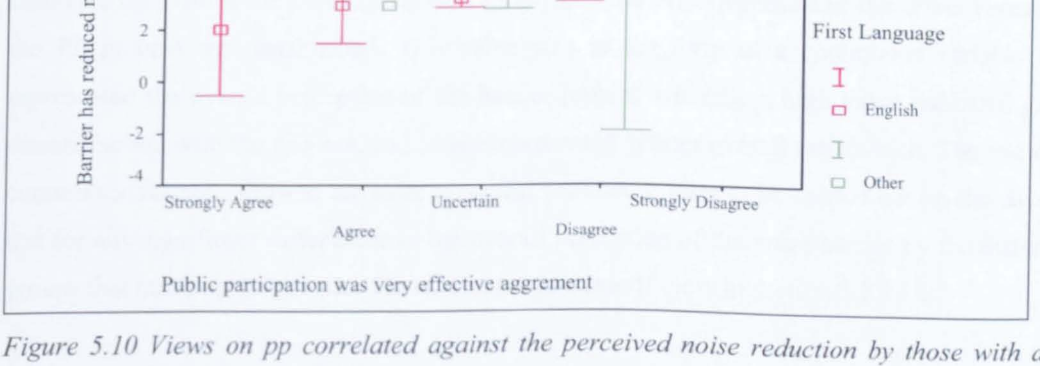

Figure 5.10 Views on pp correlated against the perceived noise reduction by those with and without English as their first language
(r (Spearman's) English Speakers=0.509 P<0.01, Other Language=0.736 P<0.05(Pallant 2001:266-7)).

The significant relationship continues for both categories within the sample, the relationship is slightly stronger for the females than the males. The final split of the data was between those with English as a first language and those with another language as their first. Again the relationship between the perception of the PP process and the perception of the barrier's ability remained significant for both groups.

In summary, a strong positive relationship occurred between the perception of the PP process and the perception of the barrier's effectiveness, this relationship is particularly significant for the subgroups. These subgroups are used throughout the analysis to identify any particular trends that are inherent in any of the groups towards their perception of the barrier project and their thoughts on how best to undertake PP. This process enabled informed decisions to be taken on PP and noise barrier development in order to achieve the best possible outcome for each sub-group of the population.

This final set of tests within this section combined the overall results of the Likert style questions (Table 5.5) to establish an overall perception of all aspects of the noise barrier project as one continuous variable. The internal validity of the data was checked using a Cronbach's Alpha Coefficient, which gave a value for the scales reliability of .41 this, was too low to prove internal validity alone. The low value was due to the low number of items in the scale with only five possible outcomes. It was, therefore, more appropriate to report the mean inter-item correlation, which had a value of 0.24, which according to Briggs and Cheek (1986), as cited in Pallant (2001), is within the optimal range for the inter-item correlation. Therefore, the overall perception of the noise barrier project had good internal consistency with an internal mean inter-item correlation of 0.24 (Pallant 2001:6).

When the results of the scales were combined and averaged an overall value representing a complete opinion of the barrier's success in terms of its effectiveness and the effectiveness of the PP process was established. This value was in the form of a continuous variable and represented the overall perception of the barrier project, whereby a high value indicated great dissatisfaction with the process, and lower represented greater overall satisfaction. The use of a continuous variable allowed for more powerful parametric tests to be carried out on the data to test for any significant differences in the overall perception of the noise barrier by the different groups that made up the sample. These tests are presented below in section 5.2.3.1/2.

5.2.3.1 One-way ANOVA test of significant difference

A one-way analysis of a variance test was applied to the results of the overall perception of the barrier, by the three different independent variables (or groupings) which were made up of three or more groups; 'age group', 'distance from the motorway' and 'village the respondents lived in'. For all three variables there was no significant difference between the groups when perceiving the overall barrier, i.e. there was no significant difference between the respondents from the villages of Tinsley, Brinsworth or Catcliffe on their perception of the barrier project as a whole. In addition, there was no significant difference between the different age groups[1], and their overall perception of the barrier or for people living at different distances from the motorway.

5.2.3.2 Independent t-test of significant difference

The other independent variables including gender, ethnicity, first language and disabilities were tested against the results of the overall perception of the noise barrier using an independent t-test.

The null hypothesis tested stated 'that people from the following groups (males and females/ British and Non-British/ English first language and other first language speakers, disabled and able bodied) 'showed no significant differences between their overall perceptions of the noise barrier project'.

The Levene's test for equality of variance was tested for all the groups; none of which were below 0.05; consequently none violated the assumption of equal variance, with the exception of the disabled category so non-equal variance was not assumed for this. The results of the t-test for equality of means gave a significance value (2 tailed) above 0.05 for each of the independent variables tested. This showed that the difference between the opinions of males and females on the overall perception of the barrier was not significant and the differences between those of British and other Ethnic backgrounds were not significant. The differences between the overall perception of the noise barrier and the respondent's first language were not significant, and there were no significant differences of overall opinion of the barrier project between those with and without disabilities. Therefore, the null hypothesis regarding them showing significant differences was accepted.

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[1] Age groups were reduced to five levels for the ANOVA test (1 =0-34, 2=35-44, 3=45-54, 4=55-64 5= 65+).

Although a significant correlation was not determined between the groups, the trends of similar feelings between the groups are still valid as they further illustrate the dissatisfaction through the high scores allocated demonstrating the total Likert scores. The outcomes of the comparisons with the distance bands and the age groups are displayed below in Figures 5.11 5.12.

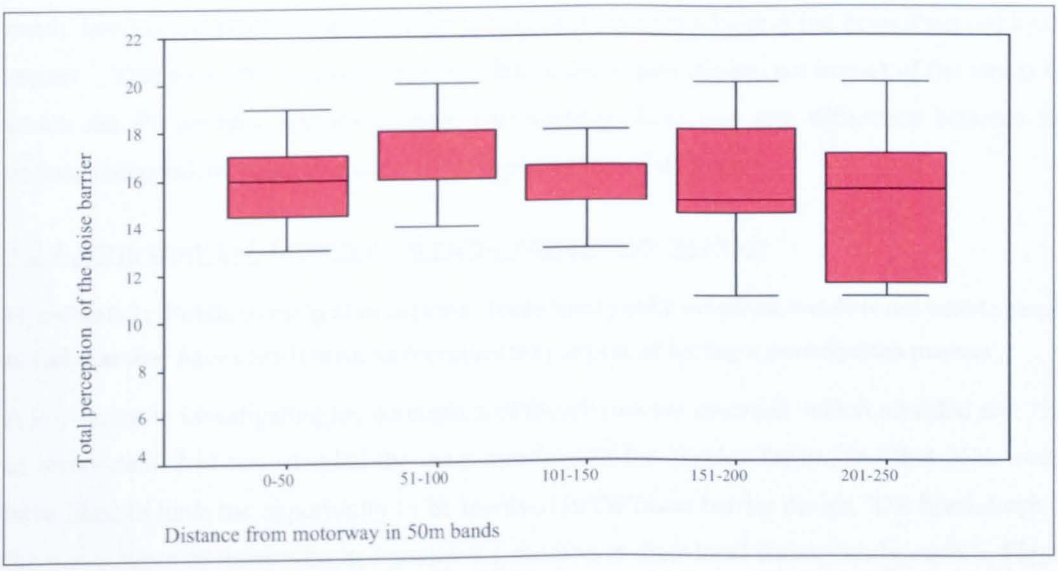

Figure 5.11 Trends of opinions on the overall perception of the noise barrier for residents living within each 50m band from the M1

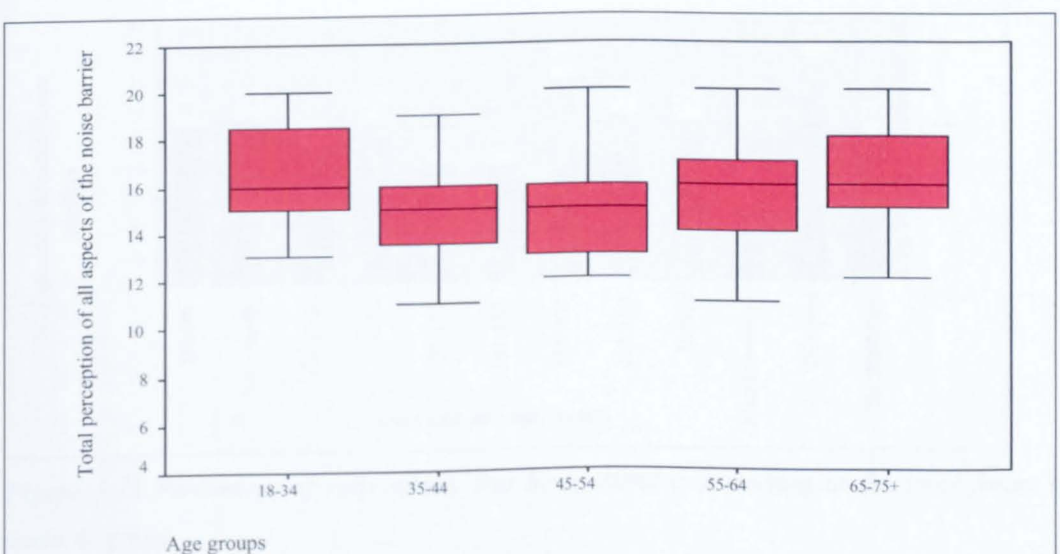

Figure 5.12 Trends of opinions on the overall perception of the noise barrier by age group.

In conclusion, the results of these parametric tests illustrated that there is no significant difference between the overall perception of the noise barrier project and the individual independent variable groups. There is no particular sub-section of the main groups whom feel significantly stronger in either direction. However, in the graphs in Figure 5.11-5.12, there is a trend between the groups, which could mean significance may have been found with a larger sample. Presuming that these variations are not significant and in light of the fact that all the graphs illustrate high values for the total perception of the barrier project, representing that the respondents were unsatisfied, it becomes clear that any particular group does not influence this result. Instead it is more evident that the impact of the barrier's failures has been observed by all sectors [1]. Therefore, the next section of the data analysis investigates the impact of the means by which the PP process was undertaken, and whether there was any difference between the various independent variable groups on their perception of its impact.

5.2.4 Participant led discussion on public engagement methods

Hypothesis 2: 'Public participation that uses traditional public meetings, but does not enable people to feel that they have contributed, undervalues the purpose of having a participation process'.

A key factor in investigating the perception of the PP process emerged, which revealed that 72% of respondents had not attended the main meetings of the Tinsley forum, and that 36% would have liked to have the opportunity to be involved in the noise barrier design. The breakdown of the percentages of those who had attended a meeting at their local forum can be seen in Figure 5.13; split to show the group variations.

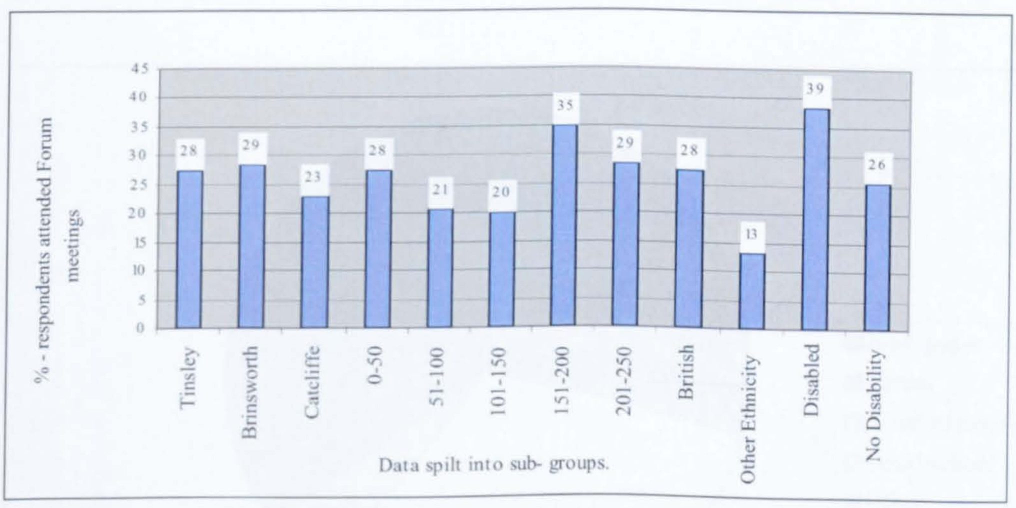

Figure 5.13 Percentage of respondents that have attended a meeting at the local forum by variable group.

[1] Unfortunately the samples for these sub-groups were quite small due to the limited resources within the study, consequently a type II error, could have occurred. However, this was unavoidable, but can be raised as a note of concern for improvement of the sampling methodology in the event of the replication of this enquiry.

The very low numbers within each group who had attended a meeting of the local forum led to the development of the null hypothesis, 'there was no-significant difference in the perception of the PP process between those respondents who had attended the forum (an attendee), and those who had not (non-attendee)'. The test results, which used a Mann-Whitney Test (Pallant 2001:260-1), showed that there was no significant difference in the perception of the PP process, by those who had attended meetings at the forum and those who had not. The null hypothesis was, therefore, accepted and the data revealed that awareness of the forum and attendance at the meetings did not alter the resident's perception of the PP more than those that had not. Consequently, it can be concluded that as attendance at the meeting had not significantly altered their opinions then the PP process had not been particularly successful.

The results of the questionnaire also raised the enquiry regarding 'information sources for the respondents that were aware of the barrier' and 'how this influenced, if indeed it did, their feelings about their involvement in the barrier project'. Obviously there was a smaller sample to evaluate this question, due to the fact that many of the respondents were not aware of the barrier's existence. Figure 5.14 illustrates the main means by which those informed had become aware of the barrier. This further proves the ineffective nature by which the public consultation process was undertaken; if a more wide reaching approach had been adopted it can be presumed that more respondents would have become aware through an official source.

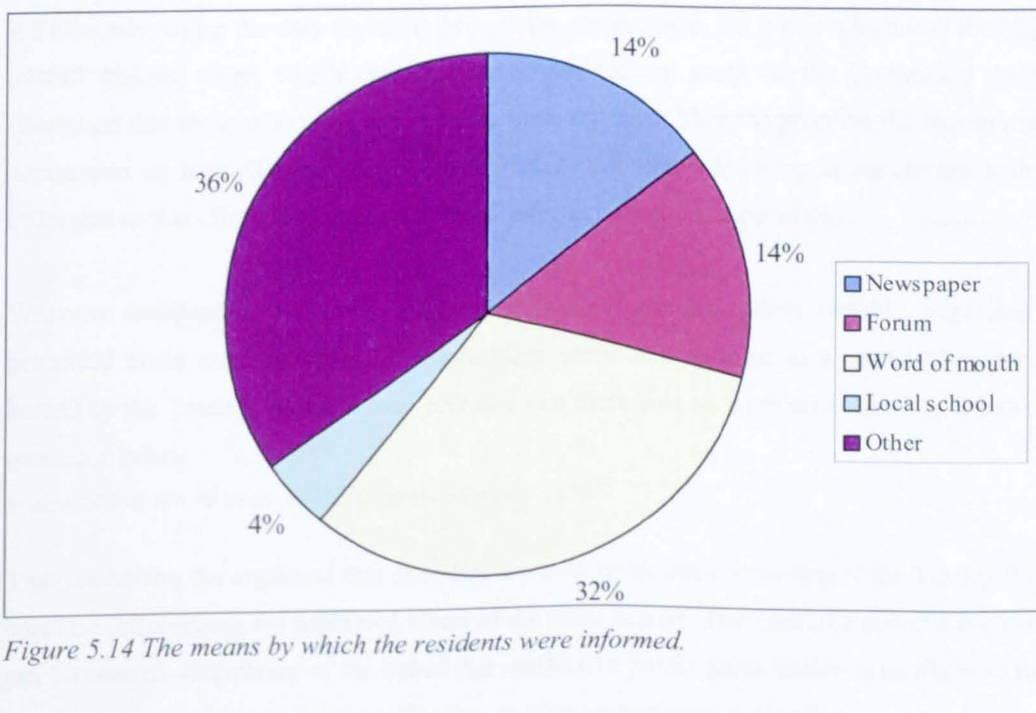

Figure 5.14 The means by which the residents were informed.

Using a Kruskal-Wallis test, the relationship between the different means by which the public had been informed of the noise barrier's construction, and their perception of the PP process were tested for any significant difference using a 0.05 significance level. The null hypothesis of this analysis therefore stated that 'the perceived success of the PP process was not influenced by the means by which the residents were informed of the barrier's construction'. The results concluded that there was no significant difference between the groups. In addition the highest score of the continuous variable, representing 'strongly disagreeing' with the positive statements given regarding the participation process, illustrated that those who had heard about the barrier through the school were least likely to agree that the PP process was a success.

In addition a null hypothesis was developed that tested the following statement, 'that the perception of the barrier's ability to attenuate noise was not influenced by the means by which the residents were informed of the barrier's construction'. The two variables were the continuous dependant variable, that described the residents' perception of the barrier's ability to attenuate noise, and the independent categorical variable 'the means by which the residents had been informed about the barrier'. Again the value of the Kruskal-Wallis proved there was no significant difference between the methods of being informed at the 0.05 significance level. There was no significant difference found between the means by which the respondents had been informed about the barrier and their perception of the noise attenuation properties of the barrier, therefore the null hypothesis was accepted.

Additionally, using the data revealed through the mean ranks, the group which had the highest overall ranking score, which corresponded to the highest score on the continuous variable, illustrated that those who went to the forum were the most likely to perceive the barrier's noise attenuation as less effective. This was indicated through their strong disagreement with the statement to that effect, although a statistical inference does not support this.

When an independent t-test was undertaken between the dependent variable, regarding the perceived noise reduction and the independent variable-attendance in a participation process hosted by the Tinsley Forum. It was revealed that there was no correlation between the two, as presented below:

t-value =0.290; df= 96;mean =3.77; standard deviation= 1.070

Thus, enforcing the argument that attending a public participation meeting at the Tinsley Forum bares no influence on the perceived effect of the noise barrier. This lack of a positive correlation can be seen as vindication of the belief that ineffective public participation is as likely to result in a barrier not being perceived as effective, as with no participation at all.

In conclusion, the tests undertaken revealed that there was no difference in the perception of the PP process and the perception of the barrier's ability to reduce noise whether the residents had found out about the barrier through official or unofficial sources in addition to their being no correlation between attending a meeting at the forum with the perceived effectiveness of the noise barrier. It is, therefore, evident that those who were informed about the barrier through attending the public meetings were no more likely to either perceive an effective PP process, or perceive the barrier to effectively reduce noise, than those residents who had only heard about it through unofficial sources such as word of mouth. In addition, the data revealed that the residents who had most frequently disagreed with the statement 'Public participation in the design process was very effective; all the residents had the opportunity to make their suggestions', were in fact those who had been involved in the official participation process'.

As this method of PP had so evidently failed, the next stage of the analysis endeavoured to find out from the opinion of the residents themselves 'what would be the best method of public participation', and more importantly if these methods were adopted would this make them participate, as it would be pointless to make the effort to accommodate people who would not integrate into the projects anyway.

5.2.5 Respondent Preference for Participation Methods

Hypothesis 3: 'The use of the traditional public meeting is not viewed in the eyes of the respondents as the best means of engaging them, an alternative measure would be more popular'.

To understand better how to involve the public they were asked to rate a number of methods of involving residents in a PP process these are illustrated in Figure 5.15. These methods were assessed using a Likert Scale, which gave the opportunity to give each option a score from best to worst, the higher the value of the total scores the least popular the option was. The results of the Friedman's test suggested that there were significant differences between the opinions of the residents on each of the options as indicated with a significance level of 0.001.

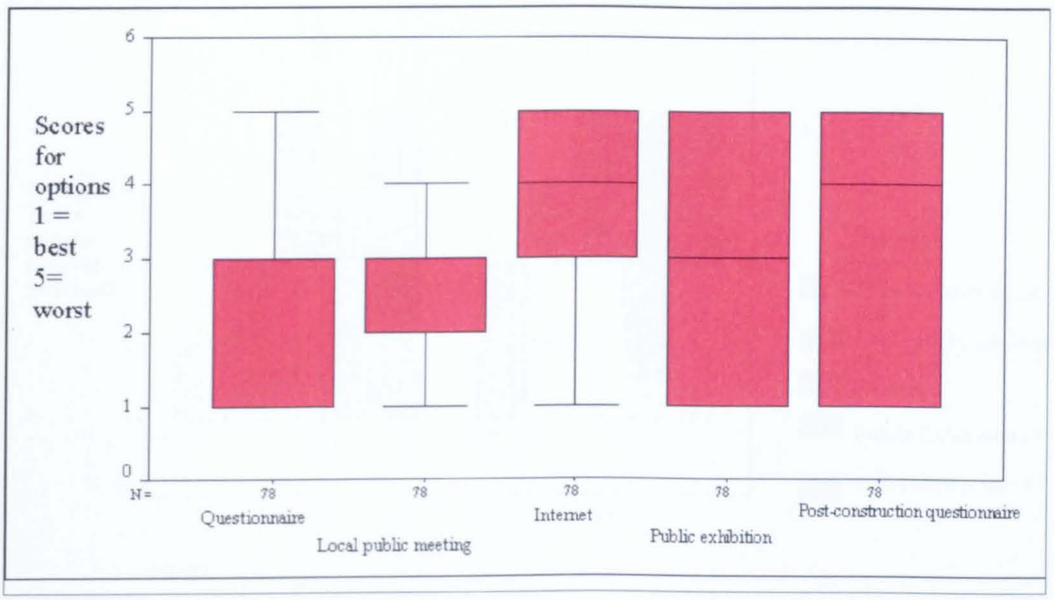

Figure 5.15 Resident's opinions on the best way to engage the public in the participation process (Friedman's Test =0 .001(Pallant 2001:265-6)).

The results showed that on the whole, the most popular means was using a response questionnaire in the home, followed by a joint response towards both an exhibition to view the finalised plans and a local public meeting, following this was a post-construction questionnaire. This option invoked many comments which illustrated that anything post construction would be pointless in the view of the respondents, as any complaints would not be addressed. The least popular method was the use of the Internet this is contrary to findings in a previous case study where the use of the Internet on a planning project was successfully developed by Leeds University (Carver 2002) enabling busy and housebound residents to put forward suggestions online. However, in the areas under consideration here, 61% of the population did not have access to or were unable to use the Internet, illustrating further that methods that suit one case will not necessarily be acceptable to all.

In order to establish whether there was a significant difference between the opinions of the independent subgroups, and their ratings of potential PP methods the non-parametric Friedman's test was applied to the data split by the sub-groups of the independent variables. The results of the Friedman's test and the illustration of the trends discovered in the analysis between the sub-groups are displayed in Figures 5.16-5.20 below.

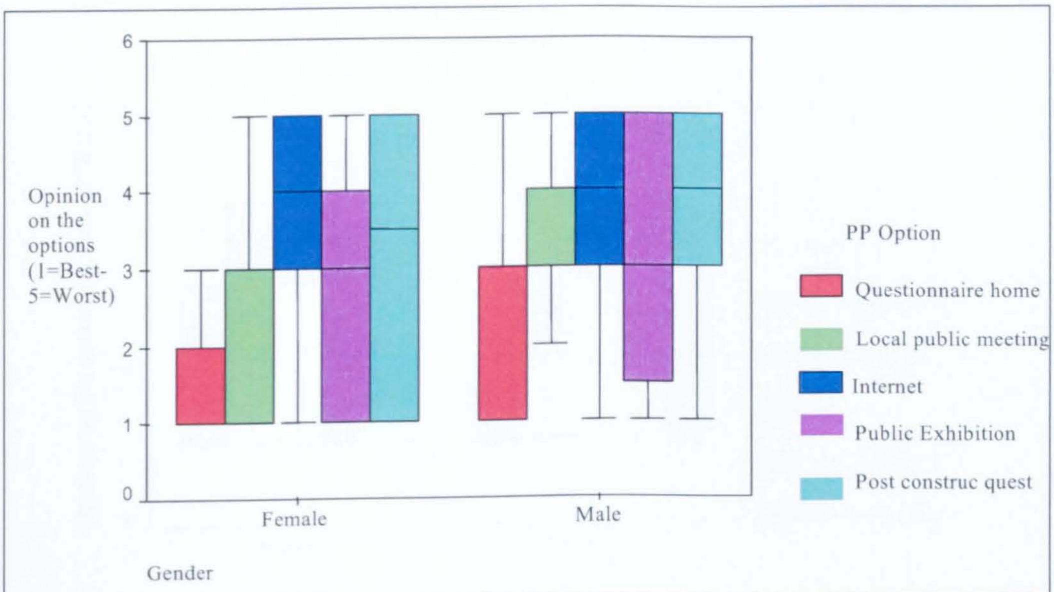

Figure 5.16 The split of opinions between males and females regarding how they rated the alternative options of public participation

(Friedman's test; significant at the 0.001 levels (Pallant 2001:265-6)).

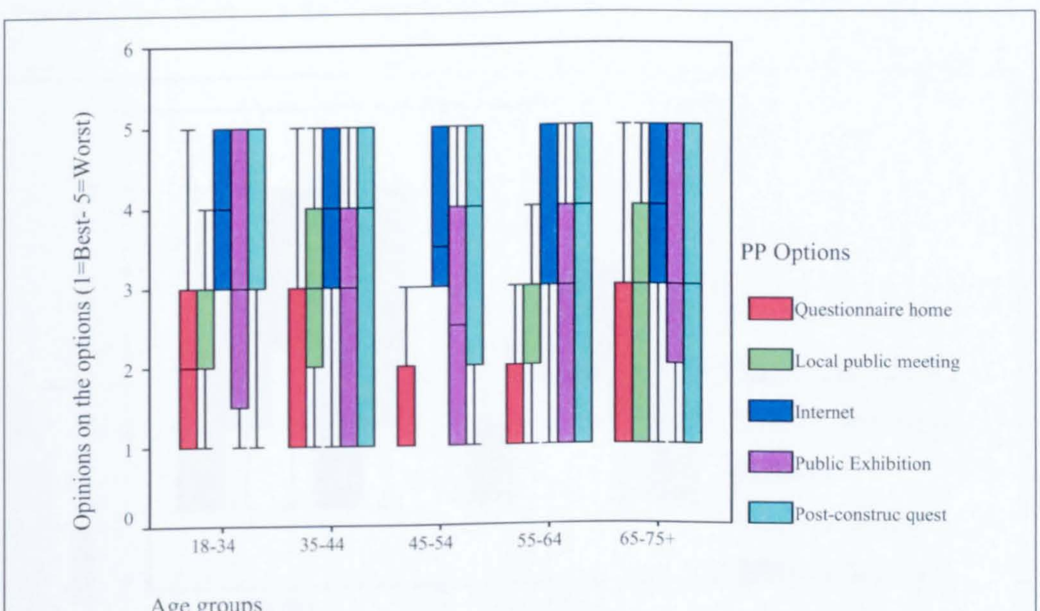

Figure 5.17 The split of opinions between the age groups regarding how they rated the alternative options of public participation

(Friedman's test; significant at 0 .05 levels (Pallant 2001:265-6))

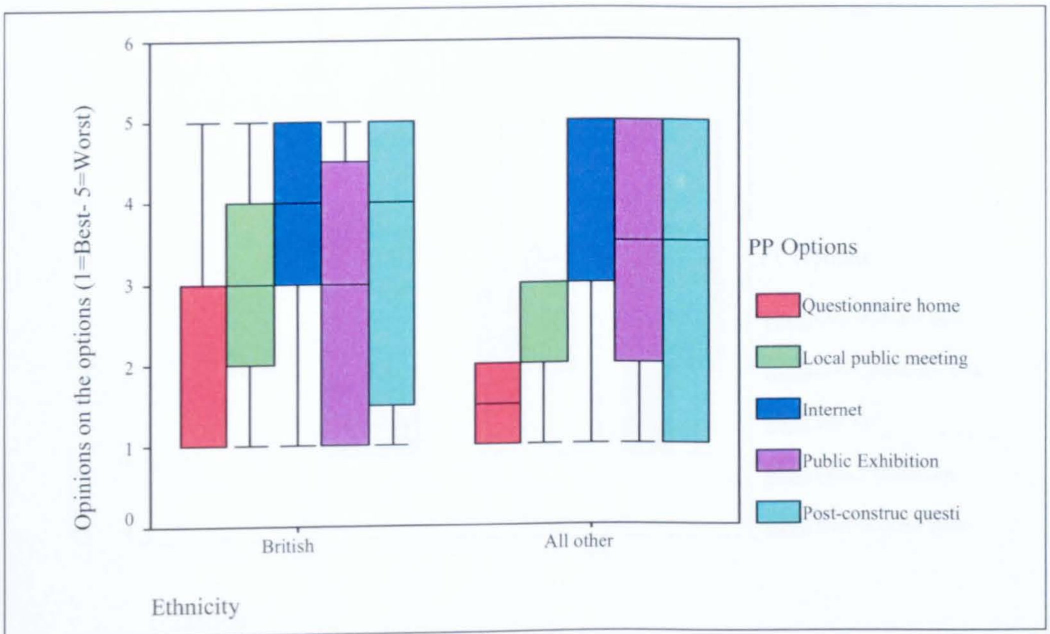

Figure 5.18 The split of opinions between those of British and those of other ethnic backgrounds regarding how they rated the alternative options of public participation

(Friedman's Test; Significant at 0.05 Levels(Pallant 2001:265-6))

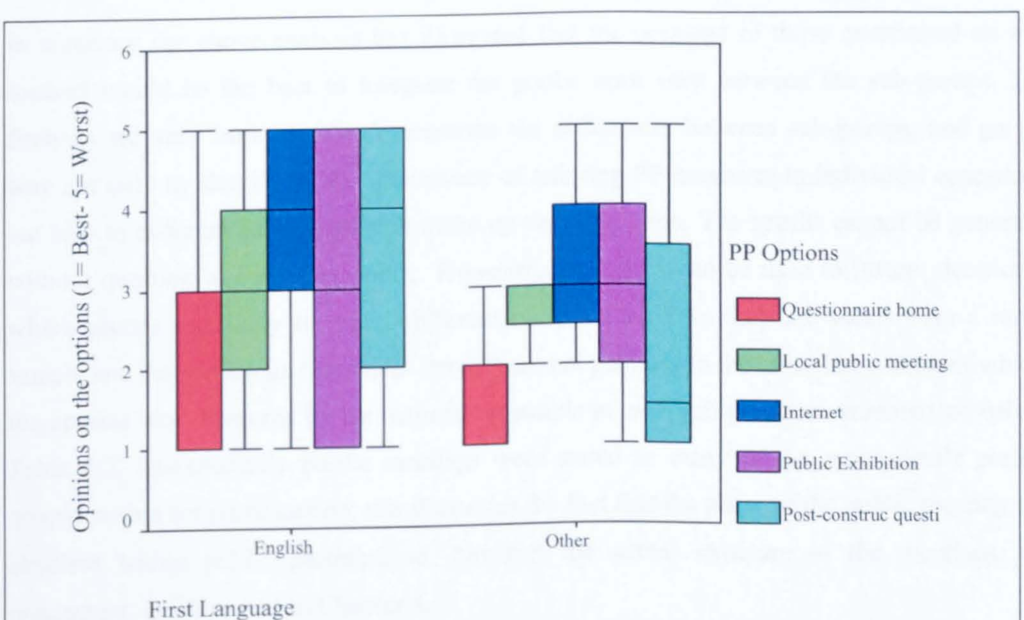

Figure 5.19 The split of opinions residents with English as their first language and others regarding how they rated the alternative options of public participation

(Friedman's Test; Significant at 0 .05 Levels (Pallant 2001:265-6))

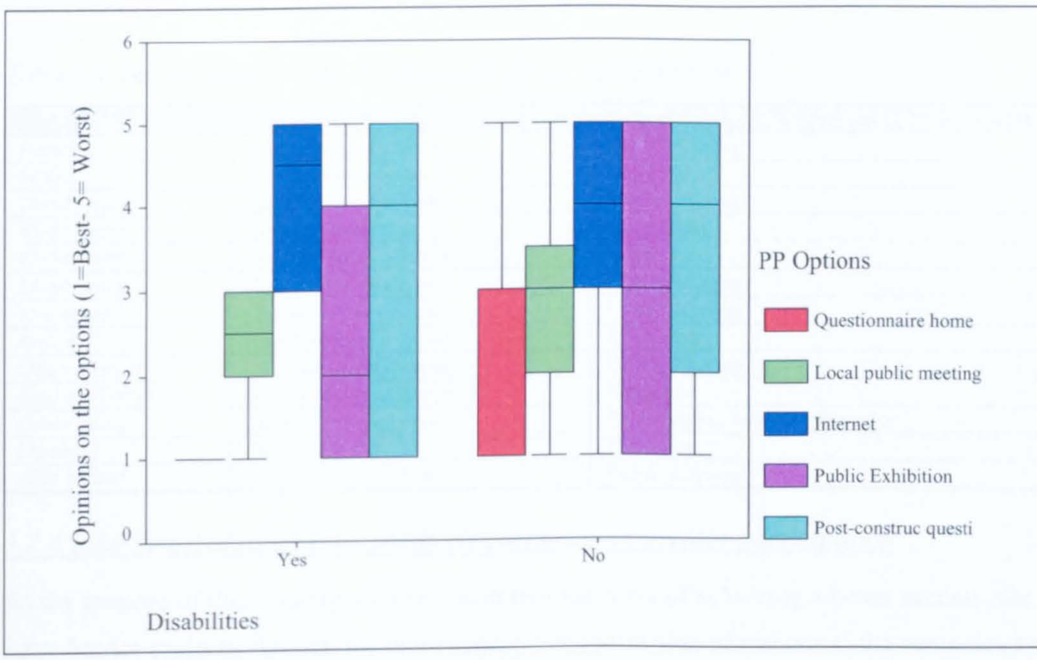

Figure 5.20 The split of opinions residents with and without disabilities regarding how they rated the alternative options of public participation

(Friedman's Test; Significant at 0 .05 Levels (Pallant 2001:265-6))

In summary the above analysis has illustrated that the opinions of those questioned on which method would be the best to integrate the public does vary between the sub-groups. These findings are very important to demonstrate the differences between sub-groups, and go some way not only to identifying the importance of tailoring PP measures to individual case-studies, but also to different sub-groups that make up the population. The results cannot be generalised without question to the wider public. However, the results can be used to inform decisions on which groups are likely to prefer different options for PP as they are taken from a random sample and the groupings (i.e. male/ female) are not peculiar to the area. The results of which of the options were favoured by the majority of people in each sub-group are summarised below in Table 5.7. Unexpectedly public meetings were stated as many of the respondent's preferred second option for participation, this illustrates the fact that the place of the public meeting is not obsolete within public participation, however the actual structure of the meetings needs refinement, as illustrated in Chapter 4.

The preference for a questionnaire in the home may have been biased by the fact that the respondents were being evaluated using this process. The results may have been more informative if a greater selection of participation procedures had been offered as choices, such as 'planning for real techniques' and 'citizen forums'. However, to presume that the respondents would understand these methods would be unfeasible. In addition, to the space on the questionnaire being limited to allow for further explanation.

Table 5.7 The favoured 1st and 2nd choice for PP by the subgroups

Groups	First Choice for PP	Second Choice for PP
Females	Questionnaire at home	Public Meeting
Males	Questionnaire at home	Exhibition
18-34 years	Questionnaire at home	Public Meeting
35-44 years	Questionnaire at home	Exhibition
45-54 years	Questionnaire at home	Exhibition
55-64 years	Questionnaire at home	Public Meeting
65+ years	Questionnaire at home	Public Meeting
British	Questionnaire at home	Exhibition
Other ethnicity	Questionnaire at home	Public Meeting
English (Lang)	Questionnaire at home	Exhibition
Other (Lang)	Questionnaire at home	Post-construction questionnaire.
Disabled	Public Meeting	Exhibition
Able bodied.	Questionnaire at home	Public Meeting

5.2.6 Likelihood of alternative methods encouraging greater participation

As the purpose of this investigation was to determine ways of achieving a better success rate for noise barrier projects, through the more appropriate redirection of resources, the outcome of this section is key. However, if despite these measures being in place, the public would still not be prepared to get involved in the planning process through PP then there would be little point implementing them.

In order to evaluate whether improving the options for people would actually encourage the public to become involved, the respondents were asked to answer the following set of questions, with either a 'yes' or 'no': 'If you could use any of the following methods which would be more likely to make you get involved in Public Participation'

- Do it over the Internet
- If meetings were more frequent
- If meetings were arranged for different groups
- If meetings were better advertised
- Other (please state).

Figure 5.21 below summarises how the respondents reacted to each option by revealing the percentage of respondents who said they would be more likely to become involved in PP of these alternative options were available.

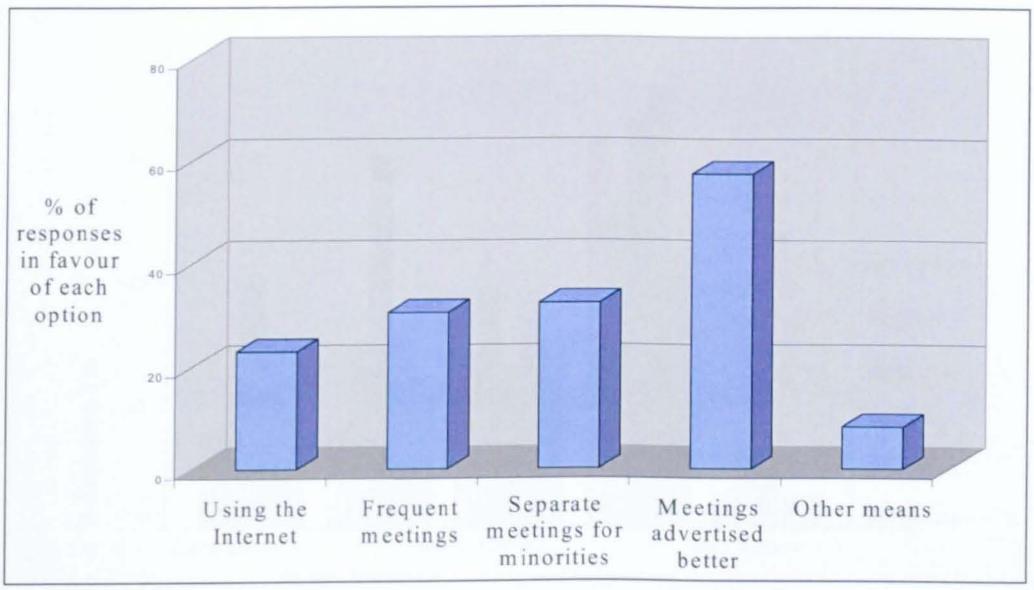

Figure 5.21 Percentage of respondents that replied 'yes', indicating they would get involved with public participation if alternative options were available.

The results in Figure 5.21 indicate that advertising meetings more effectively would influence the largest proportion of respondents to attend a PP process. Separate meetings for minority groups followed this, which was also a popular option to encourage greater involvement. The option of 'more frequent meetings' encouraged an extra 30% to say they would get involved, with the least likely option for encouraging more respondents to get involved being through the use of the Internet. To analyse whether there was any significant difference between the different subgroups, and which method would be more likely to encourage their involvement, the data was again split into sub-groups as before and the results were analysed with a Cochran's statistical test. The Cochran's test was used over the Friedman's test due to the dichotomous nature of the dependant variable. The results are displayed below in graphical form in Figures 5.22.

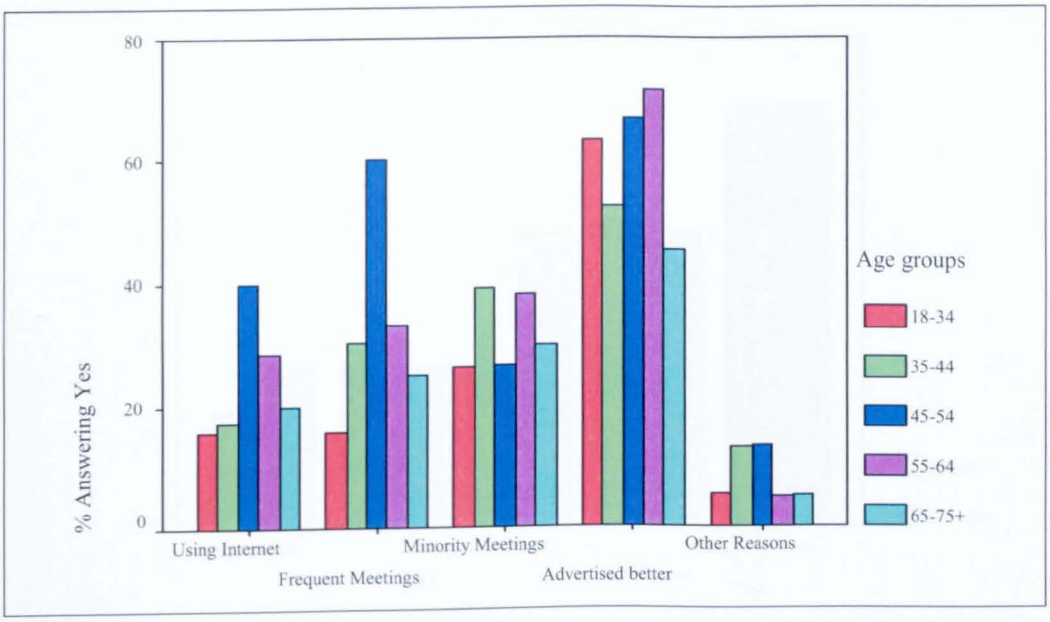

Figure 5.22 Percentage of respondents that replied 'yes', to the likelihood of the measures encouraging them to get involved as split by age groups.

(Significant at the 0.001 levels. Cochran Q= Ages (18-34) Q= 19.16; df = 4; p<0.001 / (35-44) Q= 11.02; df = 4 p<0.001 / (45-54) Q= 14.00; df = 4 p<0.001 / (55-64) Q= 23.54; df = 4 p<0.05/ (65+) NS)

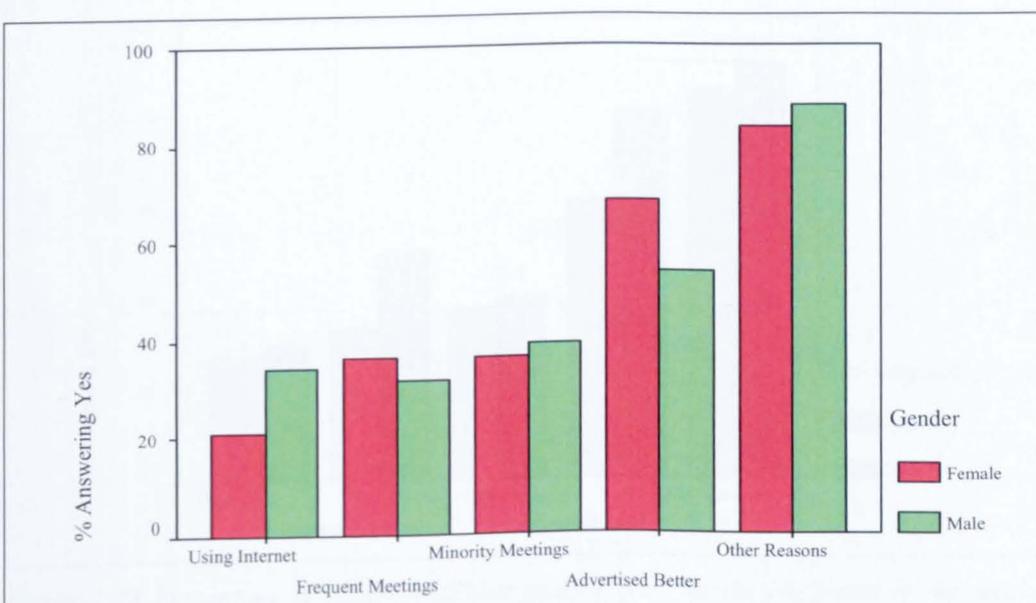

Figure 5.23Percentage of respondents that replied 'yes', to the likelihood of the measures encouraging them to get involved as split by gender.

(Significant at the 0.001 levels. Cochran Q=56.828;df 4; p<0.001 -(female): Cochran Q=17.51;df 4 p<0.001 -(Male):

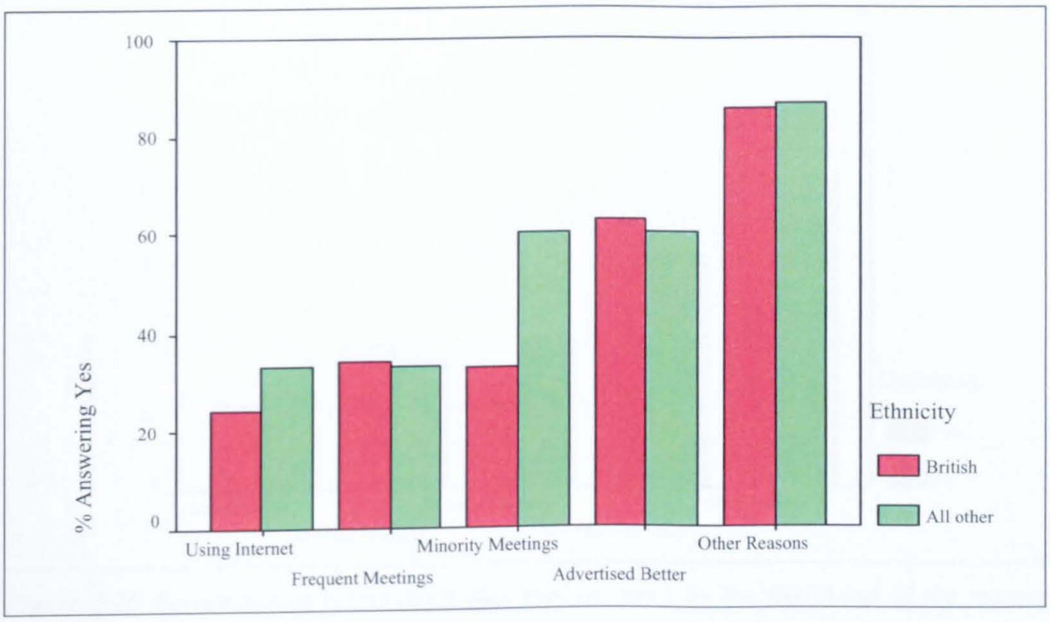

Figure 5.24 Percentage of respondents that replied 'yes', to the likelihood of the measures encouraging them to get involved as split by ethnicity.

(Significant at the 0.05 levels. Cochran Q=60.740;df 4; p<0.05 -(British): Cochran Q=11.857;df 4; p<0.05 -(Other).

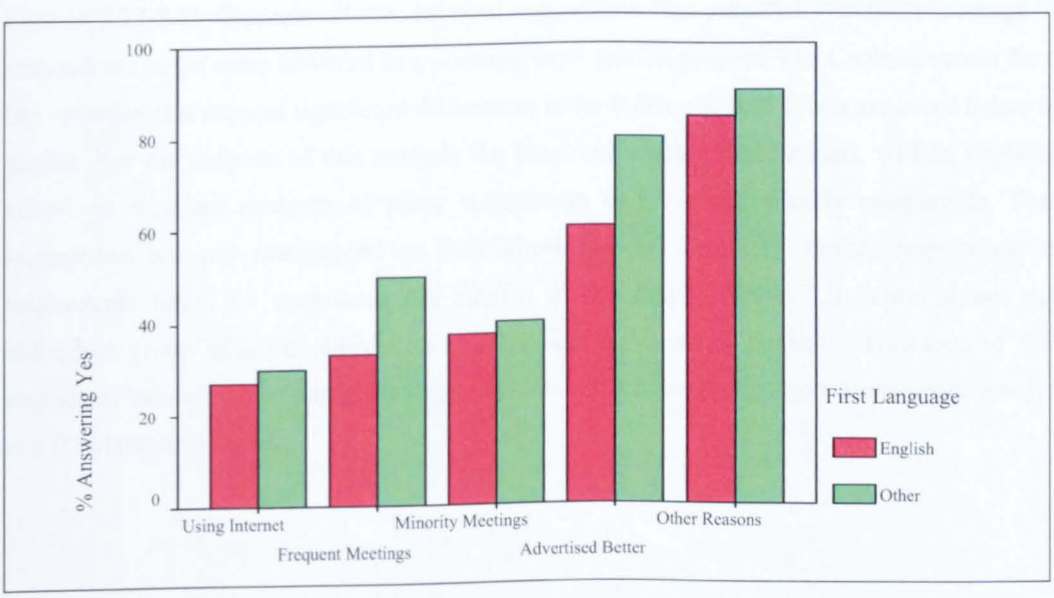

Figure 5.25 Percentage of respondents that replied 'yes', to the likelihood of the measures encouraging them to get involved as split by first language.

(Significant at below the 0.05 levels. Cochran Q=54.70;df 4; p<0.05 -(English): Cochran Q=14.00;df 4l;p<0.05 -(Other):

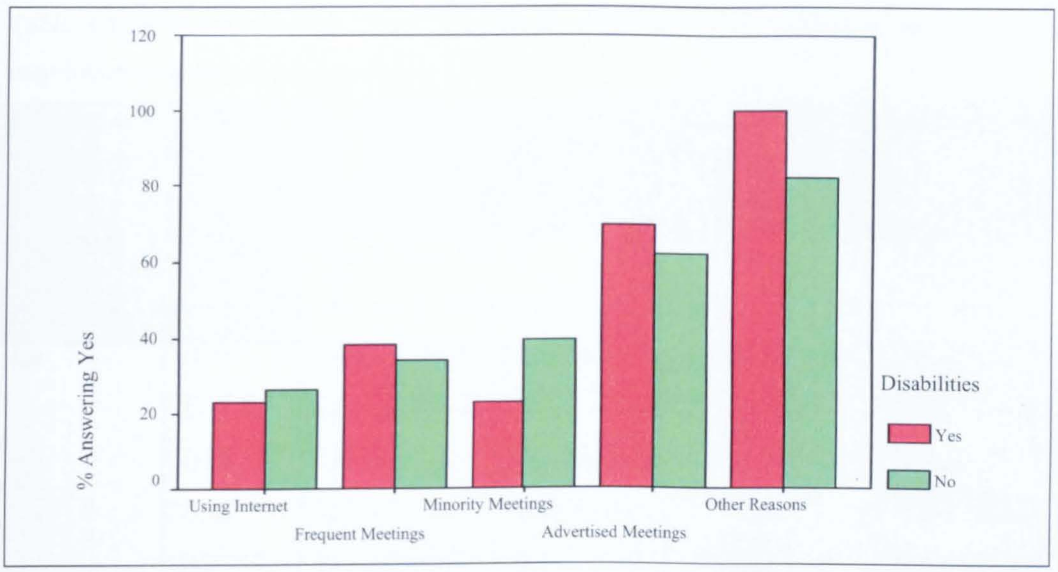

Figure 5.26 Percentage of respondents that replied 'yes', to the likelihood of the measures encouraging them to get involved as split by disabilities.

(Significant at below the .05 levels. Cochran $Q=15.71$;df 4; $p<.05$ -(Disabled): Cochran $Q=53.03$;df 4; $p<.05$-(Able bodied)):

Figures 5.22-5.26 illustrate all the different suggestions that potentially would encourage the respondents to get more involved in a planning participation process. The Cochran values for all the variables that showed significant differences at the 0.001 and 0.05 levels are noted below the graphs. For the purpose of this analysis the bars representing other means, will be explained below, as they are made-up of many suggestions they are not directly comparable. These suggestions are not disregarded as they allow insights into any further suggestions the respondents have. To summarise the outputs of the graphs, Table 5.8 below shows each individual group with the suggestions that gained the most to the least percentage of 'yes' responses, indicating that particular suggestion would encourage them to become more involved in a PP planning process.

Table 5.8 Summary of which suggestions would be more likely to encourage members of the population subgroup to participate.

Variable	*Group*	*Suggestions in descending order from the highest percentage of yes votes (A) to that, with the least (D) for each sub-group.*			
		Highest % of 'Yes Votes' ⟵			⟶ *Lowest % of 'Yes Votes'*
Age	*18-34*	*Advertised better*	*Minority Meetings*	*Using Internet*	*Frequent Meetings*
	35-44	*Advertised better*	*Minority Meetings*	*Frequent Meetings*	*Using Internet*
	45-54	*Advertised better*	*Frequent Meetings*	*Using Internet*	*Minority Meetings*
	55-64	*Advertised better*	*Minority Meetings*	*Frequent Meetings*	*Using Internet*
	65+	*Advertised better*	*Minority Meetings*	*Frequent Meetings*	*Using Internet*
Gender	*Female*	*Advertised better*	*Frequent Meetings*	*Minority Meetings*	*Using Internet*
	Male	*Advertised better*	*Minority Meetings*	*Using Internet*	*Frequent Meetings*
Ethnicity	*British*	*Advertised better*	*Frequent Meetings*	*Minority Meetings*	*Using Internet*
	Other	*Advertised better & Minority Meetings*	*Frequent Meetings & Using Internet*		
Language	*English*	*Advertised better*	*Minority Meetings & Frequent Meetings*	*Using Internet*	
	Other	*Advertised better*	*Frequent Meetings*	*Using Internet*	*Minority Meetings*
Disabilities	*Disabled*	*Advertised better*	*Frequent Meetings*	*Using Internet*	*Minority Meetings*
	Able bodied	*Advertised better*	*Minority Meetings*	*Frequent Meetings*	*Using Internet*

A key finding of this investigation was that the groups unanimously cited that having meetings better advertised would encourage them to become involved in local planning issues, with people from minority ethnic backgrounds also stating that meetings arranged for minority groups would encourage them to get involved. The option of minority meetings and meetings being carried out more frequently received a large proportion of the 'yes' votes from all the other groups. Therefore from these results, although they can only be completely generalised to the population from which they belong, can enable trends of the opinions of different sub-groups to be analysed. It is clear that in the event of any future need for planning participation, if the demographics of the area were obtained and analysed prior to the implication of any participation procedures, the procedures could be tailored to the sub-groups that make up the population, to encourage a greater response and success rate.

The other options that the respondents gave are noted in the following quotes, which included:

- "Plenty of advance notice given of the meetings":
- "Could be sure that it wasn't just a talking shop ":
- "Questionnaire in the home with accompanying full information booklet":
- "Arranged at different times i.e. for shift workers":
- "If our views counted for something"

This again illustrates firstly the inaccessible nature of the public meeting in its current form with some sectors of the community wanting to be involved if the opportunity was there, and also the mistrust of the current methods, in that they are perceived as being a "talking shop", or place where real decisions and influences cannot be made and felt, all the reservations could be easily resolved in this situation by better and more effective communication between the local authority planners, the project planners and the public.

Finally and most importantly the residents were asked whether they would like to be involved in PP, if all of these options were open to them, as there would be little point in making provisions for those who are not interested, the results of this showed that 36 % of respondents would want to be involved 27 % would not, even if provisions were made for them and 33% did not know[1]. As this result showed that proportionally, in relation to the whole population, there were not a huge number of people that would have definitely wanted to get involved. The replies regarding which measure would make the respondents get more involved were compared with the results of whether the respondents were affected by road traffic noise within their homes and gardens. The results of which can be seen in Figure 5.27 below.

The final test used a Cochran's Test of significant difference, which was undertaken to determine the importance of determining the salience of the issues to the residents in their decisions to get involved. The null hypothesis developed to test this stated; 'there was no difference between those who were affected by road traffic noise (RTN) and those that were not and their likelihood to become involved in planning procedures with the provision of more accessible methods.'

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[1] The remaining percentage being made up of missing data.

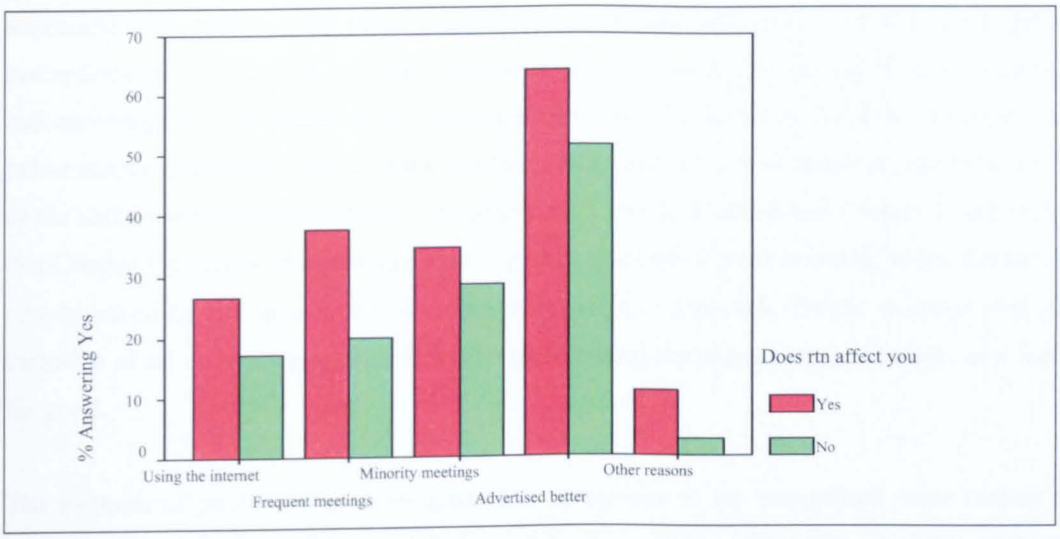

Figure 5.27 Comparison of individuals affected and unaffected by road traffic noise and the percentage of them who would be likely to get involved with a public participation process.

'Affected by noise'- Yes -Cochran's $Q = 43.61$; $df\ 4$; $p = <0.05$ –No 26.20; $df\ 4$; $p = <0.05$.

The test found that there was a significant difference between those who were affected by noise and those who were not. The null hypothesis was, therefore, rejected and the importance of finding out whether the potential respondents would be likely to be impacted upon prior to undertaking a PP process was established as a criteria necessary to identifying a specific group for targeting and engaging in a PP procedure for noise barrier development. Therefore, it can be concluded that prior to the adoption of measures intended to integrate the residents of an area into the planning process it should be established that the issue is salient to them in the first instance.

5.3 Conclusion and discussion

5.3.1 Summary of results

In conclusion, the findings of this study confirm the strength of the relationship between effective communication and successful noise barrier development. The results also illustrate that one method of participation does not necessarily suit all members of a community, but that there are correlations within the subsections, so if these subsections were identified prior to participation, then a mixture of methods could be adopted to generate the best outcome.

In addition, the extent of feedback with regard to the use of public meetings in their current form was illustrated. The extent to which subgroup members were alienated from the process was clearly seen, along with their willingness to get involved had the process been more accessible. This confirms that public participation is not only effective in discouraging negative perceptions of noise barriers, but also does social good, by invoking a feeling of local ownership and encouraging a determination to work as a community to better the local environment. The public meeting however, was proven to be by no means obsolete with many groups indicated it as the second most preferred choice for participation, but as illustrated in Chapter 4 and within this Chapter the means of advertising public participation procedures is crucial to the number of people attending and also to the overall success of this approach. Public meetings that are inclusive of all minority groups, and do not create social exclusion are seen widely, as a force for good.

The methods of public participation presented, as options to the respondents were limited to those that did not imply the need for specialist knowledge. Therefore, methods such as, Planning for Real techniques and citizen forums were excluded, however it is felt that should these options be available to the respondents, that they would be met with enthusiasm. The reason for this assumption is down to a reflection of the community's general acceptance of participatory measures. As described in Chapters 2 and 4, the residents of this area have in the past been largely very supportive of measures they felt they could have ownership over. Examples of which were illustrated with the purchase of the local bridge and church as a cooperative venture, along with the organisation of other local events to raise awareness of the environmental and social problems in the area.

The importance of these findings is increased due to the ratification of the Arthus Convention with its requirements for genuinely accessible participation for all members of the public. It will no longer be just an issue of under representation but a breach of statutory obligations if the public are not fully involved which in turn impedes the sustainability of a project.

As an overview Table 5.9 highlights all the tests that were undertaken with explanations of the significance of the results, and serves as an illustration of the most effective and sustainable practices that should be adopted, should a similar project be undertaken again.

Table 5.9 Overview of all inferences determined using statistical tests in chapter 5.0.

Figure or Section	*Explanation of the relationship*	*Significance test.*	*Reference*
5.4	*A significant positive relationship between the perception of the PP process and the perception of the barriers ability to attenuate noise was confirmed.*	*Spearman's Rank*	*Pallant 2001: 266-7*
5.5-5.10	*The significant positive relationship was also apparent between the PP process and the perception of the barriers ability to attenuate noise when the data was split into sub-groups. (Village, Distance from M1, Ethnicity, Disabilities, Gender, First Language).*	*Spearman's Rank*	*Pallant 2001: 266-7*
5.2.3.1	*There was no significant difference between the respondents, the different age groups, and their overall perception of the barrier or for people living at different distances from the motorway. Using the one way ANOVA test*	*One-way ANOVA test*	*Pallant 2001: 194*
5.2.3.2	*The analysis showed no significant differences between the males and females/ British and Non-British/ primarily English speakers and primarily other language speakers, disabled and able bodied and their overall perceptions of the noise barrier project. Using the Independent t-test.*	*Independent t-test*	*Pallant 2001: 180-1*
5.2.4	*The test results which used a Mann-Whitney Test of significant difference showed that there was no significant difference between those who had attended meetings at the forum and those who had not and their perception of the PP process*	*Mann-Whitney Test*	*Pallant 2001: 260-1*
5.2.4	*Using a Kruskal-Wallis Test, the relationship between the different means by which the public had been informed of the noise barrier's construction, and their perception of the PP process was significantly different*	*Kruskal-Wallis Test*	*Pallant 2001: 263-5*
5.2.4	*Independent t-test, illustrating no correlation between attendance at the Tinsley Forum and perceived effectiveness of a noise barrier*	*Independent t-test*	*Pallant 2001:183-4*
5.15	*The opinions of the independent subgroups, and their ratings of potential PP methods were analysed for significant difference. The results of the Friedman's test suggested that there were significant differences between the opinions of the residents on each of the options.*	*Friedman's test*	*Pallant 2001: 265-6*
5.16-5.20	*To establish whether there was a significant difference between the opinions of the independent subgroups, and their ratings of potential PP methods the non-parametric Friedman's test was applied to the data split by the sub-groups of the independent variables. The significant results illustrated that the opinions of which method would be the best to integrate the public does vary between the sub-groups.*	*Friedman's test*	*Pallant 2001: 265-6*
5.22-26	*To analyse whether their was any significant difference between the different subgroups and which method would be more likely to encourage their involvement in a planning participation process the data was again split into sub-groups and the results were analysed with a Cochran's statistical test. The Cochran values for all the variables that showed significant differences at the.001 and .05*	*Cochran Test*	*Bryman and Cramer 2001:128*
5.27	*This test was done to determine the importance of determining the salience of the issues to the residents in their decisions to get involved, the null hypothesis developed to test this stated; 'there was no difference between those who were affected by RTN and those that weren't and the likelihood to become involved in planning procedures with the provision of more accessible methods.' The test found that there was a significant difference between those who were affected by noise and those that weren't.*	*Cochran Test*	*Bryman and Cramer 2001:128*

Chapter 6 Noise mapping as a Planner's Tool for Public Participation Success

In Chapter 5 one of the key themes that emerged was the difference in opinion that various sectors of the community had regarding the noise barrier in the case study. Opinions also differed on the means of integrating the public into a public participation (PP) process, and on whether this would influence them personally, to adopt a more proactive role in planning issues. It was not initially possible, due to a lack of validation monitoring post-construction by the Highways Agency (HA), to enable a validation of these results by comparing the subjective opinions with an objective measurement. Therefore noise maps were developed to provide information of the noise climate pre and post construction at each of the respondent's houses.

The aim of this chapter is to develop the themes and address the queries raised earlier, beginning with the fact that many of the residents had not been made aware of the opportunity to become involved in the noise barrier planning process. A further point of discussion is that the residents, who found the issue of road traffic noise more intrusive in their lives, would be more likely to want to be involved in the planning of its remediation. Although these statements seem obvious, during the interview with the HA it was evident that when planning participation measures are implemented for noise barrier development, they are done on an ad-hoc basis (Joynt 2002). This consequently results in the alienation of large sectors of the affected community, who have the potential to inform any decisions with more authority, due to the salience of the problem to them personally.

The use of noise mapping as a tool to inform planners of where to concentrate their efforts for PP, was investigated by comparing the differences in opinion of residents with varying noise levels and noise attenuation post-construction at their home. Noise mapping was chosen due to the relevance of the subject to today's political climate, with the ongoing noise mapping of the UK being undertaken throughout 2005, this is as a result of the Governments adoption of the Ambient Noise Strategy (2001) and the advent of the EC Directive on the Assessment of Environmental Noise (Wetzel 2002). Therefore, this vast resource is already being collated, and has the potential to benefit policy beyond the current limits that it is predicted to assist.

The Directive's aims were to achieve a common understanding of the noise problem. This was to be achieved through the collection, collation and reporting of data regarding environmental noise with comparable criteria, which implied the use of harmonised indicators and evaluation methods, as well as criteria for the alignment of noise mapping (Directive of the European Parliament 2000).

6.1 Introduction of the use of noise mapping for public participation

6.1.2 The case for using noise maps

The case for utilising this resource was achieved by outlining how noise mapping should be used as a tool for guiding PP methods in planning. It is felt that although the main purpose of noise mapping is to guide planning policy, not enough emphasis is put on its ability to guide PP policy. This was investigated by the comparison of subjective public opinions, regarding the effectiveness of the noise barrier, which were collected by questionnaire during the quantitative investigation in Chapter 5. A comparison was also made between these outcomes with the objective results produced of the changes in noise level pre/post-construction, through the use of a selection of modelled noise maps of the case study area.

The chapter demonstrates how the subjective opinions of the public's perception of the noise reduction relate to the objective or modelled results. The reasons behind the public's perception are explored in relation to the results of the quantitative investigation. This helps to establish the extent to which, the level of PP in the development of the noise barrier influenced the public's perception of its ability to attenuate noise. This has enabled a conclusion to be developed, which shows that 'the greater involvement and access those needing protection from a barrier are given to the barrier's design and development, the greater the acceptance and perceived benefit the barrier would give'.

6.1.2 Chapter outline

This chapter starts with an introduction to the noise mapping software, as well as a full description of the method used to develop the maps, and comments on how various problems encountered in the modelling were resolved. The maps are then presented with information about how they were validated and calibrated relative to the real world scenario. The results of the maps are then compared against each other to quantify the objective differences between the various barrier options.

In order to further illustrate the potential benefits of noise mapping, the barrier height was varied in the three different scenarios modelled. This illustrated how noise mapping could be used to predict the potential benefits of the barrier. It also enabled the identification of houses where positive and negative influences of the noise barriers would be most greatly felt. In addition, it allowed for a comparison of subjective opinions with objective measurements to determine the extent to which public attitude resultant from extraneous variables, such as the level of participation, impacts upon the perception of a barrier's performance.

Finally the idea of focused PP is developed, which illustrates the potential utilisation of noise maps to identify smaller sections of the community, where the noise issue is most salient. This enables a more focused and tailored approach to PP rather than the more broad brushed and potentially alienating methods that are routinely implemented. The final section discusses the importance of integration as part of a wider sustainability strategy. This includes a review of how PP is being adopted by other large bodies such as Local Authorities, in comparison to the Highways Agency, and includes details of the relevance of noise mapping for directing methods.

6.2 Methodology for the development of the noise maps in the case study area

6.2.1 The extent and location of the noise maps

The noise barrier investigated in this case study extends for approximately 5km along the M1 motorway, on both the north and southbound carriageways between junction 33 and 34. It is not a continuous barrier, as not all the land within these junctions is occupied with sensitive receptors. However, for the purpose of continuity the whole length of the carriageway between the junctions was mapped. In addition, 300m away either side of each carriageway was incorporated into the noise map. This is in line with the Highways Agency's publication the Design Manual for Roads and Bridges (DRMB) and a growing body of evidence (Askew 1998; Md-Taha 1999) which suggests that, beyond 300 metres, the effects of traffic noise in correlation to perception of noise after a barrier's development become less related.

The noise mapping software used in this investigation was the Cadna/A (Version 3.1) (DataKustik 1998) noise mapping package, this is a German package that allows modelling to be undertaken in line with the CRTN Guidelines (Department of Transport 1988). A plan of the area mapped can be seen in Figure 6.1, this illustrates the extent of the road network as well as the proximity of the residential areas highlighted in grey to the M1 motorway highlighted in blue.

Figure 6.1 M1 Junctions 33-34a, residential area and contour lines. (Digimap)

The base map that was imported into the noise mapping software was in the format of an AutoCAD DXF file, this contained data on the M1 and all surrounding minor and tributary roads, as well as properties, both residential and commercial within the area. In addition, the exact location of the noise barrier was illustrated[1]. This investigation only assessed the impacts of road traffic noise, despite there being a rail network (light, passenger and freight) and Sheffield Airport. The impact of these additional noise sources was not considered as this investigation was based purely on road traffic noise, and the change of the levels post construction of the acoustic barrier. However, their potential influence on the ambient noise climate was acknowledged when the data was validated to account for any significant deviation from the modelled results. To reduce the impact of their influence on the validating noise measurements, monitoring was undertaken more than 300m from any of the rail lines, and during the afternoon when there are minimal flights from and to the airport.

6.2.2 Traffic flows and road classifications

The input data for the purpose of this investigation included: traffic data presented as AAWT (Annual Average Weekday Traffic); between 0600 and 2400 hours; the percentage of heavy goods vehicles (HGV's); an evaluation of the ground conditions and heights; road gradients and surface material, in addition to building heights and topographical area data.

Although the importance of valid, reliable and accessible traffic data is widely recognised, unfortunately as of yet there is no infrastructure in place to access and share completed road

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[1] This was acquired through RPS Consultants on behalf of WSP Carillon, (RPS Environmental Consultants and Sponsors of this work, WSP Carillon: Project managers of the area incorporating the M1 Junction 33-34).

data. It has been suggested that all digital road data be centralised and prepared in a format that could be utilised by different services with a single administration (Wetzel and Meßsysteme 2001; Wetzel 2002). For example, if the data was first acquired for the sake of traffic planning, it should be prepared from the start in a format that makes it suitable for further use in noise mapping or air pollution calculations. This would also aid the standardisation of noise mapping, a fact that has been addressed by DEFRA for the UK noise mapping project but is yet to be universally available.

It was noted at the time of this investigation that no such system was in place for the collection of traffic data, consequently this data had to be gathered from a series of sources including Rotherham Council Transport Department, Sheffield City Council's Transport Department and a series of factored spot traffic counts. The accuracy of this data was imperative as these were the main noise sources; consequently the most up-to-date figures were sought. The traffic data was collated assuming no unusual events such as local sporting events, bank holidays or large-scale pop concerts or festivals were occurring, in accordance with the Calculation of Road Traffic Noise Guidelines (CRTN) (Department of Transport 1988).

In accordance with the CRTN guidelines any unladen vehicle exceeding 1525kg, was classified as a heavy vehicle (Department of Transport 1988). The traffic speeds for the roads were classified using Table 6.1, from the CRTN guidelines. A further assumption was that all motorway and major road surfaces were covered in impervious bitumen with a texture depth of 5.0 millimetres (BESD 2000).

As data was not available from any source on minor roads in the area, advice was taken regarding the best course of action for inputting minor roads[1]. It was felt that the minor roads all carrying less than 100 veh/hour would not significantly influence the overall noise level. However, to ensure that this was the case two calculations were performed using the CADNA/A software.

The model was taken from the larger map of the whole area and simplified to test the impact of local road traffic. In order to do this receivers were positioned between the motorway which for the purpose of this experiment had 40,000 cars travelling along it in an 18-hour period, and a local road which was tested with both 0 veh/hour, 50 veh/hour travelling on each road at a maximum speed of 25 km/hour. Figure 6.2 below shows the impact of the two traffic flows; the

[1] Advised by the Professor of Traffic & Environmental Pollution, Institute for Transport Studies, University of Leeds (January 2003).

minor differences are outweighed by the significant increase in calculation time attributed to having traffic flows on local roads. Therefore, for the purpose of this investigation, local roads were all inputted with a traffic flow value of 0 veh/hour. This method has been used previously in noise mapping investigations, where all discount the input of data for traffic flows less than 2000 veh /(24 hours) (BESD 2000; Carruthers, et al. 2002; Popp 2002).

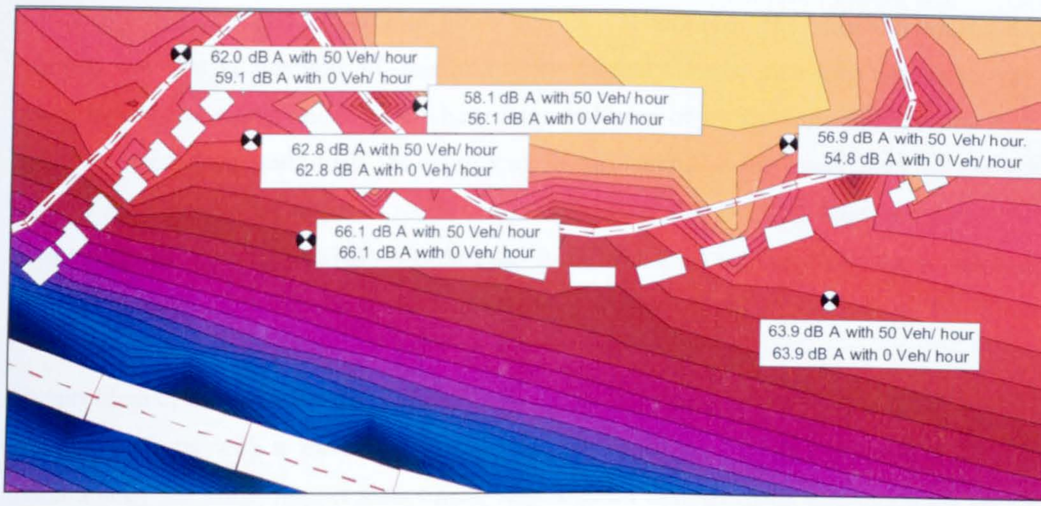

Figure 6.2 The influence of traffic volume on local roads with less than 50 veh/hour.

Table 6.1 Average speeds by road classifications in accordance with CRTN.

Road Classifications	*Traffic Speed*
Roads not subject to a speed limit of less than 60 mph	
Special roads (rural) excluding slip roads	*108 km/h*
Special roads (urban) excluding slip roads	*97 km/h*
All-purpose dual carriageways excluding slip roads	*97 km/h*
Single carriageways, more than 9 metres wide	*88 km/h*
(Slip roads are to be estimated separately)	
Roads subject to a speed limit of 50 mph	
Dual carriageways	*80 km/h*
Single carriageways	*70 km/h*
Road subject to a speed limit of less than 50 mph but more than 30 mph	
Dual carriageways	*60 km/h*
Single carriageways	*50 km/h*
Road subject to a speed limit of 30 mph or less	
All carriageways	*50 km/h*

Source: (Department of Transport 1988:6).

Road widths were classified as follows, Motorway- 37.5m, incorporating both north and southbound carriageways, from the outermost point of the hard shoulder on the far side of the carriageway to the outermost point of the hard shoulder on the nearside of the carriageway. This measurement was derived from the AutoCAD map. Major Roads, including all A-roads, were classified as 14m from the outermost point on both sides, and minor roads as 7.5 metres, including both traffic lanes flowing in opposite directions (Caruthers and Oates 2002).

6.2.3 The modelling of complex road junctions

The mapping of roundabouts presented a particular problem, in that the software being used had no function for the input of roundabouts, and so a solution had to be determined to incorporate effectively this significant source of noise into the calculations. The largest roundabout to be mapped was that at Junction 34, this had seven tributary roads, including two motorway slip roads (north and southbound M1), where large volumes of traffic were accelerating onto the motorway and decelerating off the motorway. It also included the lower deck of the viaduct (A631) and four further major A roads (A631) Bawtry Road, (A6178) Sheffield Road, (A631) Shepcote Lane, and the (A6109) Meadowhall Road which all converged on the roundabout, in addition, the motorway ran above the roundabout at approximately 20 metres.

The problem of mapping the roundabout was tackled by treating it as a road in itself, made up of separate sections with a maximum speed limit of 50 km/h. This is in line with the CRTN methodology for noise impact assessment, which states that all roads and junctions should be broken down into as smaller sections as possible containing individual flows (Department of Transport: 1988:4). Consequently each section of road was influenced by the traffic flowing on and off at the tributaries, thereby giving an accurate picture of reality. An illustration of how the complex viaduct was modelled in 3D format can be seen in Figure 6.3.

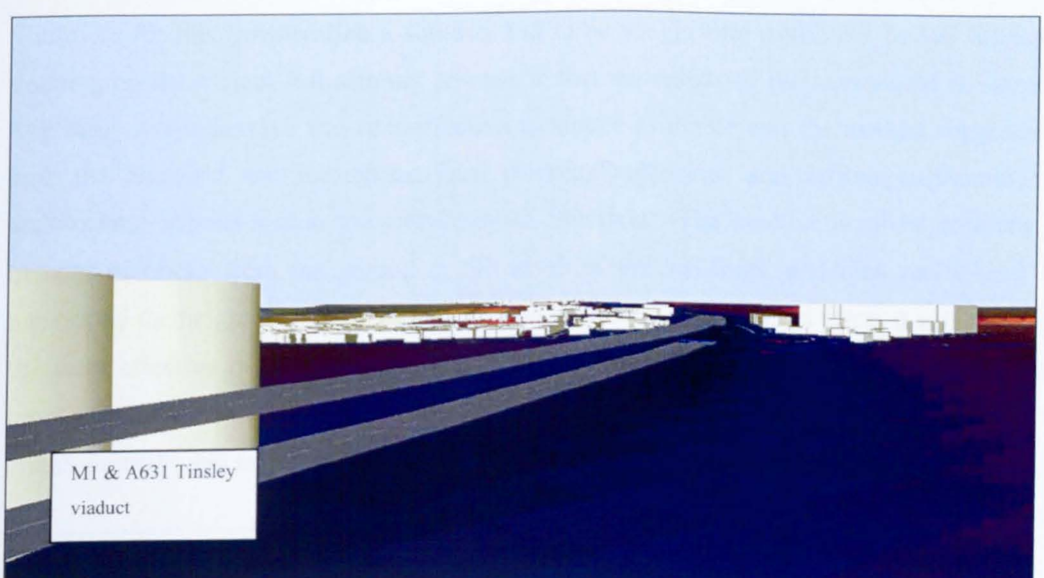

Figure 6.3 A 3D model of the Tinsley viaduct and M1 looking south towards Tinsley and Brinsworth.

6.2.4 The modelling of buildings and collection of relevant data

For clarification, the only barriers to interrupt the noise pathways within the noise map were buildings (including residential, industrial and commercial), embankments and terrain height contours, raised roads and noise barriers.

The measurement of building heights was a significant problem, as there was a lack of available data from the planning offices and the Ordnance Survey on existing building heights. This problem was also experienced during the major noise mapping projects of Birmingham City Centre (BESD 2000) and Tower Hamlets London (Brent Borough Council 2004). The Birmingham City Centre noise mapping project overcame the problem of building heights using a similar methodology to this investigation, the difference being, during the Birmingham Noise mapping study aerial photographs and digitising software were utilised to estimate building heights, (BESD 2000) which were not available to this study.

Further investigation has revealed that many of the noise maps of larger agglomerations have taken average heights, with a standard 8-metres being taken for the noise mapping of the buildings in Tower Hamlets, London (Tompsett and Liddell 2001; Brent Borough Council 2004), and a generic value for all buildings outside Central London of 17.9m, and 19.0m inside Central London for the Crossrail Scheme currently under design[1].These measures are evidently much less precise than the methods utilised in the Birmingham City Noise mapping project, but are also much less costly.

Therefore for this investigation a solution had to be sought that would not be too financially draining on the project, but also not so generic that the results of the map would be impeded. The most comprehensive and cost effective technique available was the method suggested by both the Sheffield and Rotherham local planning authorities and various engineering and architectural experts within the University of Sheffield[2]. The practise involved counting the number of bricks from the ground to the eaves of the buildings, and then multiplying this number by the height of each brick and the mortar joining it to the next brick. It was found that the most effective method of doing this for the terraced houses, which make up the largest proportion of the housing stock in Tinsley, was to count at the end of the terrace where the bricks generally ran up to the highest point of the building.

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[1] Project undertaken by RPS PLC 2004.

[2] Advice from- Dr Tyas, School of Civil Engineering, Dr Brocklesby and Professor Kang School of Architecture, University of Sheffield.

For the other housing stock types, such as the common three and two storey blocks of flats the bricks in each level were counted and measured enabling the measurement for one storey to be obtained. This then enabled a simple calculation through multiplying the height of one storey by the total number of storeys. In Brinsworth the largest proportion of the housing stock was made up of either 1930s semi-detached houses or retirement bungalows. These were all of a similar architectural design and consequent height. Therefore, small samples of heights were actually calculated for each house type, and these were allocated to similar housing with confidence.

In Catcliffe the housing stock consisted of four main house types, terraced, semi-detached, bungalows and new build detached and semi-detached. Again the simple brick counting method was used to give the building heights of the residential areas. The main non-residential buildings within the catchment area were made up of 8 one-storey schools, which were easily measured and several industrial developments on an industrial estate, these were measured through a combination of brick counting and estimations.

It was felt that should the reflections from the large industrial buildings be greater than is calculated, or if they produced more noise than is represented in the noise map, then this could be assessed when supplementary measurements were taken. This would qualify the data, and the necessary amendments to the building heights could be made.

6.2.5 Modelling pitched roofs

The issue of inputting building heights was further complicated when deciding whether to input building heights up to the eaves, or to model building heights up to the roof, (a difference in some circumstances of up to 1.5 metres). It was felt that to ignore this factor and input the total height including the roof, could have potentially created the problem of extra unnecessary height and unrepresentative shadowing as illustrated in Figure 6.4.

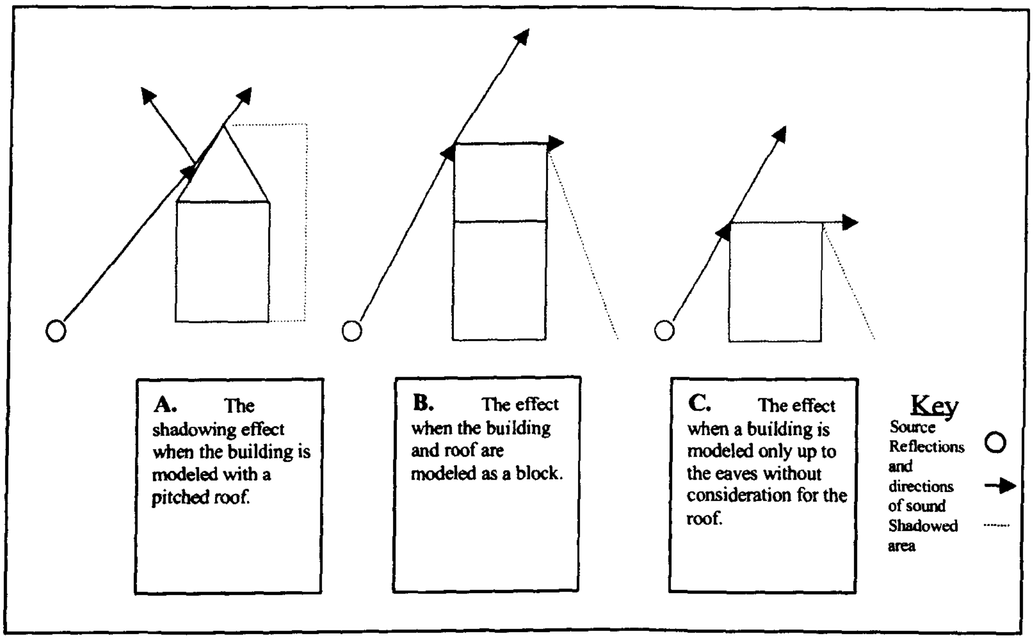


Figure 6.4 The noise reflections and shadowing effect when buildings are modelled with different roof configurations

After consultation with both the developers of the Cadna/A software and for verification the distributor of Soundplan, the following advice and decision was made. According to the Cadna/A developers, in most cases the average height of a building for acoustical calculation is the height from the ground to the eaves plus approximately 2/3 of the height between the eaves and the top of the roof. However, with a flat roof no correction was obviously necessary.

It was felt that only in a few cases would it be necessary to input the exact height and construction of the roof e.g. if the receiver point was very near to the sound source, which would then cause the building to effectively shield the receiver point (Probst 2003). Under these conditions it would have been best to insert an additional polygon point to take into account the ridge of the building and give the point the real height of the roof, and then insert a barrier between the opposite ridge points with the same height as shown in Figure 6.5.

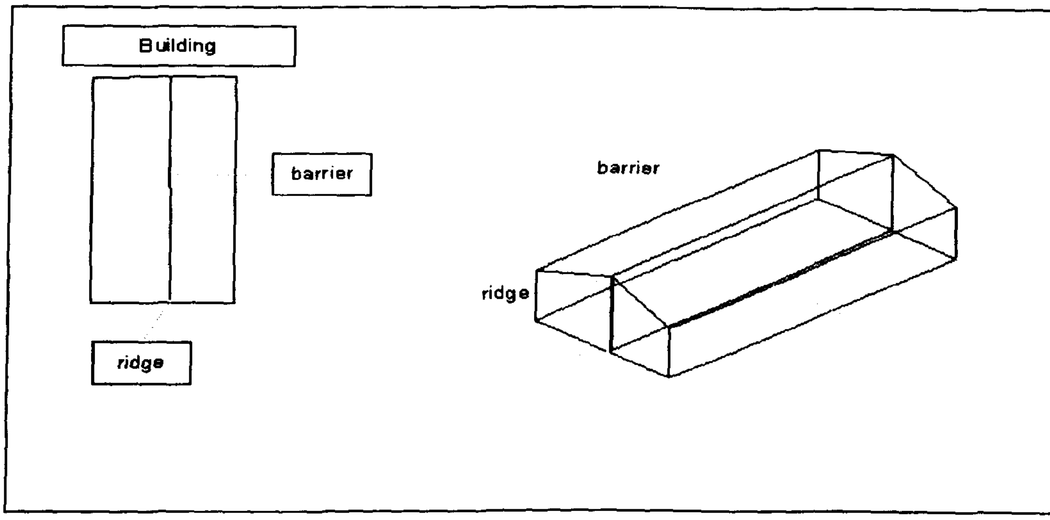


Figure 6.5 Method for inputting an exact model of a building including the roof.
(Source Probst 2003, Cadna/A).

The advice from the UK distributor of Soundplan (Winterbottom 2003), another software commercially available for noise mapping, was similar. It was recommended that the height of the eaves should be used. This was attributed, partly because of the time consuming nature of modelling all the different possible shapes of roofs accurately, but also because the effect on the path difference of a sloping roof would not result in a greater variation than if two walls were spaced apart[1].

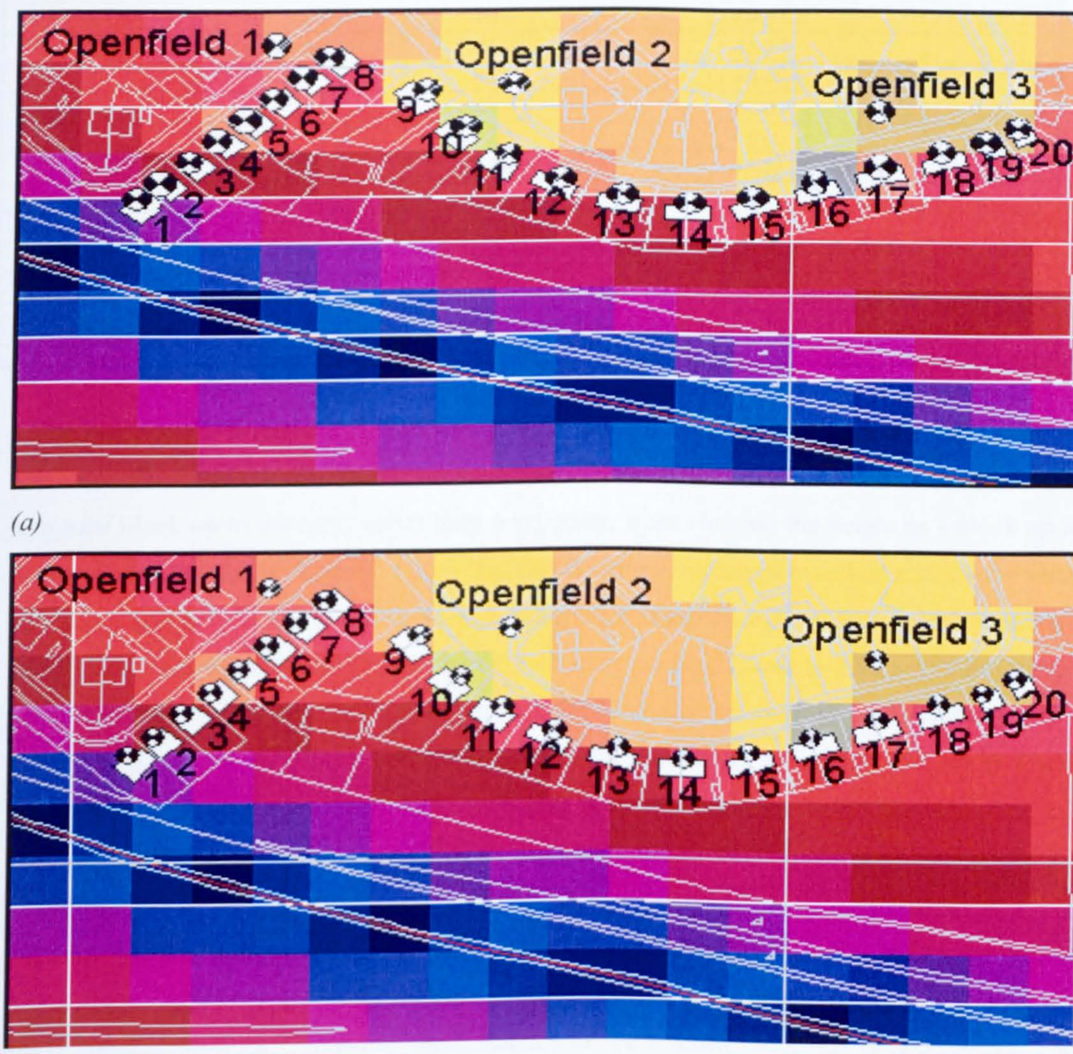
In light of this advice, and due to the large scale of the area to be mapped, the decision was made not to individually model each roof with a barrier and an alternative means of accurately inputting the building heights was pursued. To determine the implications of this decision, the difference in noise levels at specified receivers were calculated between modelling the buildings with their heights up to the eaves and as a solid block up to the top of the roof.

To make the comparison a small area was taken from the case study noise map containing 21 houses, traffic data was input as one lane of motorway, running between 37-147 metres from the receivers, with a value of 40000 veh/ 18hour, the calculation was run both with the heights up to the eaves plus 2/3rds, of the height up to the top of the pitch to account for the effects of the sloping roof and up to the total roof height as a flat roof, effectively giving the buildings an extra level. Receiver's were distributed at the rear of each property 1m from the façade, and

[1] (I.e. Draw from the source over the top of the front wall and then from the receiver over the top of the back wall and the point where they meet are often not very different to the position of the ridge).

1.5m of the ground with a further 3 positions located 20m from the rear of the properties in an openfield location.

To evaluate the influence of roof height a standard height of 8.5m was chosen, as this reflected the majority of the housing heights in the study. The first calculation displayed in Figure 6.6 (a) as a noise contour map illustrates the impact of modelling the height up to the top of the roof. Effectively as a flat roofed structure, Figure 6.6 (b) illustrates the influence of inputting the roof height as the height up to the eaves plus 2/3rds of the height between the eaves and the top of the roof. For this example a height of 1.5m was presumed, giving an overall inputted height of 7.99m.



(a)

(b)

Figure 6.6 (a &b) Test of influence of roof heights on receivers when measured to the eaves plus 2/3rds.

Table 6.2 Difference in noise levels, with the building modelled up to the height of the roof and to the eaves.

Receiver	Distance from Source (m)	Roof (8.5m) as flat. (dB(A))	Roof (7.99m) up to the eaves plus 2/3 to the ridge. (dB(A))	Difference in dB(A)
1	37.1	64.6	64.7	0.1
2	46.4	63.6	63.6	0.0
3	58.6	61.9	61.9	0.0
4	70.4	60.5	60.5	0.0
5	82.0	59.1	59.2	0.1
6	94.3	58.3	58.4	0.1
7	106.6	57.4	57.5	0.1
8	117.9	56.6	56.6	0.0
9	114.0	48.2	48.7	0.5
10	102.2	47.6	48.1	0.5
11	94.5	46.7	47.2	0.5
12	90.2	46.3	46.8	0.5
13	88.5	45.7	46.3	0.6
14	90.4	45.8	46.4	0.6
15	98.7	47.0	47.6	0.6
16	110.8	47.5	48.0	0.5
17	123.6	47.4	47.9	0.5
18	135.1	47.2	47.7	0.5
19	143.3	47.3	47.8	0.5
20	151.5	47.3	47.8	0.5
Openfield 1	116.5	58.5	58.5	0.0
Openfield 2	125.5	55.5	55.8	0.3
Openfield 3	147.3	54.3	54.6	0.3

Table 6.2 shows the impact of the two heights upon the receivers, including the openfield receivers. The output of the calculation illustrates that the difference between entering the height as a total block up to the roof, varies only marginally, from entering the height as a block up to the eaves plus 2/3rds for the roof. Given that this is not a comparison based on exactly the same condition, and that the site is not an 'ideal' condition for comparison (say, free field, one infinite row of houses, a simple point or line source, etc), it would be difficult to give a straightforward reason for the difference. Diffraction through the house sides may also affect the results. However, given that the difference is only between 0.1 and 0.5dB, the conclusion can be made, that between the two roofs modelled the difference is acceptable/insignificant, and therefore, the example with the height eaves plus 2/3rds for the roof was chosen to represent all pitched roofs.

Figure 6.7 below illustrates how the modelled buildings look when inserted within the model. As the figure shows, the buildings are represented as blocks in the 3D model. However, with the above methodology for calculating the influence of the pitched roofs this is appropriate. The varying colours on the building facades indicate the noise levels and the effects of shadowing by buildings.

Similarly Huang (2003) evaluated the impacts of modelling various rood configurations. The findings of his investigation mirrored those in this investigation, in so any variations between the modelled flat and pitched roofs were in the region of less than 1dB. Huang, however, adopted a different method of modelling the pitch, which, it was reported, consistently represented the 'real building situation', with buildings of heights h=5m, h=7.5m and h=10m respectively, when a standard value of 0.7m was added to the height up to the eaves. This approach was not adopted but represents an alternative effective means of incorporating pitched roofs into a model (Huang 2003).

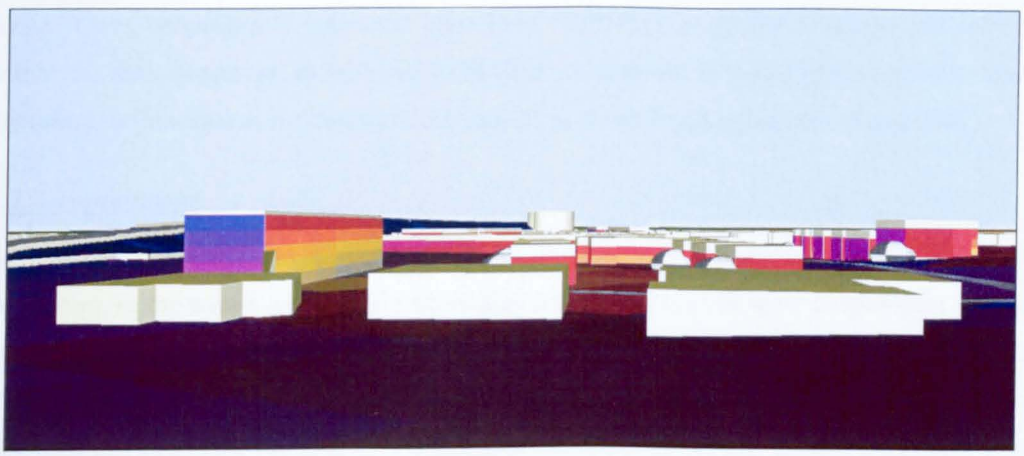


Figure 6.7 3D models of buildings with colour bands depicting the façade levels.

6.2.6 Reflections and absorption

In some major UK noise mapping projects, reflections have not been included due to time restrictions (BESD 2000). However, it is felt that in some built up locations the predicted noise level may be much lower than in reality when reflections are discounted (Manvell 2002; Wetzel 2002). This loss of accuracy must, however, be weighted against the proportional increase in calculation times, related to the number of reflections that the noise mapping software must calculate. In large models it would be an unsolvable task to calculate all possible reflections. However, to tackle this, the developers of a German noise mapping pilot study for the town of Herne, the "Landesumweltamt" of Nordrhein- Westfalen, documented that the rate of increase in receiver levels declines rapidly with increasing fetching radius (Manvell 2002).

Recent research undertaken using Cadna/A found that when the results of a test comparing 1, 3, 5, 10 and 20[1] reflections respectively, was undertaken with a boundary absorption coefficient of 0.1. That despite the accuracy of the noise levels improving at the 10 modelled receptors. The

[1] 20 reflections is the limit for the Cadna/A software.

difference between the minimum and maximum order of reflection was still just 1.81dB (Huang 2003).

Therefore, when reflections were considered, in order for the examples to run within a realistic time scale in relation to a full noise mapping study of a large urban area, only first order reflections were considered (DataKustik 1998), and the maximum search radius for reflective sources was taken as 100m, and the maximum reflective source to immision point search radius was reduced to 100m (Carruthers, et al. 2002).

Again it was unfeasible to insert the absorption coefficient of all the buildings and materials within the area. However, as with the reflections, to discount it would give unreliable results. Therefore, an absorption coefficient of 0.1 was taken for all building façades (Kang 2002).

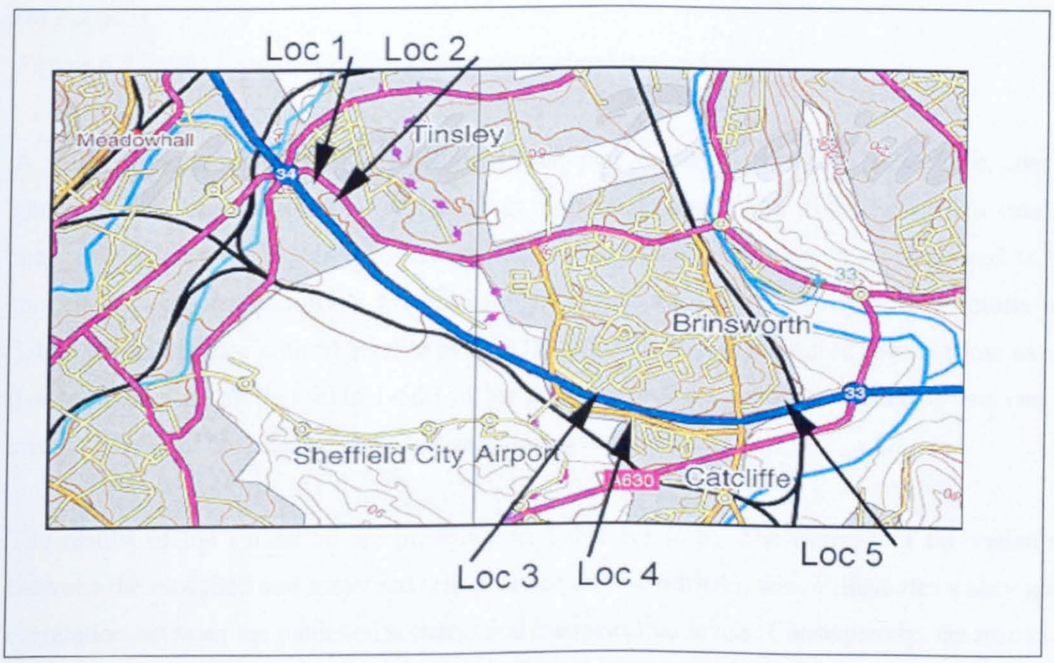
6.2.7 Topography

To improve the accuracy of the noise maps, the use of accurate topographical data was imperative, as the terrain of the land surrounding a sound source can have a significant influence on noise propagation. Therefore a 10x10m contour grid (E-Map 2004) was overlaid on the map of the area, which accurately gave the terrain height every $10m^2$. The Cadna/A software was then able to extrapolate the grid by triangulating between the contour points, effectively giving each point on the grid an accurate 3D height reference. This was important, as the terrain height varied significantly across the length of the area. Therefore, if it had not been considered, areas of land, which lie effectively in the shadow zone of the motorway, might have had noise levels predicted in excess of the actual situation. The contour of the terrain has two major effects on the calculation of sound propagation. It determines the height of the source, the shielding objects, and the emission points. For short distances, this in turn, may affect the length of the sound path, thus the propagation loss and also the path length difference around the barrier, and consequently the insertion loss.

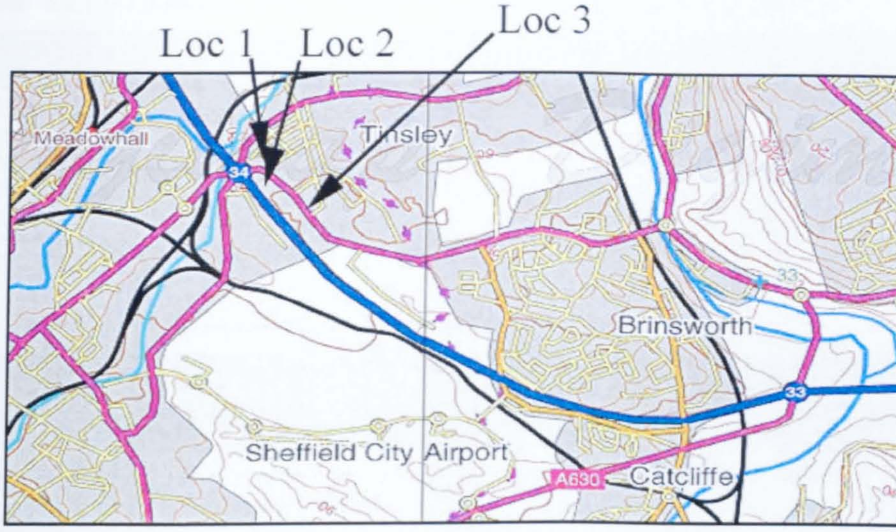
There was little significant gradient on the motorway itself, with the dramatic drops in land height occurring on embankments running parallel to the motorway. Therefore, with the gradient at less than 5%, it did not need to be considered in the noise map (Department of Transport 1988). The one road with a steep gradient of 5%, Whitehill Lane, had the value input manually, and the software automatically calculated the increased noise resultant from vehicles travelling up against the gradient. The main area uses were residential, industrial and open recreational grassland. This was considered and integrated into the map to account for the varying absorption coefficients, as areas with soft and absorbent ground cover, reduce the reflection effects. Without consideration of this the noise levels tend to be over-predicted (Department of Transport 1988).

6.2.8 Calibration & validation

Various factors affect the quality of a noise map, and sources of uncertainty of between 5 & 10dB can be expected for calculated noise maps, primarily depending on the quality of the input data. By comparison a 2-week measurement can be within 1dB of the annual level, with a probability of 54% and an expanded uncertainty of 6dB (Manvell 2002). The validation was undertaken by monitoring the noise levels at 5 open field locations as $L_{Aeq\ (15min)}$ and 3 façade locations during a dry and representative weekday between the hours of 1000 and 1600, using a Cirrus Integrated sound level metre, CRL 2.22. This was calibrated before and after the measurements with no significant variations. The locations of the validation monitoring sites for the openfield and façade data collection can be seen in Figure 6.8 (a) & (b) respectively, below.



(a) Openfield



(b) Façades

Figure 6.8 (a&b) Locations of validation-monitoring sites undertaken.

A 2dB variation between monitored and modelled results is typically acceptable, and is generally attributed to temporal variations in monitored values. The measurements to validate the modelled results in this investigation were undertaken in one day, and compared to the modelled results representing a whole year. The largest variation between the two results was 5.4dB. In accordance with Manvel et al (2002) who claim that if measured data is taken over a 2-week period it can be within 1-6dB of the actual annual scenario and modelled data can be within 5-10dB of the real scenario, this variation is acceptable.

The results of the validation are presented in Table 6.3 (a-b). The average of the variations between the modelled and measured results are equal to 2.6dB(A), which illustrates a very good correlation between the modelled scenario and the measured levels. Consequently, the results of the noise mapping data can be used with confidence. In addition to the validation results confirming the accuracy of the noise models, the fact that each of the scenarios compared were kept identical with the exception of the noise barrier height, ensured that the comparison was 'like with like' and consequently no further calibration was necessary.

Table 6.3 (a) Validation of the modelled L_{Aeq} results using monitored data[1].

Free Field Location and distance band from M1	*Modelled Results (Leq)*	*Measured Results (Leq)*	*Difference (dBA)*
Location 1 (0-50m)	*73.0*	*69.0*	*4.0*
Location 2 (0-50m)	*70.4*	*69.0*	*1.4*
Location 3 (0-50m)	*71.1*	*70.0*	*1.1*
Location 4 (100-150m)	*64.4*	*59.0*	*5.4*
Location 5 (100-150m)	*69.1*	*70.0*	*0.9*
Average variation	***69.6***	***67.4***	***2.6***

(b) Validation of the modelled L_{A10} results using monitored data[2].

Facade Location and distance band from M1	*Modelled LA10 values.*	*Measured LA10 (Façade)*	*Difference (dBA)*
Location 1 (0-50m)	*72.3*	*71.0*	*1.3*
Location 2 (100-150m)	*68.0*	*68.0*	*0.0*
Location 3 (150-200m)	*63.6*	*68.0*	*4.4*
Average variation	***68.0***	***69.0***	***1.9***

6.2.9 Receivers

The 108 respondents to the questionnaire were used as the location for the receivers, with each receiver being placed 1m from the most exposed façade and 1.5m above the ground in the case of bungalows and ordinary 2-story buildings, and at between 4m and 6.5m for the flats, dependant on which floor the respondent occupied. With regard to the noise types reaching the receivers, no source terms were neglected, with the exception of other forms of transport and minor roads. The maximum source to immision point search radius was taken to be 5km; grid interpolation was used at 9x9 (DataKustik 1998).

6.2.10 Calculation of residents annoyed

The calculation of the impact of the noise levels emanating from the motorway and surrounding network on the residents was determined using two methods. The first method was done by calculating the noise levels as an $L_{A10,\ 18hr}$. This is the measurement parameter used in the Noise Insulation Regulations (1988), to determine whether properties are entitled to, either noise insulation provision or compulsory purchase of their property by the Highways Agency.

There are a number of qualifying criteria[1], one of the key ones being a noise level at the façade of the property in excess of 68dB($L_{A10,\ 18hr}$), as a result of an alteration to a carriageway.

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[1] L_{Aeq} is the sound pressure level averaged over a specified time
[2] L_{A10} is 10% of the measurement time
[1] This criterion is made up of three points which need to be fulfilled and are noted below

(i) RNL $\geq$ 68 dB(A))

(ii) RNL – PNL $\geq$ + 1.0 dB(A)

(iii) RNL – L'B $\geq$ +1.0 dB(A)

Therefore, it is a good value for which to judge the severity of the problems within this case study area. The value however is very high, and was designed as a standard in the Land Compensation Act (1978).

To evaluate the noise levels in line with more current advice, the noise maps' levels were also calculated as a L_{Aeq}. This is the noise measurement used in the World Health Organisation Recommendations for Community Noise, which is the most commonly cited in literature, regarding the comparison of modelled noise to levels of residential annoyance (Popp 2002). This states that to ensure acoustic comfort for the residents, external noise levels at the properties façade should not exceed 55dB(L_{Aeq}) during the daytime and 45dB(L_{Aeq}) at night (WHO 1999:7).

Therefore, the area was mapped using two different methods. The first calculating the $L_{A10\ 18\ hour}$ with an exceedance value of 68dB($L_{A10,\ 18hr}$), and the second set calculated as a $L_{Aeq\ 18\ hour}$ with an exceedance level of 55dB(A) [1]. Consequently, both basic maps of noise levels showed the spatial distribution of noise and also a conflict map, highlighting the regions where the given limiting values were exceeded. The results of these findings showed how many properties were in excess of the recommended values; these are displayed in Section 6.3 along with other comparisons and findings of the data.

For the purpose of this investigation, just the L_{Aeq} maps were used to evaluate the numbers of annoyed residents. To know the real conflict areas, and to show them in a correct relation, the distribution of residential buildings and the number of people living in each building had to be considered (Probst, et al. 2002). As the maps were all evaluated using, no barrier, a 2m barrier and a 3m barrier, the effects of the varying barrier size could be directly compared in terms of the reduction in numbers of annoyed residents, which in real terms would be of great benefit to policy and decision makers alike when justifying various options for planning.

The number of residents in each property was taken as a national average value of 2.32 people based on the average household size by ethnic group (National Statistics 2001:2). Therefore, the total number of properties sampled was multiplied by 2.32, to give the total number of residents represented in the sample area, i.e. 108 multiplied by 2.32 to give the total residents represented

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where RNL = relevant noise level, PNL = prevailing noise level, L'B = the contribution to the increase in the relevant noise level; Noise Insulation (Amendment) Regulations (1998))

[1] There is a relationship between L_{A10} and L_{Aeq}, when measuring road traffic noise from high vehicle flows where the statistical distribution of noise levels is approximately normal, as follows; $L_{A10} = L_{Aeq}$ +3dBA (Smith et al 1999).

in the sample as 251 people. The number of households in the sample with noise levels higher than the value stated by (WHO 1999), was then calculated to give the total number of people potentially annoyed in the calculation area. This information was calculated for the 'with and without', noise barrier situation and with the hypothetical 3m barriers, to see an indication of the number of residents potentially annoyed, with the varying barrier possibilities.

6.3 Presentation of the noise maps and comparisons with the respondent's opinions

6.3.1 Correlation between perceived efficiency of the barrier and participation

The main purpose of this part of the research was to compare any differences in the subjective results on both the effectiveness of the participation process, and the opinions of how well the noise barrier reduced noise. This was achieved by analysing the objective data, provided through the noise maps, illustrating the noise levels pre and post construction of the noise barrier. Therefore, for the purpose of this section the values given from the maps with and without a 2m barrier were used.

A before and after comparison, was not previously possible due to the fact that no official pre- and post-construction data was available. The objectively modelled results could therefore be compared to the subjectively perceived noise reductions to determine the extent to which the respondent's perception was influenced by actual noise reductions against that influenced by other factors such as PP

The public's perceptions of the barrier were determined through a number of answers given to questions in the quantitative survey. (For details see questions 15 & 19 in the questionnaire in *Appendix 2D).* For the purpose of analysis a number value was allocated to each of the possible replies, which enabled statistical analysis of the data to be undertaken.

6.3.2 The modelled noise reduction with noise barriers

Section 6.3.2 includes the actual output of the maps in terms of the modelled noise reduction attributable to the noise barriers. The maps produced are in two sections. The first presents the noise levels measured as an $L_{A10,\ 18hr}$, and the second set as a $L_{Aeq,\ 18hr}$ value, the conversion between an $L_{A10,\ 18hr}$ value and a $L_{Aeq,\ 18hr}$ value was using the CadnaA program. Consequently, six maps in all were developed, representing each of the measurement types and these were modelled with no barrier, a 2m barrier and a 3m barrier.

The receivers input at the façade of the properties that participated in the research are represented with a symbol, which after calculation shows up black if the properties' noise levels do not exceed the recommended limits, and red if they are in excess of the recommended limits An example of these symbols is shown below; the maps are illustrated in the Figures 6.9-6.10 (a-c) below.

Receiver below stated limits= Receiver in excess of stated limits=.

The large scale of the area under consideration limits the differences visible in Figure 6.9. However at the scale presented here, it is still possible to see the trend of the number of receivers exceeding the limit reducing with the increasing barrier height, as expected. In addition, the extent of the noise problems both before and after the noise barriers construction are visible, with most of the properties within 300m of the M1 motorway inside the noise bands exceeding 60dB.

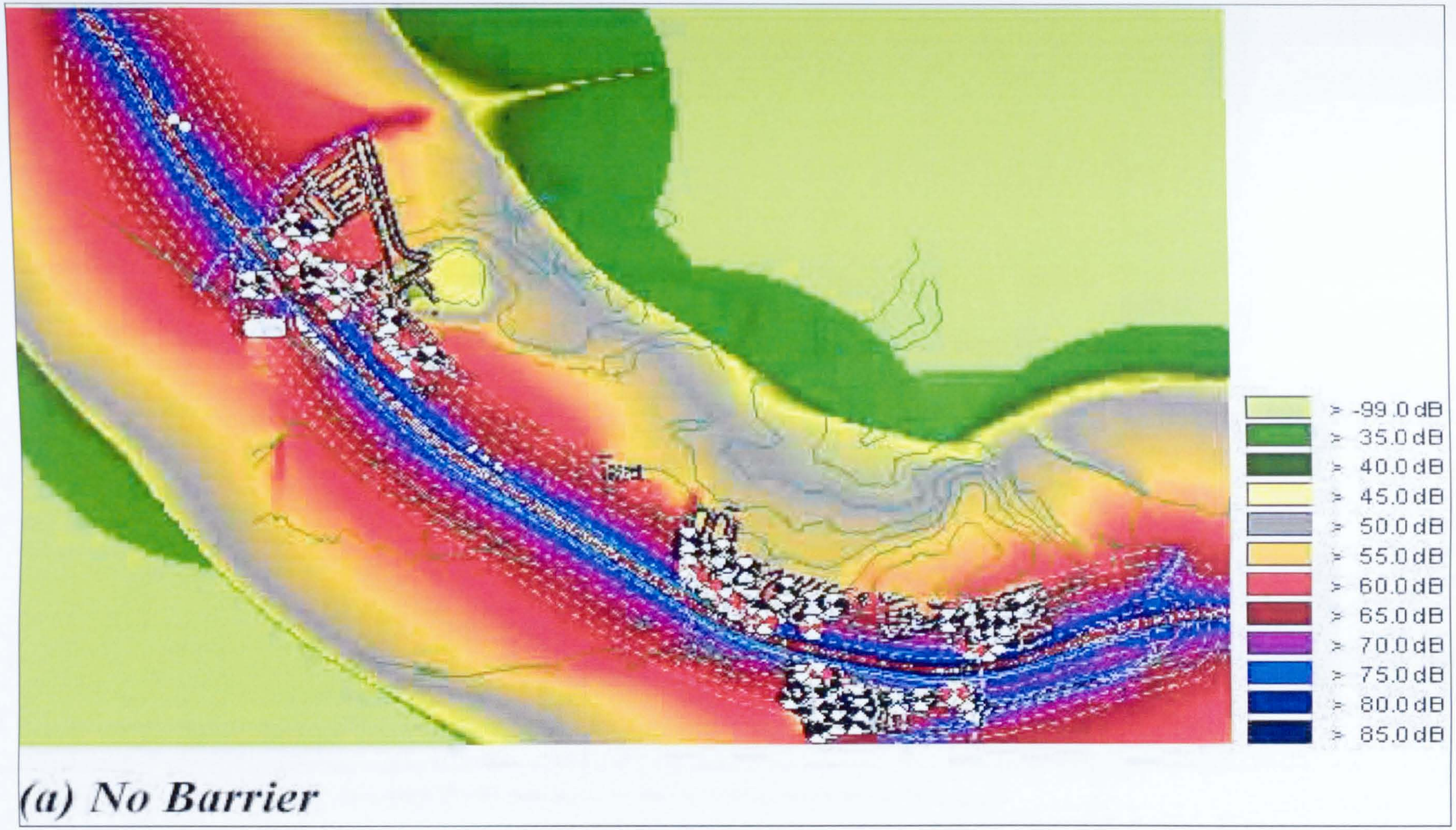

Figure 6.9(a) Map illustrating the noise levels arising with no-noise barrier heights measured as A $L_{A10\ 18\text{-}Hour}$.

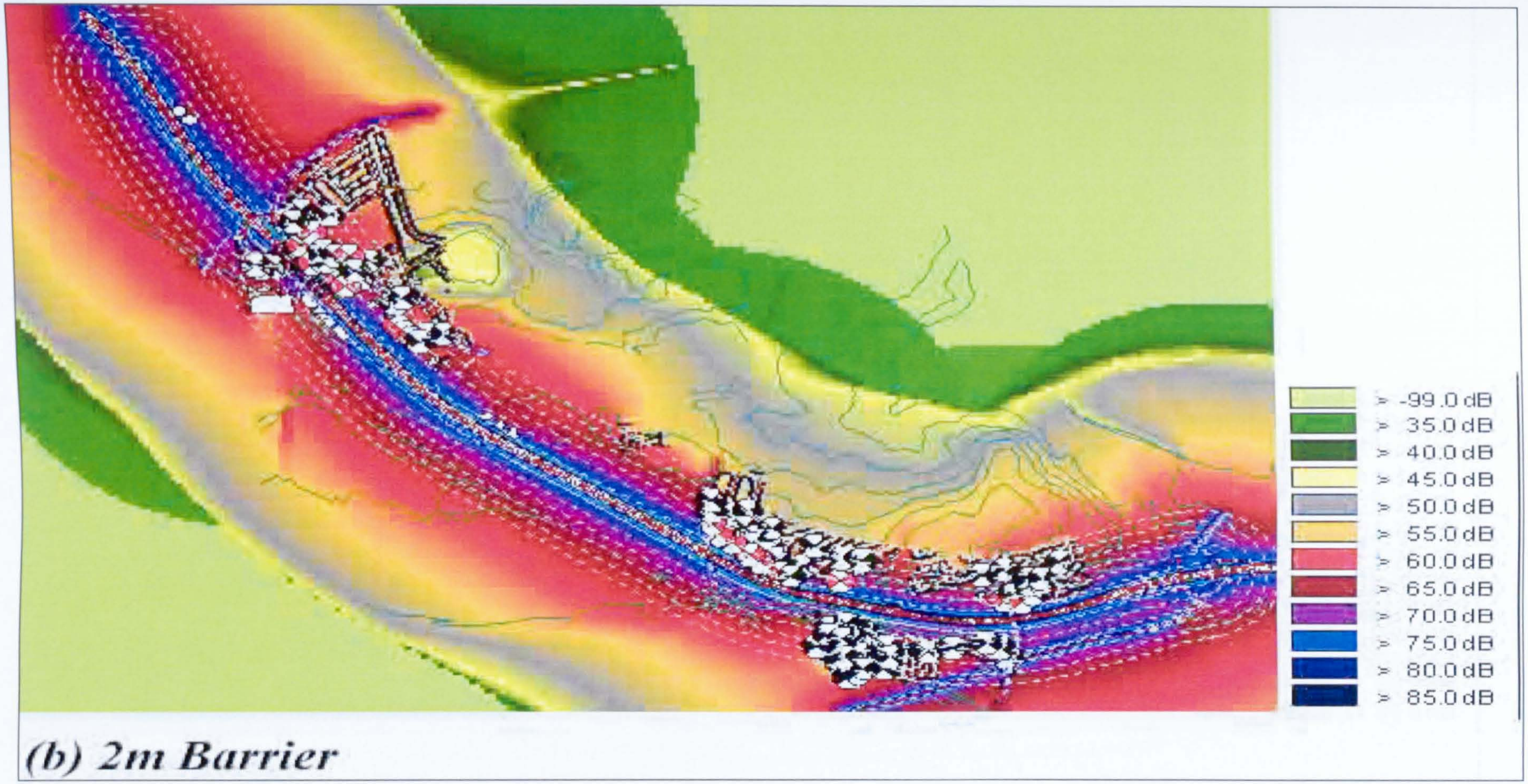

Figure 6.9(b) Map illustrating the noise levels arising with 2m-noise barrier heights measured as A $L_{A10\ 18\text{-}Hour}$.

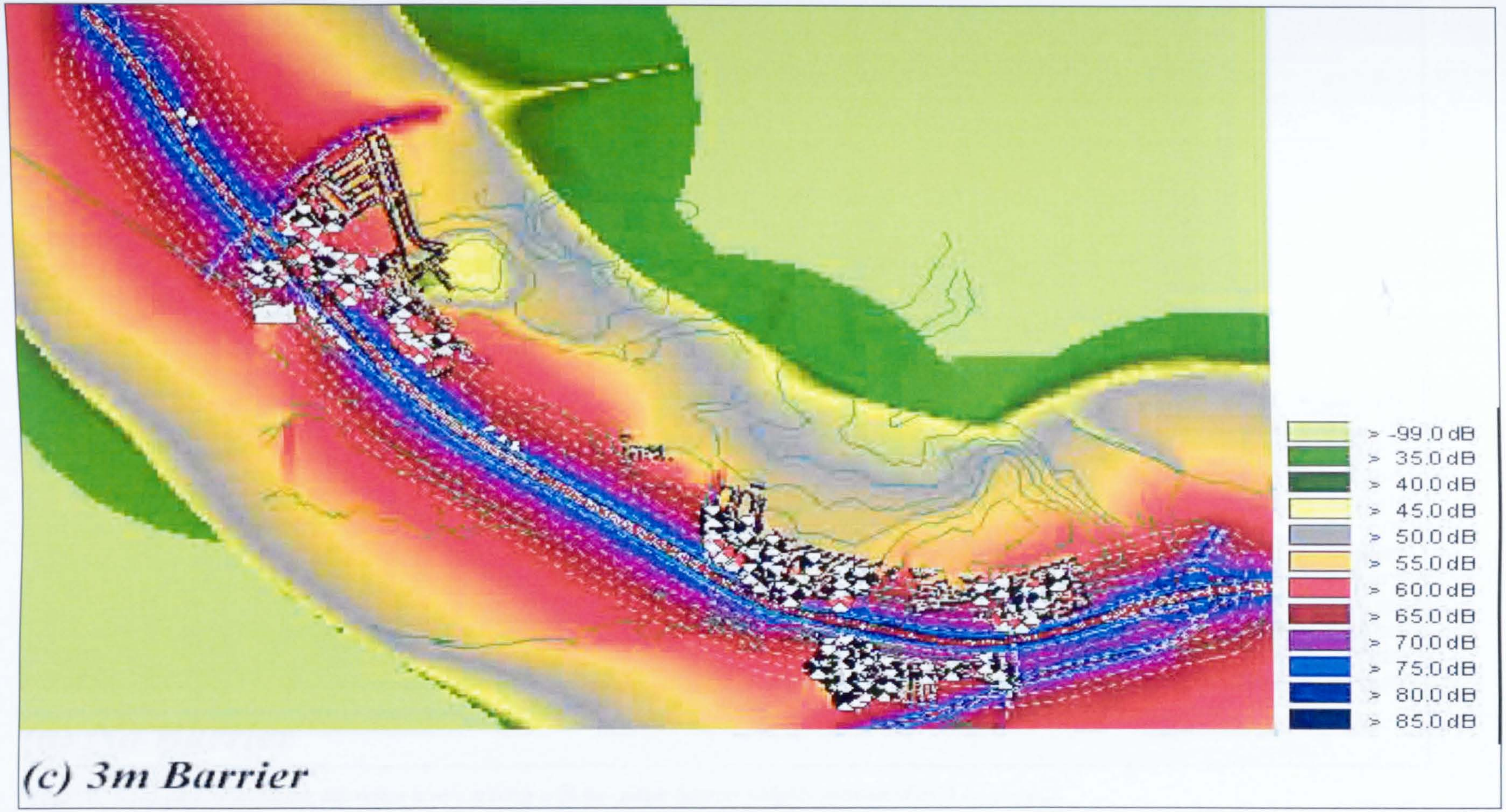

Figure 6.9(c) Map illustrating the noise levels arising with 3m-noise barrier heights measured as A $L_{A10\ 18\text{-}Hour}$.

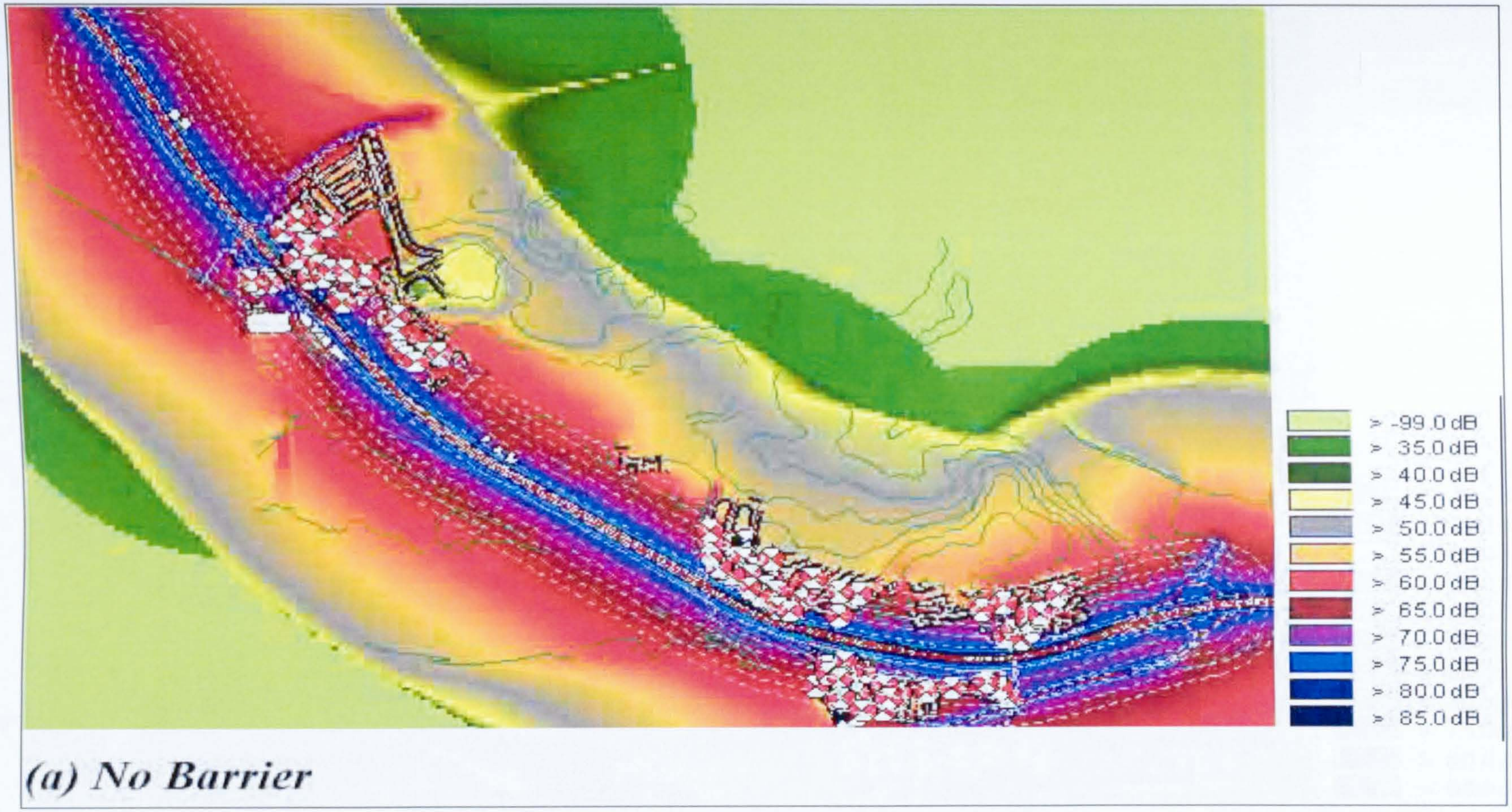

Figure 6.10 (a) Map illustrating the noise levels arising with no- noise barrier heights measured as A $L_{Aeq\text{- }18\text{-}Hour}$.

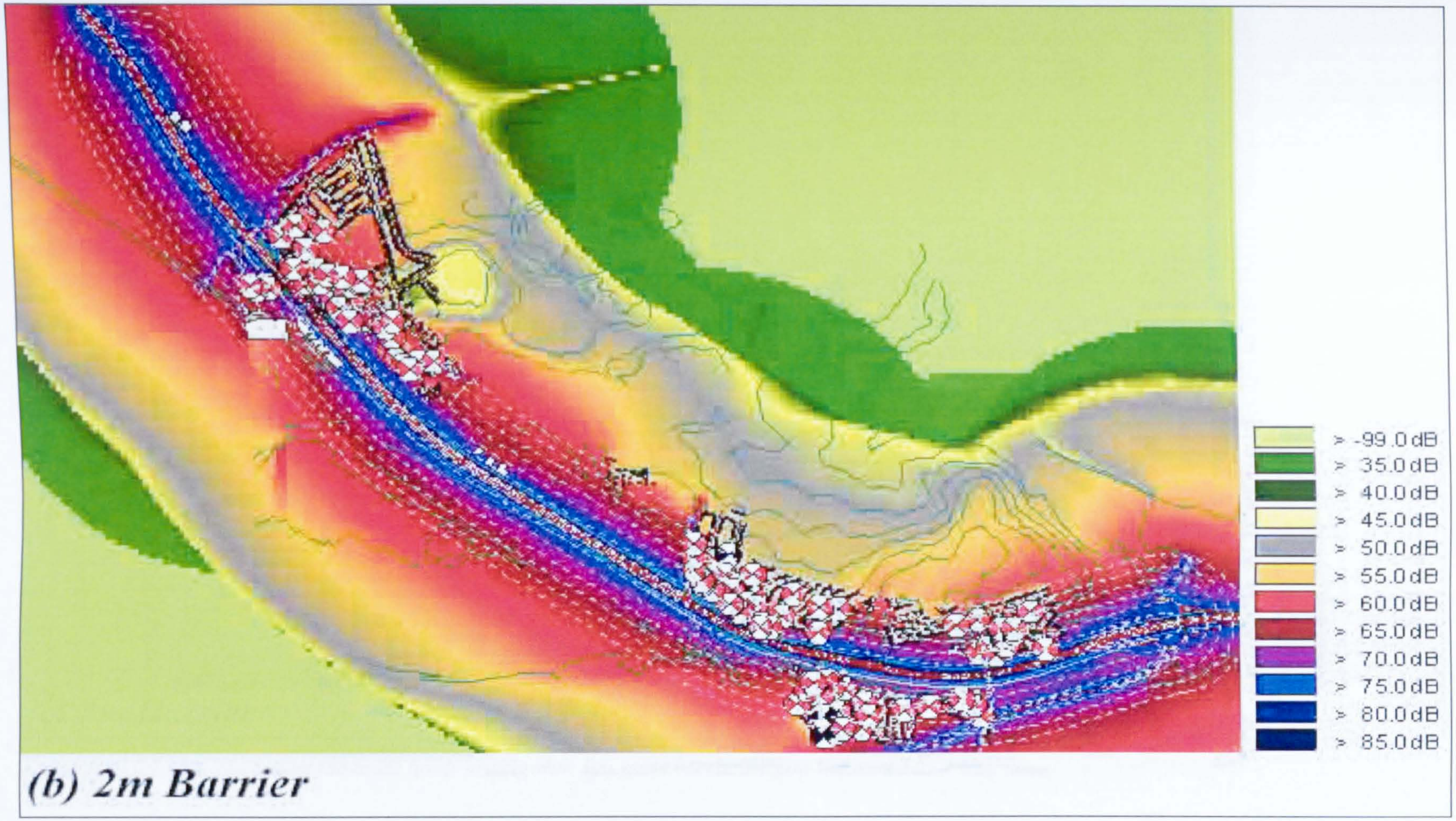

Figure 6.10 (b) Map illustrating the noise levels arising with 2m- noise barrier heights measured as A $L_{Aeq\text{-}18\text{-}Hour}$.

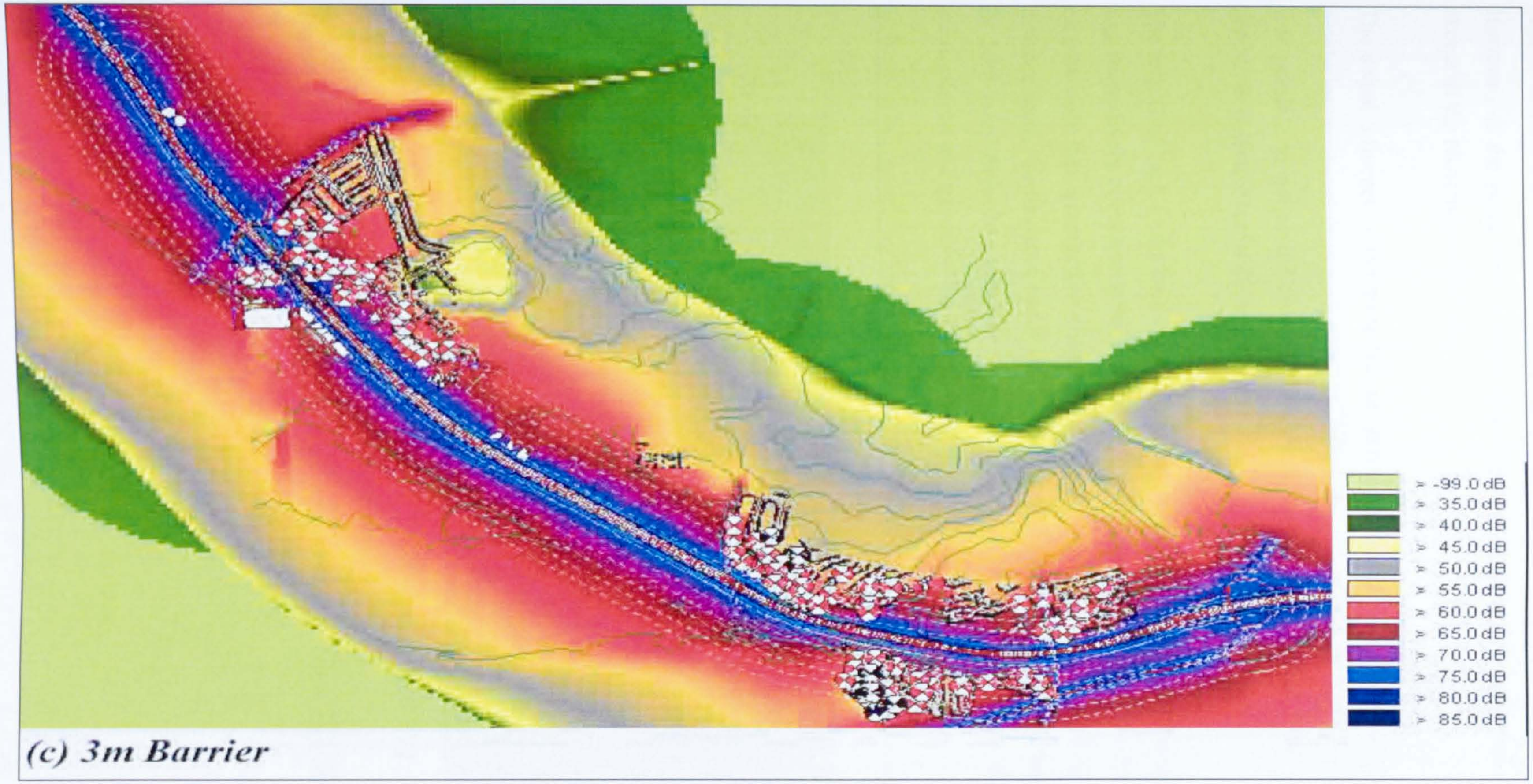

Figure 6.10 (c) Map illustrating the noise levels arising with 3m- noise barrier heights measured as A $L_{Aeq,\ 18\text{-}Hour}$.

Again, as with the L_{A10} maps, the influence of the increasing barrier heights can be seen. However, as the noise limit is much lower at 55dBA, there are many more properties in excess of the recommended levels.

The actual influence of the noise barriers is best presented numerically for comparison and graphs are produced from each map, illustrating the noise levels at each receiver. Therefore, it is possible to get an indication of how much improvement has been felt from the noise barrier, in objective terms through comparison.

The results of each of the two sets of maps were compared to see the difference in L_{A10} and L_{Aeq} respectively at each receiver with each of the varying barrier heights. The results of the outputs were then averaged to illustrate the average noise level recorded at each receiver by distance band. The distance bands can be seen as dashed lines on the noise maps, and extend by 50m away from the motorway up to 250m, the graphical and tabulated results of which are displayed in Figures 6.11 a &b and summarised in Table 6.4.

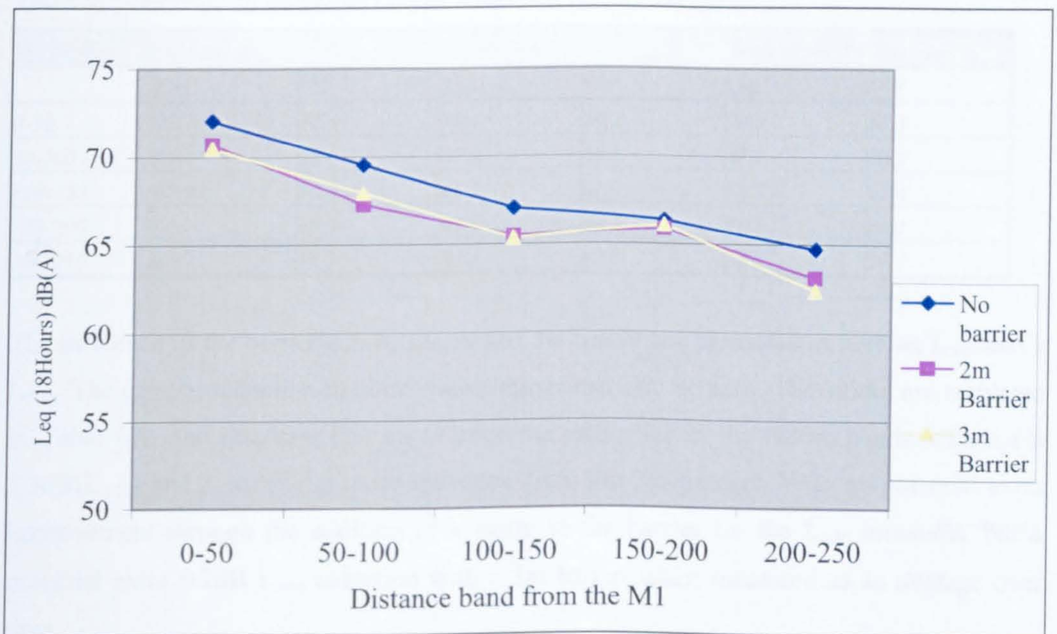

Figure 6.11 (a)LA_{eq}: The averaged noise levels at each receiver within each distance band.

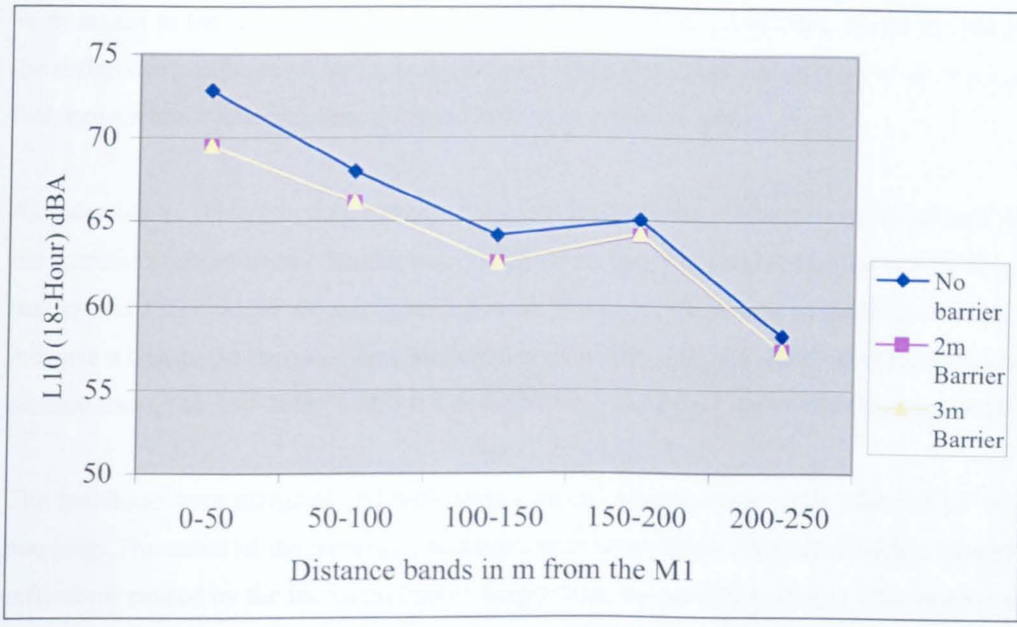

Figure 6.11(b) LA_{10} : The averaged noise levels at each receiver within each distance band.

Table 6.4 Summary of modelled results with each barrier scenario.

Distance (m)	*No barrier*		*2m Barrier*		*3m Barrier*	
	Leq	*L10*	*Leq*	*L10*	*Leq*	*L10*
0-50	*72.1*	*72.8*	*70.7*	*69.5*	*70.5*	*69.5*
50-100	*69.6*	*68.0*	*67.3*	*66.1*	*67.9*	*66.1*
100-150	*67.0*	*64.2*	*65.5*	*62.6*	*65.3*	*62.6*
150-200	*66.4*	*65.0*	*65.9*	*64.1*	*66.1*	*64.2*
200-250	*64.7*	*58.2*	*63.1*	*57.3*	*62.4*	*57.3*

The influence of the barrier can be seen when the results are presented as both an L_{A10} and a L_{Aeq}. The general reduction in noise over distance can also be seen. The values are tabulated in Table 6.4, and illustrate that on average the properties in the 0-50m bands achieved a 3.3dB(L_{A10}) and 1.4dB(L_{Aeq}) noise reduction from the 2m barriers. With no potential extra improvement through the addition of a metre to the barrier for the L_{A10} measures, but a potential extra 0.2dB L_{Aeq} reduction with a 3m barrier when measured as an average over time.

It is difficult to extract any further conclusion with regard to the impact of distance reduction, as the properties that were in the different bands were located in different places and therefore the receivers were under influences, other than that of distance from the source alone.

With regard to the fluctuations in noise levels resultant from the barriers, it can be seen that the difference can be most strongly determined when the results are measured as an L_{A10} as this measurement reflects a less averaged level with regard to time.

As indicated in Table 6.4, on the whole the noise levels at the receivers largely reduced with the increasing noise barrier height, with the greatest increase happening between having no barrier and a 2m barrier as would be expected. However, there was an anomaly of a noise increase when the 3m barriers were modelled at 50-100m, with a 0.6dBA increase in the L_{Aeq} measurement, and 150-200m with a 0.1 & 0.2dBA L_{A10} and L_{Aeq} measurement, respectively.

The increases were marginal and well within the calculation error levels allowed for noise mapping. The cause of the increases, however, were most likely resultant of either increased reflections caused by the increased barrier height from the passing vehicles. This was similar to the way in which a reflective barrier behaved in the New Zealand case study, where a noise barrier had to be removed due to actual rises in noise level at certain receivers. This was due to greater reflections from the barrier itself (Orsman B 2003). Alternatively, the error was caused as a result of potential inconsistencies in the interpolated grid, which according to Huang (2003) can lead to noise level variations of between 1-2dB(A). The increases calculated in the models here, however, were on average so marginal that they were not considered significant.

6.3.3 Predicted number of people annoyed

The results clearly show that the benefit of a 2m barrier against having no barrier was much larger than the difference between a 2m and a 3m barrier. The number of properties where noise reductions due to the noise barriers would still not be below the 55dB(A) and 68dB(A) levels stated in the WHO Guidelines (1999) and the Noise Insulation Regulations (1988) respectively are presented in Table 6.5 relative to the impacts of each barrier height.

Table 6.5 Numbers of properties in excess of the limits stated in the noise insulation regulations and WHO guidelines respectively

	Number of properties in excess of 68dBA (L10)	*Number of properties in excess of 55dBA (LAeq)*
No Barrier	*69*	*103*
2m Barrier	*80*	*101*
3m Barrier	*82*	*101*

Table 6.5 illustrates that, despite the noise barriers introduction, the noise levels remained higher than would be recommended in both the Noise Insulation Regulations and the WHO

Guidelines at many of the receptors. The interview, reported in Chapter 4, with the Highways Agency, illustrated that high unrealistic expectations can undermine the actual value of a noise barrier (Joynt 2002), as despite the introduction of noise barriers, the actual noise levels reaching receptors can remain very high.

6.3.4 The comparison of the subjective perception of noise reduction and the objective modelled levels

To determine the actual number of residents, who would be potentially annoyed by the noise reaching their homes. The number of receptors where the noise exceeded 55dB L_{Aeq} was multiplied by the figure for average household occupancy, of 2.32 persons, to give a total of 239 people with no barrier, and 234 with the 2m and 3m barriers in place. Therefore, it can be seen that despite the attempt to reduce noise levels, the actual number of people receiving noise levels that could result in their annoyance remained high.

Another problem with the small reductions in noise levels attributable to the barrier's introduction, links back to the importance of good public participation. In that, these noise reductions, although quite small, are rarely enough to produce a large positive response from the receptors without other means of endearing them to the project. As noted in Chapter 4-5, the perception of the public, prior to a barriers development, is often one of great anticipation that their property will suddenly be very peaceful (Joynt 2002).

Key to the noise mapping of the areas under investigation, was the aim to identify any differences between, the actual noise level changes resultant from the barrier, (the objective results); with the perceptions of the noise level changes reported in the questionnaire results (the subjective results). It would be assumed that the subjective perceptions would follow the objective realities, with the respondents that actually gained the benefits of noise reduction post construction, reporting this as a perceived decrease in noise. In Chapter 5, however, it was revealed that only 13% of the respondents had noted a decrease in noise post construction, 76% noted no change and 10% actually noted an increase in noise levels.

The objective results, however, showed that in reality the L_{A10} value had decreased post construction at 97% of properties, and not changed at 2% of properties. However, as a change in noise level less than 3dB is only perceivable to the human ear under laboratory conditions (Smith, et al. 1996), any increase or decrease of less than 3dB were excluded in the comparison of the subjective and objective results, leaving 26 of the properties available for a valid comparison.

To investigate this, the objective modelled results for the properties were compared to the results of the subjective questionnaire. It was found that of the properties that had been subject to noise decreases of 3dB and above, 19 % had noted a decrease in noise, 69% had perceived no change in the noise level and 12% had actually noted an increase in noise. The results of this comparison is illustrated in Figure 6.12, and when assessed, relative to the fact that an increase/ decrease in noise level of 3dB is just noticeable, where as, a change of 6dB is clearly noticeable and a change of 10dB is perceived as a doubling or halving of noise. Many of these respondents should have perceived much greater noise reductions, especially in the property, which benefited from a decrease in noise of over 7dB. These had in fact perceived an increase in noise.

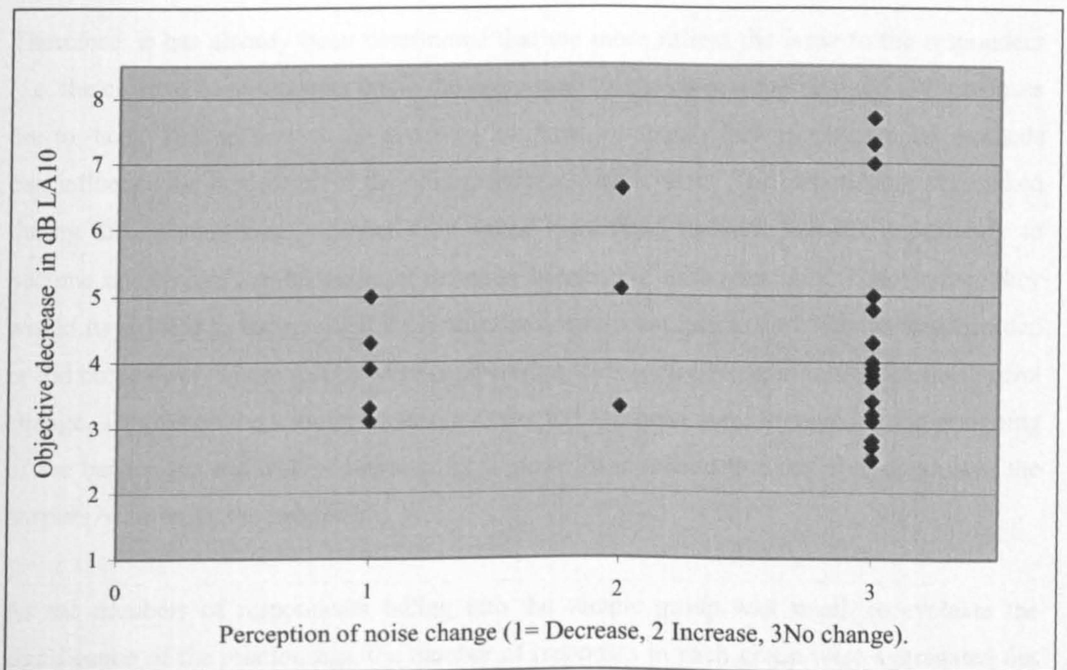

Figure 6.12 A comparison of the modelled values of the decrease in noise levels and the subjective perception

A Pearson's correlation statistical test determined the extent of any correlation between the perception of the noise barrier's effectiveness and the actual noise reduction, between having no barrier and a 2m barrier as modelled in the noise map. The result of the test illustrated no correlation; r= .05, n=108; p>0.1. Resulting in the acceptance of the null hypothesis that the subjective perception of the noise levels post construction, were unrelated to the objective facts of how the noise level had changed. This corresponded to the conclusion that there was an alternative cause influencing the residents' opinions on the noise barrier's effectiveness other than actual objective reasons.

6.3.5 The impact of the lack of public participation on the perception of the noise barriers effectiveness

One of the main purposes of this investigation was to determine the impact of PP on the perception of noise reduction by noise barriers. It was felt, in the light of the fact, that the barrier had reduced the noise at many of the properties there should have been a more positive impression of its benefits. In Chapter 5, it emerged that a large proportion of the population had perceived either; no change in noise levels post construction of the barrier, or in some cases, an increase. In addition, it was found that a relationship existed between, the distance from the motorway that the respondents were located, and the desire to be more involved with the barrier project.

Therefore, it has already been determined that the more salient the issue to the respondent (i.e. the closer the respondents are to the noise source), the more important good PP practises are to them. This section of the investigation aims to identify how much poor PP methods can influence the perception of the noise barrier's effectiveness. The respondents were asked during the questionnaire, whether they would have liked to have, had the opportunity to become involved in the designing of the noise barrier. Of these responses, 71% claimed they would have liked to be involved, 10% said they would not like to and 19% were undecided or did not answer. These results were compared to their subjective opinions of the noise level change. This tested the hypothesis that, a desire to have been more involved in the designing of the barrier and the lack of opportunity to do so, was related to a negative opinion of the barriers benefits by the residents.

As the numbers of respondents falling into the sample group was small, to evaluate the significance of the relationship, the number of responses in each group were aggregated out to indicate the data representative of the wider community, which they represented. The results are illustrated in Table 6.6, and show the number of respondents that fell into each category. This method of extrapolation to the wider population, was also adopted by Birch et al (2002), during an assessment of the uptake of public participation measures by local government.

Table 6.6 The responses of the respondents to the question of their desire to be involved in the design stage compared to the perception of the barrier

Number of respondents in each category	*Would have liked involvement in the design of the barrier*	*Would not have liked involvement in the design of the barrier*	*Unsure*
Perceived decrease in noise level	*2*	*2*	*1*
Perceived increase in noise level	*3*	*0*	*3*
Perceived no change in noise level	*12*	*2*	*3*

Pearson's value r = 0.41; n=0 252; p<0.01.

The hypothesis was tested using the Pearson's product moment statistical test, and the results showed a strong significant trend between the perceptions of the barrier's effectiveness and the respondents desire to have been more involved in the design and development process.

This result strongly suggests the conclusion, that being ostracised from the planning process creates a feeling of negativity towards the noise barrier development, and undervalues its benefits. These findings also concur with those of, Hall (1980); Cohn (1981 a); Pendakur and Pyplacz (1984); Kotzen and English (1999); Wu (1999). Therefore, it can be concluded that in light of the findings, had the public been allowed greater access to the design process the actual objective benefits produced by the barrier, as illustrated with the results of the models, may also have been perceived by the residents the barrier was designed to protect. Again the importance of gaining the subjective approval by receivers is emphasised, and the utility of noise mapping is highlighted.

6.4 Discussions and conclusions

6.4.1 A summary of the findings

The results of the comparison of the objective values calculated using the mapping software, and the subjective attitudes and opinions derived from the quantitative investigation, illustrate the problem of ineffective noise barrier development. The barrier constructed obviously did not benefit all the respondents in every area to the same degree, just as the PP process was not relevant to all the respondents in the catchment.

Despite the discussed variability in calculated noise levels resultant of unavoidable calculation errors, noise maps still offer a useful resource for indicating trends and overall noise bands on a large scale. Noise maps do still offer an effective and simple means of identifying broad areas containing those where noise is most likely to cause an adverse effect, and consequently, those that the barriers are likely to benefit more. The importance of this connection is shown with the fact that, despite the efforts and the variance in noise levels attained, that largely, there was a negative perception of the barriers effectiveness. Chapter 5 illustrated the importance of effective PP by recording individual opinions on the barriers' effectiveness, as well as recording the importance to which the respondents held their right to an opinion.

6.4.2 Discussion of the use of noise mapping as a tool to aid the public participation process

It is accepted that in today's climate, deadlines and budgets often dictate the course of planning applications, and the time frame and resources to embark on noise barrier projects such as this. However, in light of the findings of this investigation, the importance of addressing these issues cannot be underestimated. This is why noise mapping provides an exciting opportunity to direct and channel limited resources allocated for PP to their best possible effect. This can be achieved through identifying individual sectors as key to the participation role.

These key individual sectors are not necessarily of the same ethnic background, educational level or even physical status. However, with the use of noise maps the area to which the resources are spread can be vastly reduced. Thus, enabling the release of resources to target the individual sub group members using alternative and more publicly acceptable participation procedures, such as questionnaires in the home, sub-group meetings etc.

To take the possibility of this method further, the noise maps could be used even before the PP process is decided. The smaller area highlighted, could then be targeted through local subgroups and simple mailed questionnaires, to allow the residents to decide the best cause of participation, prior to their involvement in the actual design stage. This may seem an extreme method. However, the results of this investigation and those highlighted in the literature review, illustrate that the severe consequences of neglecting to follow a well-defined PP process are clear, and therefore, make this method justified in both its endeavours and extents.

The study examined in this thesis, illustrates an example of using noise mapping for aiding PP – in terms of data collection, and focusing of the target population, which can be adapted for future projects where a noise barrier has been proposed as a noise mitigation option.

6.4.3 An overview of the trends towards public participation

With the ratification by the UK Government of the Arthus convention in February 2005, the importance of PP has been further emphasised (European Parliament and of the Council 2003). It is now an obligation for all developers to incorporate effective PP into any environmental planning process. Therefore, the use of methods to improve the PP methods is of even greater importance than ever.

Through the use of the noise maps, the residents that were most likely to feel the effects of the noise pollution pre-construction, and most likely to feel the greatest benefits post construction were identified. The findings also showed that it is the groups of residents where noise is a more salient issue, who would prefer to be integrated into the planning process. The means of integrating these residents were investigated in chapter 5, with their preferences varying between subgroups.

It is proposed, through identifying firstly a more specific area for PP that the overall costs of undertaking a PP process would be reduced. Consequently enabling the savings produced to be used for a more focused method. The noise maps themselves do not identify the specific subgroups, but do identify areas, which in turn can be studied to affirm the main subgroups within them, using census data. The methods of PP can then be tailored to suit the areas. For example, if the specific areas contain mainly families of minority ethnic groups, who, according to the findings of Chapter 5, had a preference firstly for better advertised meetings and then for small minority meetings, then a meeting could be advertised and scheduled in a place likely to capture the largest number of effected residents such as a mosque etc.

One of the most popular alternatives for PP found in Chapter 5, that was stated as the most likely to attract the largest proportions to become involved, was a questionnaire in the home. Again this would present an economically unfeasible proposition, without narrowing the area down. However, if noise maps were used to pinpoint the areas where the existence of noise and the provision of a noise barrier is likely to see the greatest benefits, then a small scale questionnaire could effectively capture all of the residents, some of whom may be ostracised using more traditional methods of PP through work and family commitments, or through other restrictions, such as mobility or language.

The methods of alternative PP presented to the respondents in Chapter 5 were by no means exhaustive. But illustrated a brief overview of means, by which the Highways Agency could include residents in participation, as an alternative to their preferred method of information dissemination through public meetings. Further examination of public participation options is discussed in DETR (1994), Sanoff (2001) and Kumar (2002). A recent report by, Demelza Birch (ODPM 2002) indicated the difference between the approach of the Highways Agency, and that of Local Authorities (LA) who clearly recognise the benefits of engaging the public, particularly in terms of improving service delivery and decision-making. A majority of authorities (70%) indicating that participation initiatives are 'often' or 'fairly' influential on final decision-making.

The Local Authorities do, however, share the concerns of the Highways Agency about the time and resources required, and about motivating all sections of the community to become involved. With 56% of LA's reporting concern that participation exercises may simply capture the views of dominant, but unrepresentative, groups. This is compounded by the fact that 44% of authorities report having experienced difficulties in engaging people from certain social groups – particularly, those from ethnic minorities and young people. However, it would appear that LA's are seeking to address this issue by aiming certain participation exercises (e.g. forum-based initiatives, user management of services and co-option to committees) at specific citizen groups or neighbourhoods (Demelza Birch. ODPM 2002).

These methods could also be adopted by the Highways Agency, with the added potential of using noise maps as a means of identifying the key sectors of the affected community. This move towards integration reflects the influence of the Local Agenda 21 requirements. Illustrating also, that effective PP in noise barrier development is key to the sustainability of the project. Chapters 4-6, therefore, illustrate how projects can be developed at a public level to ensure that the non-acoustic factors are held with as much importance as the acoustic. The following chapter introduces the next phase of the non-acoustic parameters that should be incorporated into the design of a sustainable environmental noise barrier. That of the materials themselves, as key to sustainable development is the need to develop without compromising the opportunities for the wider community and future generations to provide for themselves, through resource depletion and pollution.

Chapter 7 Lifecycle Assessment and Noise Barrier Sustainability

The thesis aim was to define and reveal the importance of a sustainable approach to environmental noise barrier design. Chapters 4-6 developed a sustainable approach by defining the means for reducing the incidence of rejection of noise barriers', in addition to the recognition of the influence of emerging legislation and official guidance on the involvement of the public as a sustainability measure. The impact of neglecting these measures was illustrated both in the literature as well as in the findings of the case study investigation. However, sustainable development has many more facets, not least that of the environmental impacts of the actual materials used during the design, development and implementation of a noise barrier.

Barriers in the UK are predominantly chosen on economic grounds, however, by integrating a full lifecycle assessment (LCA) into a project's design, additional significant economic costs can be contributed after a barriers construction, and more importantly environmental costs that are inherent in the production of the materials. With increasing legislation on both low impact material use in products, and end of life disposal, these issues will become even more salient. Additionally, as noise barriers are designed specifically as a measure to reduce pollutants, then it is correct that they lead the way in environmental design.

Therefore this chapter aims to extend this holistic approach, with the introduction of a LCA of the materials used in noise barriers. This approach acknowledges the growing realisation that society can no longer develop and use resources, without consideration for the wider and future social, environmental and economic impacts they entail. Whilst further embracing the fact, that society is largely demanding a more environmental approach, when undertaking community development projects.

7.1 Developing a methodology for the lifecycle assessment of a noise barrier

7.1.1 An introduction to the LCA of standard noise barriers

A lifecycle assessment on the whole, describes the positive and negative impacts of a material, from its conception to its final disposal. The term cycle refers to the fact that all materials ultimately originate and are finally disposed of, in a common place, and as a consequence the acknowledgement of this cyclical and limited resource base is fundamental to the understanding of sustainable development.

Currently there is no specific software or methodology to determine the lifecycle impacts of noise barriers; there are conversely, several methods and software available to evaluate full buildings and individual materials. However, as discussed in the literature, these models are not appropriate to be adopted in the case of noise barrier development. Therefore, below a new methodology is developed to bridge this gap, and illustrate a means by which to make such an assessment possible.

The Highways Agency does aspire to sustainable development and states a commitment to utilising the least environmentally damaging resources, through its adherence to the Government's guidance for 'A Better Quality of Life: a Strategy for Sustainable Development for the UK' (DETR 1999), and the development of its own strategy 'Building Better Roads: Towards Sustainable Construction' (Highways Agency 2003). The Highways Agency does state that they consider 'whole life costs' in the provision of noise barriers (Highways Agency 2003). However, this is not undertaken using a specific methodology designed for noise barriers and without a specific methodology for lifecycle assessment in the context of noise barriers its endeavours can never be fully rewarded.

Therefore, the following sections lay out the methodology for calculating the LCA of a selection of noise barriers; this includes the development of a framework model, and the collation of data, with the intention that the basis of the framework model may be used again in future 'real-world' scenarios.

As noted in the literature, the calculation of a full LCA of materials from 'cradle-to-grave' is a vast area of research, and as the research undertaken within this thesis crosses many disciplines, the consideration of LCA is suitably defined to avoid over complication. Therefore, the objective of this research is to assess the impacts of nine different standard barrier material types under various LCA scenarios. This research is not a consultancy exercise with the aim of giving a definitive answer of the best material to opt for when choosing a noise barrier, as this would be an unreasonable assessment without a specific case study scenario and would lead to misleading results. However, this research illustrates the importance of acknowledging the inclusion of lifecycle analysis in the construction and successful design of noise barriers and sets out the means of achieving this.

The first stage of the LCA is the 'cradle-to-gate' analysis, where by an assessment is made of the impacts of a material in terms of its pollution, greenhouse gas emissions, finite resource use and water use from the material's extraction to the point of sale at the factory gate. This stage can be determined without a specific case study, as the materials used at this point, regardless of the future destination, will have the same embodied impacts, and consequently can be summarised as a generic output. The second stage of the LCA is far more site and scenario specific, therefore it is much harder to make generic assumptions about the impacts of various materials. However, a methodology for assessing this phase, complete with generic data that can be applied to specific scenarios, is presented for the 'gate- to-grave' section. Thus, as explained above the results of the assessment was not aimed to give a generic answer of which materials are more environmentally friendly than others, but illustrates a means by which this could be undertaken.

7.1.2 The hypothetical noise barrier

For the 'cradle-to-gate' assessment, a hypothetical noise barrier was devised, the dimensions chosen, represented simple assumptions based on standard measurements, representative of a UK case study i.e. 1 km long, and a minimum of 3m from the outside edge of the main carriageway[1] (Highways Agency 2000-2003). The materials chosen for the assessment in this investigation were selected due to their proliferation on the UK and world markets; consequently the results have applicability beyond this assessment. To ensure that the most widely available noise barrier types were compared, brochures and websites of both UK and worldwide noise barrier manufacturers were consulted, this gave a representative sample of the choices available to noise barrier providers including the Highways Agency (HA) in the UK. However, the list of materials chosen was by no means exhaustive.

The materials selected for the LCA were, aluminium, steel, pre-cast concrete, Polymethyl methacrylate (PMMA), timber and willow. Within these choices, were several variations of the materials, including recycled and non-recycled aluminium and steel, in addition to living and woven willow (web links can be seen in *Appendix 3A).*

In order to compare the materials of the hypothetical barrier objectively, in terms of embodied CO_2 and pollutant emissions, the materials had to be assessed under the same conditions of distance travelled from 'cradle-to-gate'. In a real world scenario, materials would obviously be sourced from different places, for example, timber from Scandinavia and aluminium from Scotland. However, if the embodied environmental costs of transportation were compared, it would be difficult to make an objective comparison. Consequently, for the purpose of this investigation, the materials environmental emissions were assessed equal to that, which would be produced over a 1km distance.

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[1] Some materials require further treatment to guard against salt spray when positioned less than 3m from the edge of the carriageway; this would have the potential to alter the embodied environmental impacts.

Noise barriers, like most structures are not created of one material type alone, most barriers will have a combination of materials for, structural support, and aesthetic and construction purposes. However, as the assessment of all the various combinations of different material types would pose a considerable strain on this investigation, and in light of there being no standard for these combinations, it was assumed that each noise barrier was made up wholly of one material i.e. for a timber barrier, only the lifecycle of the timber itself was assessed excluding any other materials, such as metal bolts or cement foundations.

An exception for this rule was accepted for the willow, aluminium and steel barriers, due to the essential mineral wool core, which acts as the damping/ absorptive element within the barriers. As a consequence, the full LCA for mineral wool is included for each of these barrier types, by adding the calculated impacts of the mineral wool to the impacts of the outer coating be it aluminium, steel or willow.

In accordance with the BRE 'Environmental Profiles', data for the LCA of a construction, 98% of all inputs by mass should be included, and data should also be included on all materials with a mass greater than 2% of the output (Howard, et al. 1999). For the purpose of this study, however, which compares merely the various bulk materials, rather than individual products, as would be the case in a real world scenario, this level of data was not calculated

Environmental barrier structures are standardised by several pieces of legislation and guidelines, the main piece being the Highways Agency, HA 66/95 (Highways Agency 1995). This document lays out a structured method of practise to be adhered to by all barrier manufacturers. The barrier materials specified within this document are controlled by the MCHW: Specification for Highways Works Document Volume 1, Section 2504 (Highways Agency 1998), which in turn refer to various British and International standards for material quality. The individual pieces of legislation regarding each material type are listed in *Appendix 3B.* In addition, all the material specific standards, for the use in noise barriers must conform to BS EN 1793[1] and 1794[2]. Therefore, it can be accepted that the acoustic properties of all barriers is guaranteed, if they comply with the above guidance. However, variables remain in the choice of barrier materials, due to their individual environmental implications.

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1 Road Traffic Noise Reducing Devices: - Test method for determining the acoustic performance: BS EN 1793-1/ 2:1998.
2 Road Traffic Noise Reducing Devices: - Non acoustic performance: BS EN 1794-1/ 2:2003.

7.1.3 The physical characteristics and configurations of the barriers

To be efficient a barrier should largely prevent the direct transmission of acoustic energy. In practical situations, this is achieved if the sound energy that leaks through the barrier is more than 10dB below the energy that is diffracted over the top of the barrier and around its edges. If the attenuation, in dB(A) afforded by the barrier (A), based on the path of difference is known, then the minimum mass per m^2 (M) of a barrier can be estimated. Assuming, a single homogenous material, the mass needed to effect the required attenuation can be determined using the formula represented in Equation 7.1 (Department of Transport 1976; Cited in Kotzen & English 1999: 38).

$$M = 3 \times 10\left(\frac{A-10}{14}\right) \text{kg/m}^2 \qquad (7.1)$$

It was necessary to determine the minimum mass required for the LCA, as this equated to the amount of materials that would be ordinarily used for the standard development of a noise barrier. However, for most practical cases, the structural strength of the material used for the barrier, rather than its acoustic property, is more likely to determine the mass required. As each of the materials have a minimum width to provide acoustical attenuation and structural viability.

After considering the current literature available from the noise barrier manufacturers, it was determined that the actual barrier widths, as manufactured by individual companies, vary with design and case specification. However, to undertake a generic lifecycle assessment a standard width and mass had to be determined to make comparisons between the materials.

Consequently, the data for the minimum width associated with an acoustic attenuation of 20dB or above was reviewed, in conjunction with the average material widths provided by various barrier companies, and information from the Federal Highways Agency (FHWA 2003). An average of these standard material widths was used for the assessment of each barrier type. Data for the noise reduction of various materials by mass can be seen in Table 7.1. A decision was made to choose the absolute minimum width for each material, as this reflected a lowest cost option, the most likely criteria for noise barrier choice currently (Joynt 2002).

Table 7.1 Material acoustic attenuation, minimum width and density.

Material	Thickness (mm)	Surface Density kg/m^2	Transmission Loss (TL) dB
Polycarbonate or Polymethyl Methacrylate or acrylic	13	15	22
Dense Concrete	100	244	40
Steel, 18 gauge	1.27	9.8	25
Steel, 20 gauge	0.95	7.3	22
Steel, 22 gauge	0.79	6.1	20
Aluminium Sheet	1.59	4.4	23
Aluminium Sheet	3.18	8.8	25
Aluminium Sheet	6.35	17.1	27
Wood	25	18	21
Plywood	25	16.1	23

(Adapted from:(Environmental Protection Department 2001) (For full listings of material attenuating properties see Appendix 3E)

This data, in addition to data provided from UK barrier manufacturers and the FHWA, was then used to establish the volume of material needed for the hypothetical scenario of a 1km long noise barrier, standing at 2m high. The mass and volume data were calculated by multiplying the surface density in kg/m^2, for each material, by the volume in m^3, for the whole hypothetical barrier, to give the total mass in kg/m^3. The results of which can be seen in Table 7.2. Full calculations are available in *Appendix 3C*. This total mass then served as the figure for which all the other LCA criteria were judged against. The density values were taken from standard material density tables.

The embodied carbon dioxide, energy and associated pollutants, relating to each materials general lifecycle, as a noise barrier, were then established through the collection of industry data. This was undertaken in sections due to the restriction of not having a real world scenario, as mentioned in Section 7.1.1. The first section being the 'cradle-to-gate' analysis then followed by an analysis of the maintenance requirements, transportation impacts and end of life demolition and disposal, which illustrates the 'gate-to-grave' analysis; methodology for which can be seen in Sections 7.1.6, 7.1.7 & 7.1.8.

Table. 7.2. Total mass of each material type needed to provide the hypothetical barrier.

Material	Steel 20 gauge	Aluminium 20 gauge	Timber	Concrete pre cast	PMMA	Willow (living)	Willow (woven)	Mineral wool Core for willow	Mineral wool Core for Steel & Aluminium
Length (m)	1000	1000	1000	1000	1000	1000	1000	1000	1000
Height (m)	2	2	2	2	2	2	2	2	2
Width (mm)	1.425[1/2]	3.925[2/3]	19[4/5]	125[6]	20[7]	30[8]	30[8]	240[9]	75 (10)
Volume of material (m3)	2.85	7.85	38	250	40	60	60	480	150
Weight (kg/ m2)	11.19	10.12	6.77	300	30	4.5	4.5	78.57	24.8
Density (kg/m2)	7850	2579	400	2400	150	150	150	330	330
Total Mass for whole barrier (kg)	22380	20240	15200	600000	60000	9000	9000	157140	49600
Total mass for whole barrier (t)	22.38	20.24	15.2	600	60	9	9	157.1	49.6

7.1.4 The methodology for the 'cradle-to-gate' stage of the LCA

As noted above (Section 7.1.1), no one particular commercially available LCA model was appropriate for the context of this study. Therefore, a study specific method of assessing and comparing the noise barrier materials was developed. This included many of the parameters common to all the commercially available models, but was more noise barrier specific, due to the exclusion of certain standard criteria.

The criteria excluded was that for thermal insulation, on the basis that noise barriers do not use the function of thermal insulation, and therefore can gain no net benefit, of being composed of a material with high embodied energy values, that cannot be recuperated through insulation

[1] Materials Acoustics Attenuation Width, Density: Environmental Protection Department 2001.
[2] Department of Transport 1974: (Equation)
[3] Environmental Silencing Ltd, UK. (01455) 617067
[4] Buffalo Fencing: (http://www.buffalostructures.com/)
[5] Charles Ransfords & Sons: (http://www.ransfords.co.uk)
[6] Federal Highways Agency: (http://fhwa.dot.gov/environmnet/noise/5htm).
[7] Plexiglas Soundstop: (Degussa Röehm Plexiglas, Germany: CD-Rom)
[8] ETS, Environmental Noise Barriers: (http://etsluk.com/index.htm)
[9] Integrated Pollution Prevention and Control (IPPC). Reference document on BAT in the Glass Industry: (European Commission, Brussels 2001).

benefits later on in the lifecycle. With the possible exception of photovoltaic noise barriers, which would harness the suns energy back into the electrical grid.

A second criterion that was altered for the specific properties of noise barriers was the minimum maintenance period. A standard building is accepted as having a minimum maintenance period of 60 years, however, the upper end of the minimum period for maintenance of noise barriers' is much lower, with the best performing materials, lasting only 40 years, and others lasting only between 20-25 years, before requiring replacement (Kotzen and English 1999).

Therefore, the parameters considered from extraction, production, distribution, use and disposal, were as follows, and the units they are presented in, are in accordance with the BRE recommendations for standard units (Anderson, et al. 2002):

- Extracted minerals (t)
- Waste to landfill (kg)
- Total Primary Energy [1](mainly fossil fuel energy) (MJ/ kg)[2]
- Carbon Dioxide to air (g)
- Sulphur Dioxide to air (g)
- Oxides of Nitrogen (g)
- Heavy metals to air (g)
- Heavy metals to water (mg)
- Particulates (g)
- Water used (l)
- Financial costs (£)
- Maintenance frequency and costs
- Transportation at all stages and its associated pollutants (Distance and Method)
- Inclusion of recycled materials in production
- End of life recycling potential
- Final disposal

A lifecycle assessment model was developed, that gave consideration to each input and output, throughout a material's, extraction, use and final disposal. This enabled the quantification of these factors, giving an overall comparable assessment score. The numerical value was given as

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[1] Definition of Total Primary Energy (within the context of this study): 'The combined total of feedstock energy, fuel energy (from both renewable and non renewable sources), for all processes from extraction to delivery at the factory gates'.
[2] The unit MJ/kg is the same as GJ/tonne therefore the two units are interchangeable without the need for multiplication. However for the purpose of this study the units are in MJ/kg for convenience except where otherwise stated.

a ranking for each parameter, from best to worst performance, under that category. For example, the material with the lowest embodied energy value was awarded one point under that criteria, and then each material in ascending order was given the next number.

The values, which were compared for each criteria of LCA, enabled through the manipulation of this data, (from each of the existing data sets, into weights representative of a noise barrier), the embodied lifecycle impacts for each material in the hypothetical scenario to be calculated. As the data came from several sources, it was generally displayed with varying measurement units, therefore, for the purpose of comparison; each set of data was converted to the format above, in accordance with the British Research Establishments (BRE) guidance for standard units (Howard, et al. 1999).

The materials were then compared, using firstly, a simple direct comparison and ranking of best to worst, followed by a weighting, as devised by the BRE; details of which are provided below. The material that proved to be the most environmentally benign, out of all the materials, under each of the circumstances, was deemed the most sustainable. In addition, the actual financial costs, for purchase and installation for each material are presented, in order that they can be considered inline with other influencing factors in the process of choosing a noise barrier, as cost is usually the greatest influencing issue on material choice.

The BRE weighting system for various impacts created during the lifecycle of a product was utilised, this set of consensus weightings were devised to consider the relative environmental, social and economic elements, following extensive research of many interested groups and finding a consensus on the perceived severity of impacts of various environmental and social actions (Brownhill and Rao 2002).

The weighting system was appropriate for use within this investigation, as its basis was resultant of a consensus of opinion, on the severity of individual environmental problems, many of which would be contributed to throughout the lifecycle of a noise barrier. The weighting system was applied to the results here, by multiplying the rank values by the weights below; this gave an overall weighted value for the impacts of the development for each of the barriers.

- Climate change (100 years) 38%
- Low-level ozone creation 4%
- Ecotoxicity 4%
- Acid deposition 5%
- Human toxicity to air 7%
- Fossil fuel depletion 12%

- Water extraction 5.5%
- Human toxicity to water 3%
- Eutrophication 4%
- Minerals extraction 3.5%
- Waste disposal 6%
- Ozone depletion 8%

7.1.5 Collection and manipulation of 'cradle-to-gate' data for each material

The data for this investigation was collated from a variety of relevant sources as noted above, representing, either the official industry research bodies, or other representative bodies and individual manufacturing companies. Where data was not already independently verified, as with that obtained through the BRE and EU, further research was carried out through alternative sources, to verify the values given for, the embodied pollutants, embodied energy, waste and recycling potential and water use.

The main concern, which arose through deriving the data for the investigation from such a wide variety of sources, is that firstly, the data would not be consistent with each material (i.e. 'that like would not be being compared with like'), and secondly, that the measurement units for the data presentation were in different formats. To reduce the error of the first issue, the sources were reviewed extensively to assure that the figures were representative of the material's inputs and outputs, from extraction to factory gate, and the second error was overcome by converting all the data to the common units recommended by the BRE (2000).

Due to the increased awareness of the need for sustainable development, without exception all the industries used in this investigation had LCA data available. All of which followed a standard format for reporting the parameters important to the LCA, in accordance with the International Standard ISO 14040: 1997, (The Lifecycle Assessment framework). There are a few omissions of data, thus, where no values were available; these are indicated with a no data label, as opposed to the n/a label, which indicates that the impact of the pollutant, or parameter was negligible in the LCA. The lack of some data slightly influenced the relative impacts of each material. However, this was accounted for in the overall written up assessment of each material form 'cradle-to-gate'.

7.1.5.1 Steel

The steel data was derived from the World Steel Lifecycle Inventory Methodology Report (Committee on Environmental Affairs 1999/2000), a document compiled by the International Iron and Steel Institute (IISI), to quantify resource use. Energy and environmental emissions associated with the processing of fourteen steel industry products, from the extraction of raw materials in the ground, through to the steel factory gate were reported in accordance with ISO 14040.

Downstream processing into manufactured products, their use, end-of-life and scrap recovery processes were not included in the inventory. Therefore, using this data gave the results in an appropriate form for this investigation i.e. 'cradle-to-gate'. The data used to illustrate the use of steel in noise barriers, was that for the 'Hot Dip Galvanised Sheet', for steel made using recycled materials and without, as this is the type of steel, most commonly found in the production of steel noise barriers.

7.1.5.2 Aluminium

The Aluminium data was derived from the BUWAL 250 Lifecycle Inventory Database[1], which presented the accumulation of data from within the EU, including the UK, on the LCA of aluminium. The data for the aluminium used within this section, is again from 'cradle-to-gate', for both 0% recycled aluminium and 100% recycled aluminium, the presentation of both sets of data was imperative for an assessment of aluminium's worth as a noise barrier material, as not only does it use a large amount of embodied energy in the primary process, but most aluminium used within the UK market is derived from recycled sources.

7.1.5.3 Polymethyl methacrylate

Plexiglas, is the brand name for Polymethyl methacrylate, and is the largest used brand material for non-glass transparent noise barriers in the EU, supplying nearly all of the transparent noise barrier suppliers within the UK (Boustead 1997). The data acquired was presented as Eco-profile[2] data, as opposed to lifecycle data, as the systems examined for the production of the data only follow the production sequence to the point where the product is ready for sale, again this is in line with the preferred 'cradle-to-gate' analysis for this investigation.

7.1.5.4 Pre-cast concrete

The pre-cast concrete data, was derived from the report 'the Progress of the UK Cement and Concrete Industry Towards Sustainability' (Parrott 2002). This provided a breakdown of the associated embodied energy, material and pollutant outputs and inputs, including the important role of the use of recycled aggregates. The data was correct for the year 2001, and gave values

1 Available through 'Ecosite UK'BUWAL 250 (2003). Ecobalance of aluminium: LCA of aluminium balance per KG, Ecosite.co.uk. 2003.

2 The data was derived from the report 14 of the European Plastics Industry on Polymethacrylate Boustead, I. (1997). Eco-profiles of the European Plastics Industry. Brussels, Methacrylate Technical Committee, Methacrylate Sector Group, (CEFIC): 1-47..

for almost all of the parameters used within this study, for the assessment of lifecycle impacts, apart from the values for methane and heavy metals. Therefore, it was ensured that these omissions were accounted for in the overall evaluation of the materials impact.

7.1.5.5 Mineral wool

Data on Mineral wool was derived from the glass industries IPPC report on the Best Available Technique for Production (European Commission 2001). This reported on the inputs, outputs and impacts of the process of manufacturing mineral wool.

Mineral wool is used in a variety of products for its insulating characteristics, and its relative economic benefits, in comparison to other materials. One of its most prolific uses, is as an acoustic insulator, and within the context of this study, is used as the absorbent property in aluminium, steel and willow barriers. The data presented was an industry average from processing plants around the European Community, two of which were located within the UK.

7.1.5.6 Timber

The LCA data for timber was provided from the BRE, in the approved environmental profile format. The data deemed most representative of the timber used for the production of noise barriers, was the 'production of one tonne kiln dried timber at 400 kg/m^3'. From the period January 1996 to December 1996, published in 1999, (the most up-to-date available), for UK produced timber and transport for imported timber- 'cradle-to-gate'(BRE 1999).

7.1.5.7 Willow

The willow barriers come in two varieties 'living' and 'woven', all though these two types have relatively few differences in terms of environmental impacts and pollution outputs, they are considered as two separate barrier types. The use of willow as a noise barrier material in the UK is of a comparatively small nature, however, its place in the market as an environmentally friendly option is growing (Bowles 2003). There is a relatively small production of willow barriers in the UK, and thus a lack of any industry standard data for the lifecycle impacts of the willow.

Notably, no data was available recording the release of any other pollutants than CO_2 and as the material is not processed in any other way other than weaving, the extracted materials can be presumed to be equal, to the amount of willow barrier used. The major environmental effects associated with willow noise barriers, stem from the inner absorbent mineral wool core. Therefore, any negative effects from the production of the mineral wool were countered and subtracted from the beneficial positive effects of the willow. e.g. carbon sequestration.

7.1.6 The method for the 'gate-to- grave' stage of the LCA

The following section was undertaken; to illustrate how to make an assessment of the impacts caused from a noise barrier's development from 'gate-to-grave' this was inclusive of maintenance, lifespan and end of life disposal.

As noted above, noise barrier material life spans are not inline with the typical expected lifespan of a material used within a whole building fabric. The main reason for this is the exposed nature of the situation the materials have to perform under. The usual lifespan of a material within the fabric of a building is 60 years (Anderson, et al. 2002). However, a noise barriers usually have a maximum life span of 40 years, 20 of which without maintenance. In order to include maintenance within this hypothetical noise barrier investigation, data was derived from the following sources: Kotzen and English (1999) and Bowles (2003). Unlike the other parameters in the 'cradle-to-gate' analysis, due to the lack of precise data, the level of maintenance was ranked in terms of the number of years it would be operational for, before maintenance would be required, relative to the actual lifespan of the noise barrier.

In good environmental design the idea of waste is closely associated with recycling, the BRE recommends five stages in the disposal of waste in descending order of desirability, these are reducing, reuse, recycling, energy recovery and disposal. To reduce waste simply means the elimination of unnecessary waste through, for example, tight ordering procedures and good stock control. Reuse refers to taking whole elements and, after cleaning as required, using them in a new setting. Generally reused items are of a high value such as architectural features within the built environment context, potentially however, any item that can be removed without damage can be handled in this way, which is particularly true of noise barriers, which are normally a very simple structure.

Recycling involves using the material in another form, for example, with PMMA through the process of thermal cracking, the material can be converted back to methyl methacrylate (MMA), a process that can be carried out with almost 100% recovery, and concrete and masonry can be sorted, crushed and used as a sub base or as aggregate. An important aspect of the appropriateness of recycling is how far the material must travel to be recycled; if the material has to travel thousands of miles just to be recycled, there is the possibility that more environmental impacts may be caused, than if a new product was assembled from the beginning. This, however, would have to be assessed on a case-by-case basis, and no generic answer can be given. Conversely, it can be presumed that to the most extent it would be more environmentally friendly to recycle, than to create a totally new product, on the grounds of extraction of raw materials alone.

The allocation of materials for recycling and reuse, and the associated impact upon the LCA of the different routes products take are determined below, in accordance with guidelines for environmental profiles as set out by the BRE (Howard, et al. 1999).

- Wastes or recycled products from open loop recycling are allocated burdens based on the residual value of the waste stream compared to the value of the process product (and waste stream).
- The proportion of burdens carried by waste into the future are then subtracted from the burdens assigned to the primary product.
- Hence, all of the materials arising from a process that have a financial value attract a proportion of the burdens associated with the production process.
- Where repeated recycling occurs, for example, for metals, the primary burden carried forward through each recycling, decreases until after an infinite number of recycles it reaches zero (Committee On Environmental Affairs 1999/2000:61).

Another key process within the secondary use of materials, is the recovery of energy which can take place in a number of ways, one of which being through the exploitation of the calorific value of the material for power generation. This would be possible for the timber and willow noise barriers, but concrete, steel, aluminium and PMMA have no such potential. However their embodied energy can be reduced from the outset by the use of recycled materials in their production.

One common factor for timber-based fuels (wood, bark, chips, sawdust, shavings etc) is that the CO_2 released when they are burnt has been absorbed, (sequestered) from the atmosphere, and stored during growth. Had it not been released when the wood was used for energy production, it would have been released during the biological breakdown of the wood, which would have taken place instead. The CO_2 emissions from burnt timber is therefore assumed to be zero, since the use of wood as a fuel does not contribute to the build up of CO_2 in the atmosphere. Timber however, does produce some CO_2 despite this, through the machinery, transportation and infrastructure associated with its extraction and processing.

The final option at the end of a materials useful life is disposal to landfill. This is the least environmentally friendly option, in that the material has no further purpose, except for maybe the extraction of methane gas in respect of some of the organic products such as timber and willow. Therefore, landfill should be a last resort but if it is unavoidable, the transportation to the site of landfill should be minimal to reduce further transportation related pollutants and energy use.

To evaluate the varying impacts of recycling within this study, each materials potential for recycling, and use of recycled materials in its processing were reviewed. In addition, a method developed by the BRE and Oxford Brooks University (Anderson, et al. 2002), was adopted. This method deciphered between all the aspects of recycling, by allocating a letter between A and C, to illustrate each materials relative merit in terms of environmental benefit. The method distinguished between each of the possible ways a material could gain benefit from recycling as follows:

- Recycled Input: the percentage (by mass) of recycled or waste material contained within a product:
- Recyclability: the percentage (by mass) of material capable of being recycled or reused at the end of the products useful life:
- Currently recycled: the percentage (by mass) currently being recycled or reused in the UK:

Anderson et al (2002) recommended in their Green Guide, that within an official environmental profile assessment, as would be undertaken in a real world scenario, that the benefits of recycling should not be presented as an individual section but as follows:

- Recycled content is accounted for through lower raw material use and associated impacts and any differences in the efficiency of the manufacturing process.
- Current recycling is accounted for by the lower overall impact for the primary manufacturing stage, achieved by passing a proportion of the initial processing on to the recycled material.
- However, as noted above the application of the data provided in the BRE's Green Guide, to this noise barrier investigation cannot be directly comparable, due to the usual scenarios for which it is collated; for the recycling of building element components (Anderson, et al. 2002:4).

Therefore, the data presented within the results, is purely for illustrative purposes to enable a comparison of the relative recycling benefits, associated with the noise barrier materials under investigation and consequently there was no specific data, either for individual materials or for noise barriers available from this resource. Subsequently, the data that most closely represented that of a noise barrier was used and therefore came from several different building element categories including: 1) all insulations (including those with HCFCs), 2) landscaping hard surfaces, 3) landscaping and boundary protection and 4) low pitched roofs.

7.1.7 Transportation energy and pollutants

The need for transportation occurs throughout the lifecycle of a structure from the 'cradle-to-gate' phase to the initial construction and consequent demolition and disposal, involved in the 'gate-to-grave' process. The impacts of transportation on the embodied energy, CO_2 and released pollutants are accounted for, and presented in the industry data, used within this study, for all the materials from extraction to the factory gate. As data beyond the factory gate would be subject to their being an actual location for the barrier, in addition to a definite mode and distance travelled, of both the finished product from the factory gate, and at the end of life for disposal, an alternative method for incorporating this important parameter into the LCA had to be devised.

The common unit used to illustrate the amount of energy used is 'tonnes of oil equivalent' (TOE). This is due to the fact, that often many different fuel types are used in the production of energy; therefore, there is a need for a common factor to validate this comparison. One TOE equals 10^7 kilocalories, which in broad terms is about 1.1 tonnes of crude oil, 1.6 tonnes of coal, 1,071 m^3 of natural gas or 11,630 kWh of electrical energy. This quantity can vary from year to year, as this is dependant on the quality of the fuels (Department of Trade and Industry 1997). Therefore, for the purpose of this study the methodology for material transportation, only illustrates the values for road and rail, as these were the most significant in the context of transportation of completed noise barriers.

The first step of assessing this parameter was to establish the difference in impacts caused from the varying options of transportation. Figure 7.1, gives a generic estimate of the transportation impacts, in terms of million tonnes of oil equivalent (TOE), over the passed 3 decades. The trend of the large consumption of energy, associated with road transport is further illustrated in Table 7.3, which presents the split of freight transportation, between modes in the year 2000 for freight movements inside the UK, with the greatest consumption of energy being attributed to transportation via road.

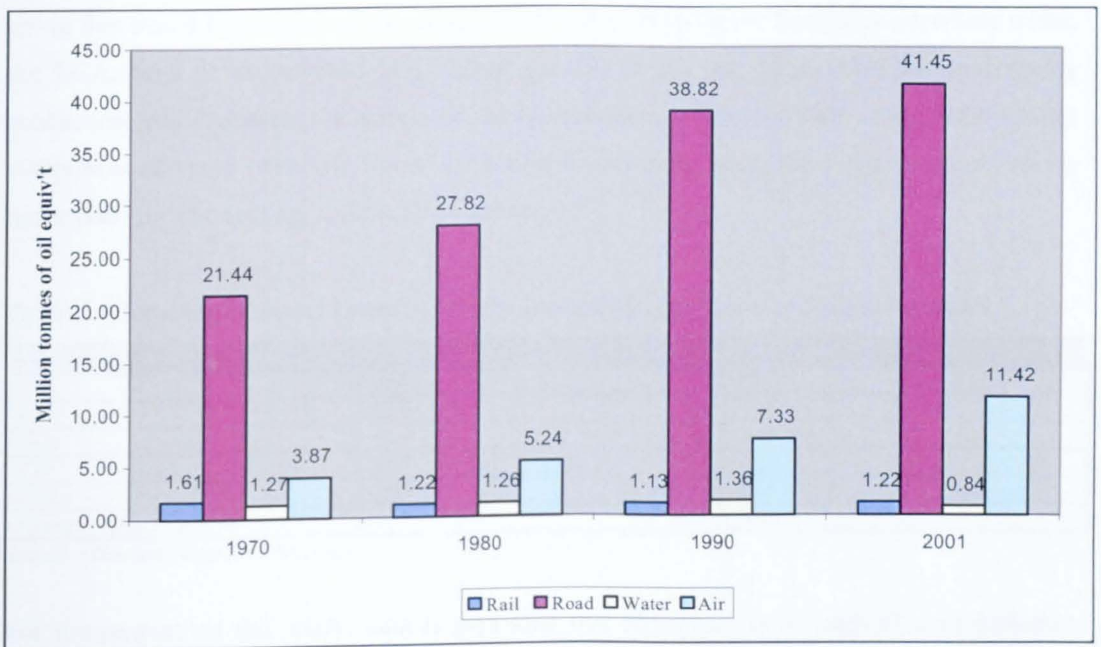

Figure 7.1. Transport energy consumption by type of transport up to 2001

(From: (DTI 2002:14).

Table 7.3. Freight tonne-kilometres by road, rail, air, water and pipeline, 2000, on a 'Goods moved' basis.

	Million freight tonne-				
Year	Road	Rail	Air [1]	Water [2]	Pipeline
2000	158,000	18,000	33	0	11,000

[1]. Cargo and mail for domestic flights only, in the UK.

[2]. Figures compiled on a new basis from 1972 to include all UK coastwise and one-port freight movements by sea, and inland waterway traffic. *(Data adapted from:(DTI 2002:15).*

Included in the transport using the roads in the year 2000, cars made up 44.3 %, light goods vehicles (LGV's) made up 10.1%, heavy goods vehicles (HGV's) made up 15.4% and buses and motorcycles 1.9% (DTI 2002).Therefore, it can be seen that the use of both LGV's and HGV's, make a significant contribution to the overall traffic fleet, and with this, there are obvious implications for carbon dioxide levels, other pollutant emissions and energy consumption.

Table 7.4 illustrates the reference to calculate the environmental impacts of transporting materials in tonnes, by the various different transportation methods available using the most common fuel source for each freight transport mode. Clearly, in the case of a real life scenario, data would have to be acquired at the planning stages, on which would be the preferred type of material for the job. With respect to transportation, the most appropriate material would be that with a factory or processing plant located closest to the construction site. However, as noted above this would be just part of the overall LCA, which could show that gains elsewhere within the LCA, such as sequestered CO_2 during growth, or the use of recycled material during production, could counter the effects of the transportation. Transportation is the main energy component of some materials where extraction is relatively easy, but large volumes require movement, for example aggregates for concrete.

Table 7.4 Total emissions and primary energy use by different modes of freight transport,

Emissions/ g per t per Km	*Rail*	*Road*
CO_2	*41.0*	*207*
CH4	*0.06*	*0.30*
NOx	*0.20*	*3.60*
CO	*0.05*	*2.40*
VOCs	*0.08*	*1.10*
Energy / KJ per t per km	*677*	*2890*

Source: (Thermie Program 1999:114).

For the purpose of this study, data is presented that illustrates, how much of each pollutant noted in Table 7.4, would be released for a trip 1km long, for each of the materials compared. No answer can be given to which has the greatest impact on the environment, in relation to the transportation, as a definitive answer, for mode; distance and recycling potential would be particular to any individual scenario. However, as a general guide the figures could be supplemented with actual distances and modes for any particular scenario.

Due to the potential for variance as a result of the aforementioned influences, for the purpose of this study, good driver practise and full vehicle maintenance to a high standard was presumed (Brocklesby 1997). In addition to all the variants, there is one other major issue, the type of fuel used for transportation, as petrol contains 0.0353 giga joules per litre, diesel contains 0.0388 giga joules per litre and LPG contains 0.0260 giga joules per litre (ETSU 1996). Diesel can be seen to have the most energy, closely followed by petrol, with liquefied petroleum last. The high-energy potentials of petrol and diesel are the main attractions of these as fuels for road transportation, as large distances can be travelled using a relatively small and light fuel reserve.

The final weights of each of the barrier types for the hypothetical barrier, 1km long by 2m wide can be seen in Table 7.5, the final weights encompassed both the main material, and that of the absorbing mineral wool for all of the absorptive barriers. These weights are multiplied by the figures given in Table 7.4 (total emissions and primary energy use by different modes of freight transport), to give the values of pollutants per tonne of each material per kilometre travelled by road or rail.

Table 7.5. Total weights of each barrier type for the hypothetical scenario.

Barrier Type	*Total weight in tonnes for completed barrier.*
Reflective Timber	*15.2*
Absorbent aluminium barrier with Mineral wool inner core	*69.84*
Absorbent steel barrier with Mineral wool inner core	*71.98*
PMMA	*60*
Absorbent willow barrier with Mineral wool inner core	*166.1*
Concrete	*600*

7.1.8 Evaluation and interpretation of the sustainability of each material

The method of collating all the data into a LCA that is easily comparable is taken in several stages, in accordance with the BRE environmental profiles methodology, as follows:

- Defining the goal and scope
- Inventory data collection and analysis
- Impact assessment:
  - Classification
  - Characterisation
  - Normalisation
  - Weighting (Mundy, et al. 2001:2-5)

For the purpose of this study, it was unnecessary to evaluate the data further than the initial impact assessment stage, as the study aim was not to give a ranking, as this is very much dependant upon the individual scenario. The aim instead, was to illustrate the process using a hypothetical scenario. Elements of the following methods were adopted, including the weighting values used, however as explained this could only be achieved up to the 'gate' stage.

Classification refers to all the aspects of a LCA's impact, upon various environmental problems. These are broken down into the following groups for clarification: acid deposition; climate change; fossil fuel depletion and extraction; minerals extraction; ozone depletion; pollution to air; human toxicity; low level ozone creation; pollution to water; ecotoxicity; eutrophication, human toxicity; transport pollution and congestion: freight, waste disposal and water extraction. The BRE provides an extensive data table (Howard, et al. 1999), which allows each of the aspects causing these impacts to be simplified into an impact relevant to a reference point of 1 allocated to one of the predominant pollutants. This is explained further under characterisation, and the reference pollutants are shown in Table 7.7.

Characterisation is the process of defining the contribution of an environmental burden (intervention), to a particular category or impact. For each category, there may be one burden, which makes a contribution, which is considered to have a contribution to that impact, or 'potency', of 1. Other burdens are provided with a potency factor relative to this. Alternatively, the burden can be characterised, by measuring it in a particular unit, such as tonnes of oil equivalent. The data for this comparison was available from the British Research Establishment (Howard, et al. 1999). However, a brief overview illustrating the particular category of impact and the burdens that all the other impacts are related to is displayed in Table 7.6 below.

Normalisation gives a list of figures called the 'impact profile' or the 'ecoprofile', specifying the quantified contribution of the product or functional unit, to the problem occurring nationally or internationally during one year, i.e. product problem level/ national or internal problem level, so all categories have units of time (Mundy, et al. 2001). In accordance with the BRE methodology, the impacts are normalised according to the impacts of the annual activity of 1 UK citizen[1]. The corresponding values are noted in Table 7.6 below and are the standard for normalisation.

Table 7.6 Normalisation factors for each impact category.

Impact Category	*Annual impact from 1 UK citizen*
Acid Deposition	*55.88 kg SO_2 eq*
Climate Change	*12270 kg CO_2 eq (100 year)*
Fossil Fuel Depletion and Extraction	*4.085 toe*
Minerals Extraction	*5.04 t*
Ozone Depletion	*0.29 kg CFC11 eq*
Pollution to air:	
Human Toxicity	*90.7 kg. tox*
Low Level Ozone Creation	*32.23 kg ethane eq (PCOP)*
Pollution to Water:	
Ecotoxicity	*178000 m^3 tox*
Eutrophication	*8.006 kg PO_4 eq*
Human Toxicity	*0.0117 kg. tox*
Transport Pollution and Congestion: Freight	*4140.84 tonne.km*
Waste Disposal	*7.194t*
Water Extraction	*417,600 l*

Weighting is the final procedure in the LCA in accordance with the BRE methodology this entails giving weight to the data. As it is hard to compare one environmental impact with another and give a value judgement over which is more detrimental than the next. Therefore, the BRE devised a system called Ecopoints, which takes the normalised data and compares it to a weighted factor illustrating the severity of the pollutant problem. The factors were devised through extensive research undertaken by the DETR, which involved a consensus-based research programme to weight sustainable construction issues. The study obtained the perspectives of different panels, representing interest groups drawn from across the UK construction industry. These panels assessed economic, social and environmental sustainability issues. For the purpose of this investigation, the weighting factors for each of the impacts are

[1] 'Normalisation' is the process of making different impacts dimensionless, i.e. without any units, so that they can be added together. In this case, the normalisation factor is the impact of one UK citizen for 1 year. Impacts from a manufacturing process are expressed as a proportion of the same type of impact from one UK citizen. Anderson, J. et al. (2002)...

applied to the ranking; this simplifies the process whilst maintaining the important feature of a relative comparison.

Through consultation with the panels, the research establishment quantified the relative importance of different sustainability issues, across the construction industry, finding a significant degree of agreement between the interest groups (Anderson, et al. 2002). This is an invaluable tool, especially in light of the importance of public participation within the planning industry, due to the ease by which non-technical experts are able to make informed decisions on the environmental benefits and impacts of varying materials. However, despite the relevance of using this, there is still an element of chance, in that the data is ultimately evaluated using subjective perceived data.

Through both the review of the literature, and the outlining of this method, a contribution has been made to the aim of developing noise barriers, which are successful in more than just acoustic terms. This review, and the method to illustrate the importance of these considerations within the wider context of design are anticipated to fill the void of knowledge that is currently apparent; the final points of this method are illustrated below.

As an alternative to the methodology of the BRE, and as explained in light of the lack of a particular scenario an alternative means of illustrating the data was devised. This involved the use of a simple ranking system. Following the collection and processing of the data into a common form, the values were ranked for each particular aspect. For example the material that produced the least carbon dioxide from 'cradle-to-gate' was ranked 1 up to the material that produced the most carbon dioxide from 'cradle-to-gate', which was ranked 9. To give an overall indication of how the noise barrier materials performed from 'cradle-to-gate' all the ranked values were added giving a total for each barrier.

As noted above, the pollutants were then allotted an associated overall environmental impact, i.e. potential for global warming, pollutants to air/ water etc. The official weights could then be applied to the ranks, to give an overall assessment of the environmental aspects for each of the noise barrier materials for the hypothetical scenario, and a judgement of the most to least sustainable barrier from 'cradle-to-gate' was reported.

In summation of the methodology, the gleaning of the best methods from each of the commercially available LCA models, and the removal of irrelevant data, has enabled a method to be developed for analysing the LCA of specific noise barriers. This outlined methodology, in collaboration with the collated data presented in this research developed for the analysis, would be relevant for real world scenarios, where decisions over noise barrier materials must be made.

7.2 Results

7.2.1 'Cradle-to-gate' analysis

The method described in Section 7.1.6, was utilised for all the different materials in respect of each of the parameters. Table 7.7 illustrates the various attributes associated with the nine barrier types under investigation, from which the impacts of each parameter could be assessed and simplified into ranks.

To illustrate the impacts of the absorbent barriers, the data for the inner absorbent core was added to that of the outer material, reflecting the overall 'cradle-to-gate' impacts for the whole barrier system. As the constituents of mineral wool vary, with both the properties required of the material and the components added, a value for the amount of extracted minerals for any batch could not be standardised (Environment Agency 2001). Consequently, an estimation of the percentage mineral extraction had to be accepted based on industry data, which is calculated on the fact that the major output mass flow is the product, which might be from 55% to 85% of material input.

For the purpose of this study, an average value between these two figures was taken which equalled 70% of material input, and using the data on how much mineral wool would be necessary for each barrier, the value for the extracted minerals were estimated as 10998 kg for the willow barrier cores and 34720 kg for the metal barriers absorbent core respectively [1] .

7.2.2 Analysis of ranked results for each barrier type

Table 7.7, reveals the values for each of the hypothetical barriers from 'cradle-to-gate', in terms of their environmental impact, and Table 7.8a illustrates these as weighted ranks for each parameter from best (lowest value) to worst (highest ranked value). The weights applied correspond to those developed by the BRE as referenced in Section 7.1.4, as some of the data was unavailable, represented in the table as 0, the comparisons were not fair. To correct for this, where data for any of the parameters was missing, that particular parameters impact for all the barriers was removed, and the results were again totalled. Table 7.8a illustrates the true picture

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[1] Calculation of extracted mineral value for inner core of willow and metal barriers respectively.
Total value of material needed (kg) x 70% = Total estimated extracted minerals (kg).
Willow 157140 kg x 70% = 10998kg
Metal 49600 kg x 70% = 34720 kg

for all the barriers with a full data set, where as Table 7.8b allows for this missing data by removing it, and makes the data comparable.

The objective of this stage of the lifecycle analysis was to illustrate the differences in environmental impacts produced by nine different barrier types. The method chosen of illustrating the environmental impacts in ranks, enables the objective of establishing a simple means of analysing the data, without carrying out a full LCA, which would have require both an actual case study scenario and specialist software.

Table 7.7 Overall results of the 'cradle-to-gate' assessment for the nine barriers

Parameter Totals for hypothetical barriers	*Concrete pre cast*	*PMMA (Plexiglas)*	*Total for 0% aluminium barrier & Mineral wool*	*Total for 100% aluminium barrier & Mineral wool*	*Steel recycled & Mineral wool*	*Steel not recycled & Mineral wool*	*Living willow barrier & Mineral wool*	*Woven willow barrier & Mineral wool*	*Timber*
Extracted Minerals (t)	*548*	*39*	*201*	*84*	*151*	*159*	*269*	*269*	*538*
Waste to Landfill in (kg)	*376800*	*17038*	*4049*	*N/a*	*36*	*33810*	*N/a*	*N/a*	*845*
Primary Energy MJ	*3660000*	*10136900*	*1190320*	*166320*	*755309*	*819775*	*1964250*	*1964250*	*76000*
Carbon Dioxide to Air CO_2 (g)	*68400000*	*524395000*	*692600*	*307195*	*358070*	*61017600*	*-14356930*	*-17686930*	*4256000*
Sulphur Dioxide to Air SO_2 (g)	*16380000*	*2531000*	*1940700*	*550700*	*406798*	*515900*	*942800*	*942800*	*13072*
Oxides of nitrogen in NO_X (g)	*363600*	*2075000*	*618560*	*79560*	*23653*	*129560*	*1289000*	*1289000*	*26220*
Carbon Monoxide CO (g)	*170400*	*372400*	*2082600*	*1733600*	*1724778*	*2498000*	*5463000*	*5463000*	*10032*
Methane CH_4 (g)	*No data*	*2280000*	*807200*	*96200*	*32910*	*38870*	*No data*	*No data*	*6232*
Fluoride HF mg	*No data*	*540000*	*5959360*	*818400*	*818400*	*818400*	*2592810*	*2592810*	*4909*
Chloride HCL mg	*No data*	*10200000*	*21086400*	*6716000*	*8293814*	*8519314*	*18071100*	*18071100*	*1.4*
Heavy metals to air (g)	*286.2*	*1216*	*15640.25*	*15620*	*15620*	*16030*	*49500*	*49500*	*0.03*
Heavy metals to water in (mg)	*No data*	*532000*	*40480.00*	*N/a*	*2954*	*3670000*	*N/a*	*N/a*	*948*
Particulates PM (g)	*31800*	*630000*	*774860*	*42860*	*78450*	*87190*	*56570*	*56570*	*1976*
Water Used (l)	*840000*	*395200*	*268431158*	*268149751*	*268426674*	*268450081*	*848556000*	*848556000*	*440800*

Table 7.8a. Results of the 'cradle-to-gate' analysis using the ranking methodology inclusive of missing data

	Weighting Factors%	Concrete pre- cast	PMMA (Plexiglas)	Non-recycled aluminium & mineral wool	Recycled aluminium & mineral wool	Steel recycled & mineral wool	Steel not recycled & mineral wool	Living willow & mineral wool (inc: sequestered CO2)	Woven willow & mineral wool, (inc: sequestered CO2)	Timber
Total NOx (g)	7	5.35	8.56	6.42	3.21	1.07	4.28	7.49	7.49	2.14
Total Waste to Landfill (kg)	6	8.56	6.36	5.3	2.12	3.18	7.42	1.06	1.06	4.24
Total Primary Energy (MJ)	12	7.84	8.96	5.6	2.24	3.36	4.48	6.72	6.72	1.12
Total CO2 to Air (g)	38	11.04	12.42	8.28	4.14	5.52	9.66	1.38	2.76	6.9
Total SO2 to Air (g)	5	8.4	7.35	6.3	4.2	2.1	3.15	5.25	5.25	1.05
CO (g)	4	2.08	3.12	6.24	5.2	4.16	7.28	8.32	8.32	1.04
CH4(g)	38	0	8.28	6.9	5.52	2.76	4.14	0	0	1.38
Total Heavy metals to air (g)	7	2.14	3.21	6.42	4.28	5.35	7.49	8.56	8.56	1.07
Total Heavy metals to water (mg)	3	0	4.12	3.09	1.03	2.06	5.15	1.03	1.03	1.03
Total PM (g)	7	2.14	7.49	8.56	3.21	5.35	6.42	4.28	4.28	1.07
Total Water Used (l)	5.5	3	1.055	6.33	4.22	5.275	7.385	8.44	8.44	2.11
HF (mg)	4	0	2.08	7.28	3.12	4.16	5.2	6.24	6.24	1.04
HCL (mg)	4	0	5.2	7.28	2.08	3.12	4.16	6.24	6.24	1.04
Total extracted minerals (t)	3.5	8.28	1.035	5.175	2.07	3.105	4.14	6.21	6.21	7.245
Totals of all ranked values		58.83	79.24	89.175	46.64	50.57	80.355	71.22	72.6	32.475

Table 7.8b. Results of the weighted cradle to gate' analysis with data omissions removed

	Weighting Factors%	Concrete pre- cast	PMMA (Plexiglas)	Non-recycled aluminium & mineral wool	Recycled aluminium & mineral wool	Steel recycled & mineral wool	Steel not recycled & mineral wool	Living willow & mineral wool (inc: sequestered CO2)	Woven willow & mineral wool, (inc: sequestered CO2)	Timber
Total NOx (g)	7	5.35	8.56	6.42	3.21	1.07	4.28	7.49	7.49	2.14
Total Waste to Landfill (Kg)	6	8.56	6.36	5.3	2.12	3.18	7.42	1.06	1.06	4.24
Total Primary Energy (MJ)	12	7.84	8.96	5.6	2.24	3.36	4.48	6.72	6.72	1.12
Total CO2 to Air (g)	38	11.04	12.42	8.28	4.14	5.52	9.66	1.38	2.76	6.9
Total SO2 to Air (g)	5	8.4	7.35	6.3	4.2	2.1	3.15	5.25	5.25	1.05
CO (g)	4	2.08	3.12	6.24	5.2	4.16	7.28	8.32	8.32	1.04
Total Heavy metals to air (g)	7	2.14	3.21	6.42	4.28	5.35	7.49	8.56	8.56	1.07
Total PM (g)	7	2.14	7.49	8.56	3.21	5.35	6.42	4.28	4.28	1.07
Total Water Used (l)	5.5	3	1.055	6.33	4.22	5.275	7.385	8.44	8.44	2.11
Total extracted minerals (t)	3.5	8.28	1.035	5.175	2.07	3.105	4.14	6.21	6.21	7.245
Totals of all ranked values		58.8	59.6	64.6	34.9	38.5	61.7	57.7	59.1	28.0

Figure 7.2, illustrates the overall results of the barrier materials assessment. For the purpose of clarity the results for each parameter were ranked from between 1 and 9, where values were the same they shared the rank, and these values were totalled, giving an overall figure for each barrier. The lower the overall total of the ranked and weighted values, the more environmentally friendly and sustainable the barrier could be presumed to be, this is illustrated in Figure 7.2. As this is not influenced by an actual location of a construction site, it can be taken as illustrative of the real world scenario for these particular barrier materials from extraction, to delivery at the factory gate.

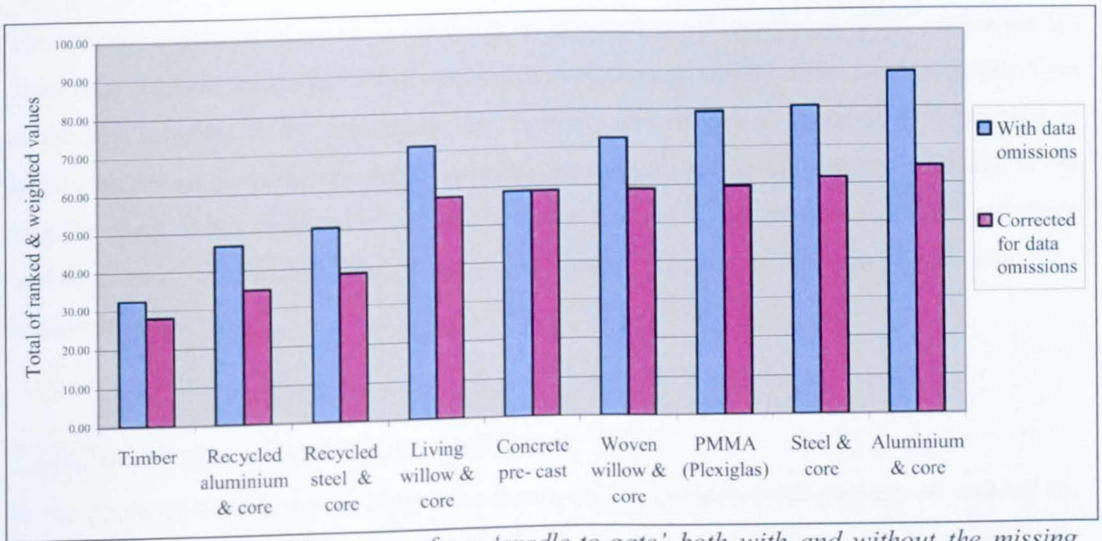

Figure 7.2 The sustainable aspects from 'cradle-to-gate' both with and without the missing data[1]

The findings presented in Figure 7.2 show the most environmentally unsustainable materials as the un-recycled metal barriers, followed by the PMMA. As noted, this section only describes the impacts from 'cradle-to-gate', and beyond this as referred to previously some of these materials can be recycled, some of which by 100%. Consequently, in the overall lifecycle assessment, these materials could redeem some sustainability factors making them relatively less harmful.

One of the most surprising factors is the relatively low sustainability indicator for the willow barriers, as despite their inherent CO_2 sequestration, due to their mineral wool inner core they still have a relatively large impact. These barriers are sold on the premise that they are an environmentally friendly option, however, as can be seen this is not entirely accurate. Therefore, it would be of great benefit if an alternative to the mineral wool inner core could be used, examples of which are exhibited in the Netherlands, where the use of a solid in-fill of soil is

[1] *Core refers to the absorbent mineral wool, and materials are not recycled unless otherwise stated.*

adopted (Kotzen and English 1999:132). With this option it is likely that the willow barriers would be the most environmentally sustainable.

Some aspects of willow noise barriers do have environmentally beneficial attributes that the other barrier types do not possess, such as the creation of habitats for small mammals, birds and insects and wildlife corridors. However, whilst the willow barrier manufacturers continue to use mineral wool insulation the environmental benefits will remain less, than that which it is marketed upon.

The relative impact of using recycled metal, as opposed to un-recycled is large, consequently, illustrating the beneficial effects that can be achieved through careful sourcing of materials. One of the key surprises in the findings is the relatively low impact of concrete. This material is largely perceived as an unsustainable material, however; in reality the impacts are much lower than for many of the others. Unsurprisingly, timber had the lowest environmental impacts from 'cradle-to-gate', which does lead to some justification of their prolific use, other than their relative low cost.

7.2.3 'Gate-to-grave' analysis: an overview

In the previous section, conclusions were drawn on the environmental impacts of each of the nine noise barriers from their extraction 'cradle' to the point of delivery 'gate'. As noted above, beyond the factory gate many more factors determine the environmental impacts throughout a noise barriers lifecycle, which are entirely dependant on the location that the barrier will be constructed in. Consequently, without a particular case study to relate the 'gate-to-grave' analysis to, any results would be inconclusive. However, as the phases beyond the factory gate play an incremental part in the whole lifecycle assessment, to omit this stage would result in a less valuable conclusion.

Consequently, the next phase of the lifecycle assessment is presented as a methodology for further application with a real world scenario, using ranking systems where appropriate. This incorporates the maintenance costs, transportation beyond the factory gate including to the construction site, and then on, to either a further recycling plant or alternative final disposal, as well as an overview of the relative financial costs of each of the barrier types.

7.2.4 Maintenance cost indicators

Maintenance is a very important aspect of a LCA, as it can increase both the financial and environmental impacts of a material over a lifetime significantly. The data provided in Table 7.9

is the official data reported from the Highways Agency with regard to expected maintenance requirements for the varying barrier types (Highways Agency 1995). Significantly, no actual costs could be allocated to any of the materials without a specific case study scenario, as factors such as location, road type and local climate would significantly influence how much maintenance would be necessary.

Figure 7.3 illustrates the potential differences in maintenance burdens, with PMMA demanding the most maintenance, due mainly to the requirements for cleaning, living willow also has quite high maintenance demands, due to the fact that it grows, and therefore needs to be maintained to ensure that it does not become a driving obstruction.

As discussed, maintenance is very much influenced by the barrier location, for example a metal barrier close to the coast may suffer greater corrosion and become the most demanding, a concrete screen could provide a surface for graffiti, and PMMA and timber could be more prone to destruction by vandals. These factors must all be considered when choosing an optimum solution to a noise pollution problem.

Table 7.9 Maintenance cost indicators- (1 Fairly Low impact- 5 Fairly High).

Barrier Type	*Factors Considered*	*Relative Cost*	*Environmental Score*
Timber Screen	*Inspection/repair, periodic treatment.*	*Fairly Low*	*1*
Concrete Screen	*Inspection/ repair, periodic cleaning.*	*Low*	*2*
Metal Panels Absorbent Panels	*Inspection/ repair/repainting/ treatment, tightening bolts, check earthing.*	*Fairly Low*	*1*
Transparent panels	*Inspection/ Repair, regular cleaning, treatment*	*Fairly High*	*5*
Willow weaved barrier	*Inspection/repair, periodic treatment.*	*Fairly Low*	*1*
Willow living Barrier	*Inspection, drip irrigation, cutting back 3 times in first year and annually there after, pest & disease control, repairing, spring fertilising.*	*Moderate*	*3*

(Source: (Kotzen and English 1999:156; Bowles 2003)

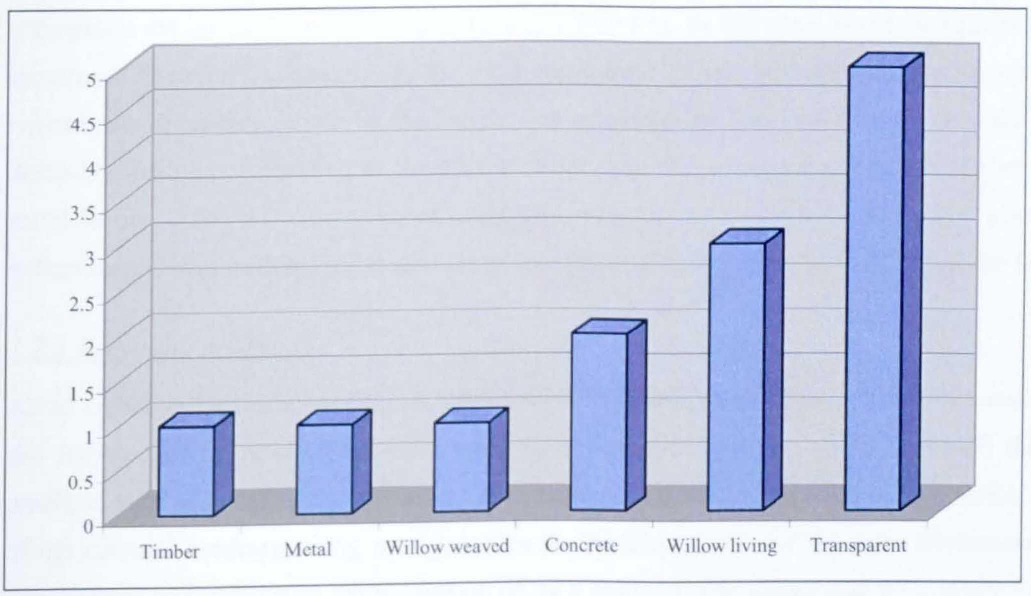

Figure 7.3 The relative levels of maintenance necessary throughout each of the barriers lifecycles. (environmental score- 1 fairly low - 5 fairly high maintenance)

Table 7.10 Maintenance and replacement intervals for noise barrier materials.

Material	*Minimum replacement period*
Concrete pre cast	*40 years* [1]
PMMA (Plexiglas)	*20-25 years* [2]
Aluminium	*30 years* [3]
Steel	*20-25 years* [4]
Timber	*20 to 40 years depending upon the preservative treatment* [5]
Willow (woven)	*25 Years +* [6]
Willow (living)	*25 Years* [6]

For these barriers, it should be noted that those needing replacement before the proposed 40 year limit, will incur all the above lifecycle impacts again for the replacement barrier, and will therefore potentially perform worst overall, making them more environmentally damaging, and financially burdening than is necessary. In a statement by the Highways Agency, a preference for barriers with a maintenance free life of 40 years was deemed desirable (Thomas 2005). However, officially the limit of 20 years without maintenance is standard (Kotzen and English 1999:98).

It should firstly be highlighted when summarising the impacts of maintenance and replacement schemes for the noise barriers, that the two are inextricably linked, in that without the

[1] Gramm Barrier Systems, UK, ARC Concrete Ltd, UK, Borall Edenhall Concrete Products, UK.
[2] Gramm Barrier Systems, UK, and Parachemie, Germany.
[3] Hill & Smith, UK, Industrial Acoustics Company Ltd, UK, Radian Acoustics UK
[4] Environmental silencing Ltd, UK, Ecometal, UK, Industrial Acoustics Company Ltd, UK
[5] (Burn fencing Ltd, Buffalo Structures, Gramm Barrier Systems, Charles Ransfords
[6] ETS: Green Barrier in Woven willow, GSB Holdings Ltd, Tubosider UK Ltd
[6] IBID

appropriate maintenance for each barrier being adhered to, its life span would be significantly shortened. Therefore, in summation the most appropriate barrier in terms of maintenance and replacement frequency would be the barrier that combines the least maintenance and the best durability qualities. According to the results shown here this would be a concrete, timber or a metal barrier. When this fact is related to the cost per m^2 of a barrier (in Table 7.13) it gives an indication and explanation for the vast use of concrete and timber noise barriers within the UK.

7.2.5 Recycling potential

All of the materials under investigation have either the potential to be recycled or in some way use recycled components. Therefore, below is a description of the extent to which this is practised with each material. The benefit and frequency of this is discussed below, under each of the material headings, along with a written description of some of the main environmental implications associated with the production of each material. The values and the impacts of the levels of recycled input into each production system are noted within the overall impacts in Section 7.2.2 above.

To ensure that an accurate assessment of the recycling potential of each of the materials was incorporated into the LCA, 'The Green Guide to Specification' (Anderson, et al. 2002), was used to identify materials, which most closely resembled those in each of the noise barriers under investigation. The materials were presented giving a value for it's ability to be recycled, or use recycled materials. The values are given in letter format with A, representing best environmental performance followed by B and C. This was converted to numerical format with 1 = A (least environmental impact), 2 = B and 3 = C (greatest environmental impact). The values under each recycling category 1) recycled input 2) recyclability 3) currently recycled and 4) energy saved by recycling, were then summed to give an overall value of the potential environmental benefit of each of the materials represented, this data is illustrated in Figure 7.4.

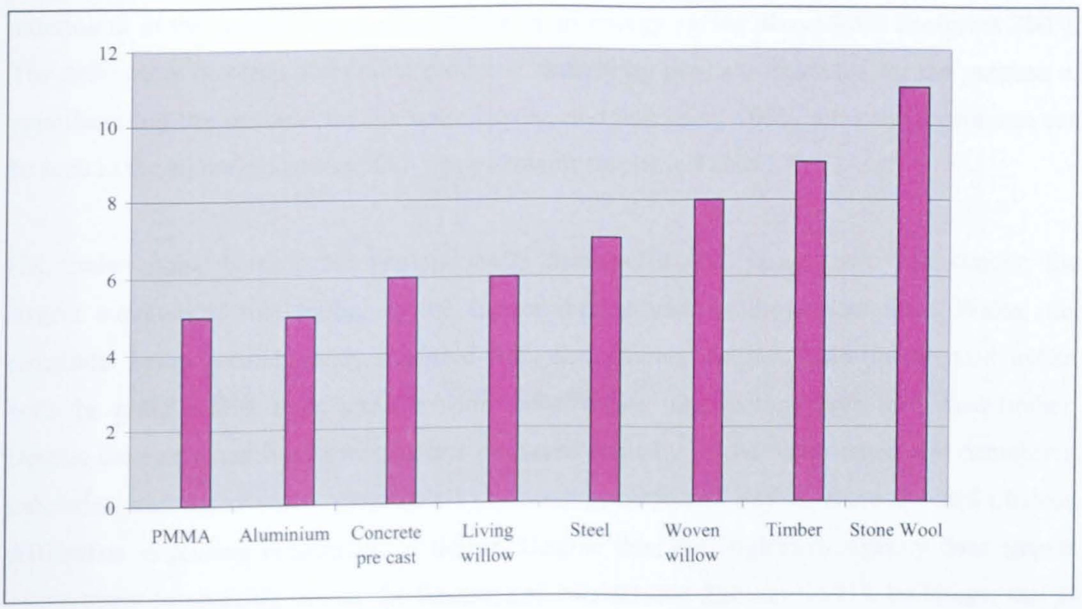

Figure 7.4 The relative potential environmental benefits afforded for each material from all aspects of recycling (adapted from BRE Anderson et al (2000)

Essential materials for the production of steel are coke (made from coal) and iron ore, the extraction of which results in large amounts of waste material. However, steel is easily recycled, and up to 60-70% is currently recovered in the UK (Bergeret 2003:2). There is a 96% difference in feedstock energy[1] between recycled and non-recycled steel, (or steel with system expansion and without system expansion) (Committee on Environmental Affairs 1999/2000:28).

In addition to this, there are further recycling gains to be made during the production of steel, from the waste product of blast furnace slag (BF slag), which can be used as an alternative to Portland cement; (0.26kg of BF slag is generated per kg of hot metal). More than 90% of the total amount is exported for external applications, 60% of which is for Portland cement (Committee on Environmental Affairs 1999/2000). The recycling potential for both steel and aluminium, discussed below, indicate how a material with large environmental costs in the 'cradle-to-gate' process, can redeem some sustainable attributes in the second phase of the LCA.

Aluminium's principle constituent is bauxite, which is strip-mined, and causes habitat degradation. However, much aluminium is recycled in the UK, and making use of recycled

[1] Feedstock energy-is that part of the primary energy entering the system, which is not consumed and/or is available as fuel energy and for use outside the system boundary. In the case of steel making, this includes the calorific value of energy of the outputs (such as that contained in products, recovered materials and waste) as well as fuel losses (Committee on Environmental Affairs (1999/2000). World Steel Lifecycle Inventory: Methodology Report. Brussels, International Iron and Steel Institute: 1-90.

aluminium in the production process results in an energy saving above 80% (Bergeret 2003). The differences between aluminium produced entirely by products extracted for the purpose of manufacturing the material for the noise barrier, and that using 100% recycled aluminium can be seen in the embodied energy, CO_2 and pollutants results in Table 7.7.

UK timber noise barriers are predominantly constructed with homegrown soft timber; the largest supplier of this timber to the barrier market sources the timber from Wales, the remainder being predominantly imported from Scandinavia. As yet, little timber used within both the noise barrier trade and the wider construction trade comes from reclaimed timber. Despite the vast quantities of wood waste produced annually by the construction and demolition industries, and the obvious 'greenness'' of choosing reclaimed timber, there are still obvious difficulties in reusing constructional timber. Despite this, the Highways Agency does have a commitment to sourcing timber for fencing and barriers and furniture in HA buildings, that is certified to have derived from sustainable sources (Highways Agency 2003).

The recycling potential of timber from noise barriers, is possibly not as apparent as for other materials discussed. This is due to the exposed nature of the noise barrier during its life. A timber frame within the fabric of a building may be relatively undisturbed over time, in terms of rotting and weakening (Anderson, et al. 2000:33). However, a noise barrier would be exposed to all the elements, and consequently only has a predicted replacement rate of 20-40 years, at which point it can be presumed that the timber would no longer be of sufficient quality to warrant widespread reclamation or recycling

PMMA is different from virtually all other plastics, in that it can be readily recycled back to the original monomer. Thermal cracking, the process by which PMMA is converted back to methyl methacrylate (MMA), can be carried out with almost 100% recovery. The resulting monomer can be separated from any fillers, distilled and decolourised, so that it is almost indistinguishable from virgin material.

This important characteristic potentially has a great impact on the practicability of recycling products made from the polymer, including noise barriers, and significantly influences the LCA of barriers made of PMMA. To ensure that this recycling process is undertaken, the manufactures of Polymethyl methacrylate, claim that all products supplied out of Polymethyl methacrylate are returned to the manufactures at the end of the barriers useful life and are fully recycled using the aforementioned methodology (Boustead 1997). Despite this, it must be borne in mind that the manufacturing plant for this product is in Germany, meaning that any recycling benefits must be offset with the impacts of transportation back to the manufactures (Rohm Plexiglas).

Pre-cast concrete blocks made from cement, sand and lime are a widely used structural material and can contain a large proportion of pulverised fuel ash/ fly ash, which is a by-product of the burning of fossil fuels in power stations (Bergeret 2003). In addition, blast furnace slag, the by-product of the steel manufacturing process, can also be used as a Portland cement substitute, again reducing other industries waste impacts (Committee on Environmental Affairs 1999/2000).

The Pre-cast concrete structures themselves can also be recycled at 'end of life', as they are made from assembled individual components. At life end or functional changes, they can be dismantled, with limited noise, dust and waste. Individual components can often be separated and re-used, including the reinforcement steel, which can be separated from the matrix and be recycled. The concrete is crushed and reused; the use of up to 20% recycled aggregates has little influence on the performance of reinforcement and pre-stressed concrete elements (BIBM, Bureau International Du Beton Manufacture et al. 2002).

Willow can be seen as a very environmentally friendly material throughout its lifecycle from planting, harvesting and use, through to recycling by composting or shredding. The material sequesters more carbon dioxide than it emits, and produces limited amounts of other pollutants through its processing and transportation. This is for two main reasons, firstly it is grown largely as a sustainable crop, and therefore for each section of willow removed, a new plot will be replanted. Secondly, due to the relative small nature of the business, transportation from extraction, to the processing area are generally small, due to the uneconomical nature of transporting willow over large distances. As noted previously, the failure of the willow barriers in ecological terms is a result of the mineral wool inner core, which contains significant pollutants.

The mineral wool or rockwool is a stone-based thermal insulation, sourced from lava deposits of volcanic diabase rock (ovaline dolomite), which are melted in a cupola furnace like a controlled man-made volcano, to which limestone and coke are added. As the re-melted lava comes out of the furnace, it is spun, given water repellence treatment and bound together in a wool-like fleece; the batch may also contain recycled elements which include basalt, briquetted recycled material and blast furnace slag and this can vary from 0% to 100% of the product (Environment Agency 2001).

The percentage of each raw material in the batch can vary significantly particularly where substantial amounts of recycled materials are used. The final product takes the form of continuous blocks ideal for, acoustic control, (Rockwool Co UK 2003). However as illustrated above the extraction processing and generation are not without environmental impacts.

A summary of the recycled input and potential for recycling after use, are indicated in Table 7.11 below. This can be used as a tool for determining the impacts of various noise barrier materials, in addition to the findings of the 'cradle-to-gate' analysis, and in tandem with the findings of the maintenance and transportation impacts.

Table 7.11 Ratings for each barrier material or components recycling benefits derived from the BRE standards

Barrier Material	*Recycled Input*	*Recyclability*	*Currently recycled*	*Energy saved by recycling*
Concrete pre cast [1]	*C*	*A*	*A*	*A*
PMMAPlexiglas [2]	*A*	*A*	*A*	*B*
Aluminium [3]	*A*	*B*	*A*	*A*
Steel [4]	*C*	*A*	*A*	*B*
Living willow [5]	*A*	*A*	*C*	*A*
Woven willow [6]	*A*	*B*	*B*	*C*
Mineral wool [7]	*B*	*C*	*C*	*C*
Timber [8]	*C*	*B*	*C*	*A*

Adapted from: (Anderson, et al. 2002:4).

Through the collection of relevant data on recycling, a complete picture is established, both of the potential and extent to which recycled materials are included in products, and also, in how products can be recycled at the end of life, including the expected energy conserved from using these procedures. This is incorporated into the methodology through this work, to enable easy identification of recycling benefits for future projects.

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[1] Pre-cast concrete - concrete paving slabs, from the Landscaping Hard Surface section p76.
[2] PMMA- no closely resembling data; therefore estimations for the values were made using industry literature.
[3] Aluminium - coated aluminium composite roof cladding, insulation on steel roof structure, from the low-pitched roof section p45.
[4] Steel - galvanised steel railings, from the landscaping: boundary protection section p78
[5] Living willow -hedging or any living barrier, from the landscaping: boundary protection section p78
[6] Woven willow no closely resembling data; therefore estimations for the values were made using industry literature.
[7] Mineral wool - rock wool insulation, density 200kg/m^3, from the all insulations (including those using HCFCs) section p70
[8] Timber – pre-treated timber close boarded fence, from the landscaping: boundary protection section p78

For waste management and recycling, to be beneficial, the energy and resources used to recycle a product, including all the transportation, processing and redistributing, must be less than that to make a new product. This is largely the case for most materials, but it varies to its level of benefit depending on where the original site is for the construction, and how far this is from both a recycling site and the site for the use of the new recycled material.

Therefore, the data presented above illustrates the generic recycling situation for all the materials under consideration. It can be seen that all the materials under consideration have both a recycled material input and the potential to be recycled. This is a tribute to the significant steps, all areas of the construction industry are taking to integrate good environmental practise into their production systems. This also helps environmental noise barrier designers to select from a number of environmentally beneficial materials, allowing for further consideration to be placed on other aspects of importance, rather than just cost and aesthetics.

The data in Table 7.11, and Figure 7.4, allow the recycling results to be quantified into a more understandable format. This by no-means illustrates the complete picture, as it is not yet a legal requirement to either use recycled materials in a noise barrier, or ensure a noise barrier is recycled at the end of its working life. Therefore, whether the product uses recycled materials or is recycled at the end of it's working life is down to the discretion of the manufacturer and owner, this merely illustrates the scenario under the optimum conditions.

7.2.6 Transportation embodied energy, CO_2 and pollutants

One of the single most influential factors of environmental degradation related to any products LCA is transportation as it is incremental at all stages from extraction to final disposal. As illustrated in Figure 7.1; Section 7.17, the preferred mode of transport used within the UK, for the delivery of raw materials and finished products, is road transportation; this is also environmentally the most detrimental.

Consequently, the impacts of transportation of noise barrier materials are not always directly correlated with the distance from where they were sourced, when compared to one another. As products that are sourced overseas generally arrive in the UK in bulk freight via sea, which can sometimes result in a comparable environmental impact to products sourced within the UK, but transported totally via road. Thus, more factors influence the impacts of transportation than the distance travelled from 'cradle-to-grave', such as primary mode of transportation, weight of materials transported and number of return journeys required transporting the materials for a full barrier.

Therefore, this section compares all materials under the equivalent scenarios, using the hypothetical barrier weights, representative of the weight for a 1km stretch of noise barrier 2m high as calculated in Table 7.2, and illustrated in Figure 7.5 (a-F), being transported 1km by rail or road, with the aim being to create a template for real world scenarios to be adapted to, and to give a general idea of the impacts of transporting the various material types.

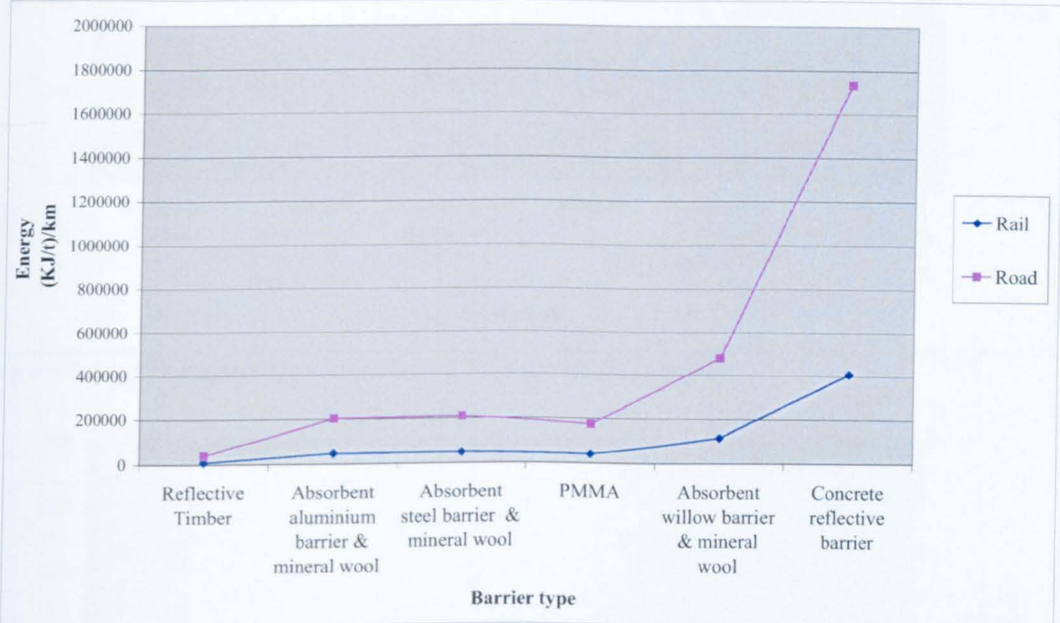


Figure 7.5 (a) Transportation energy consumption per tonne over 1k.

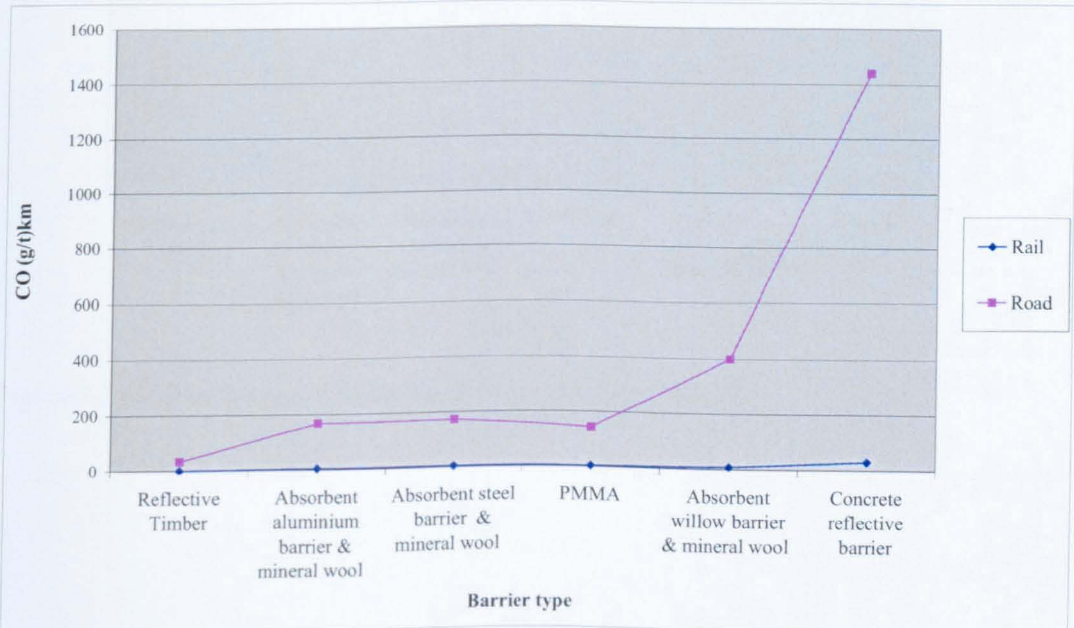


Figure 7.5 (b) Transportation emissions of carbon monoxide per tonne over 1km

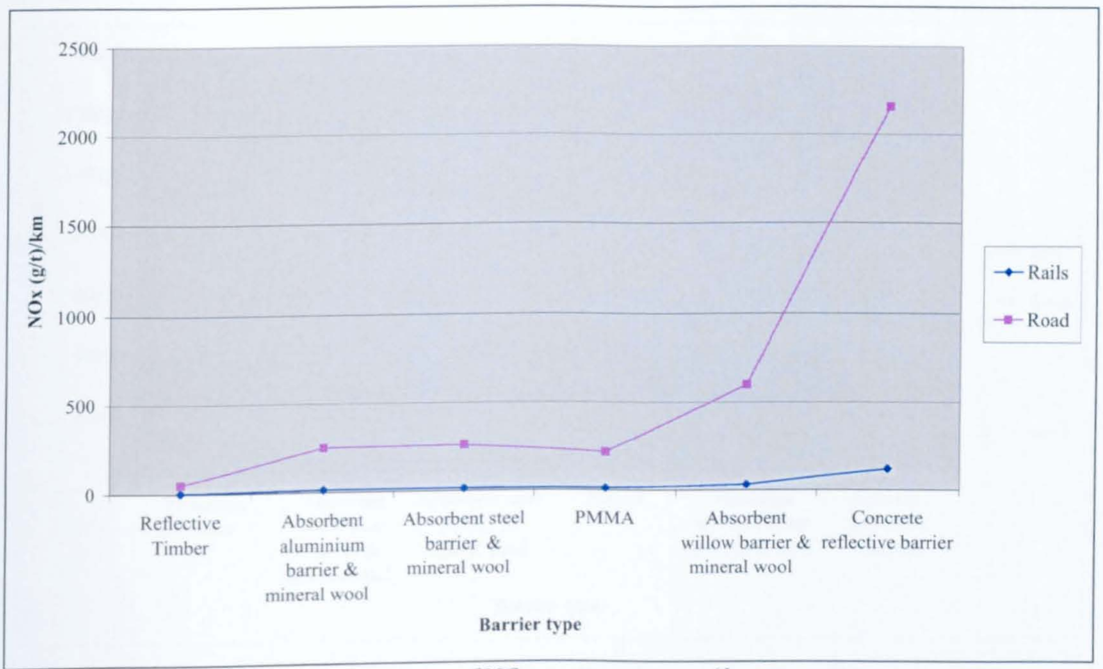


Figure 7.5 (c) Transportation emissions of NOx per tonne over 1km

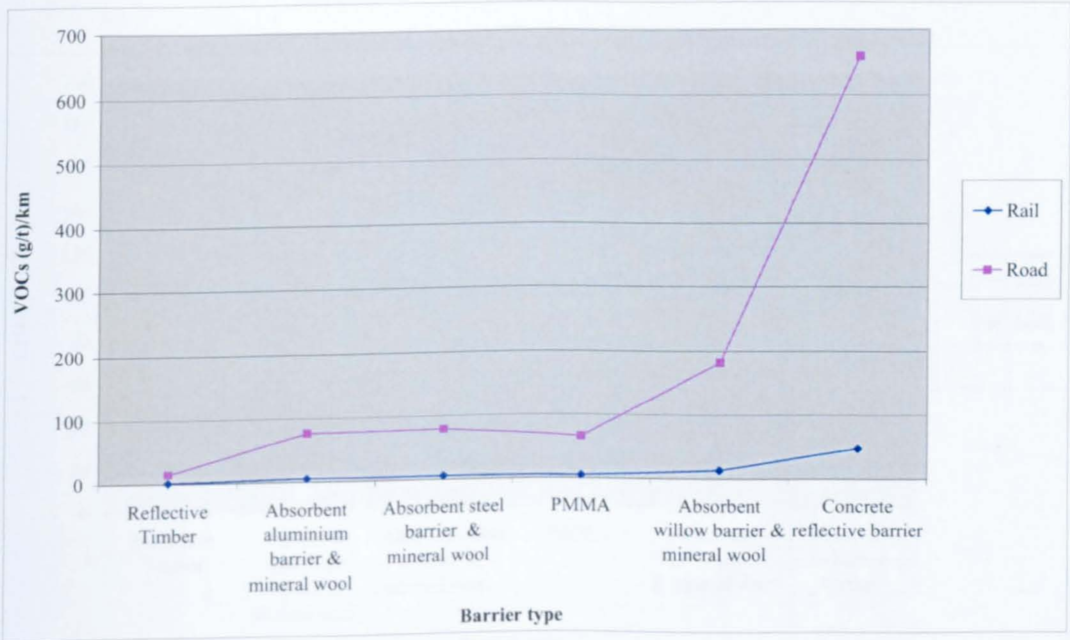


Figure 7.5 (d) Transportation emissions of VOCs per tonne over 1km

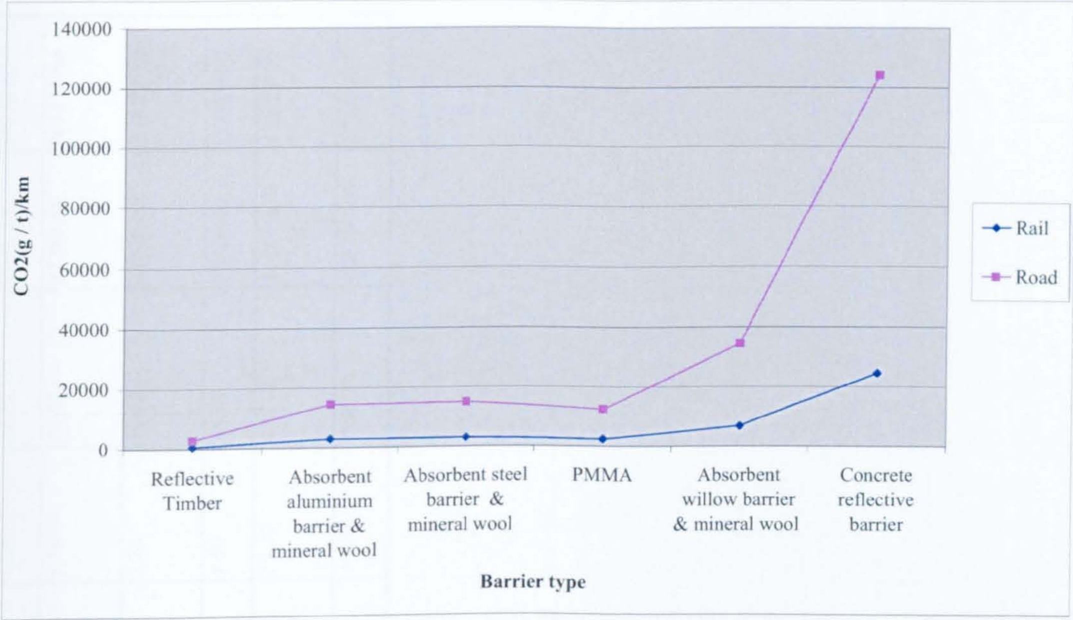


Figure 7.5 (e) Transportation emissions of carbon dioxide per tonne over 1km

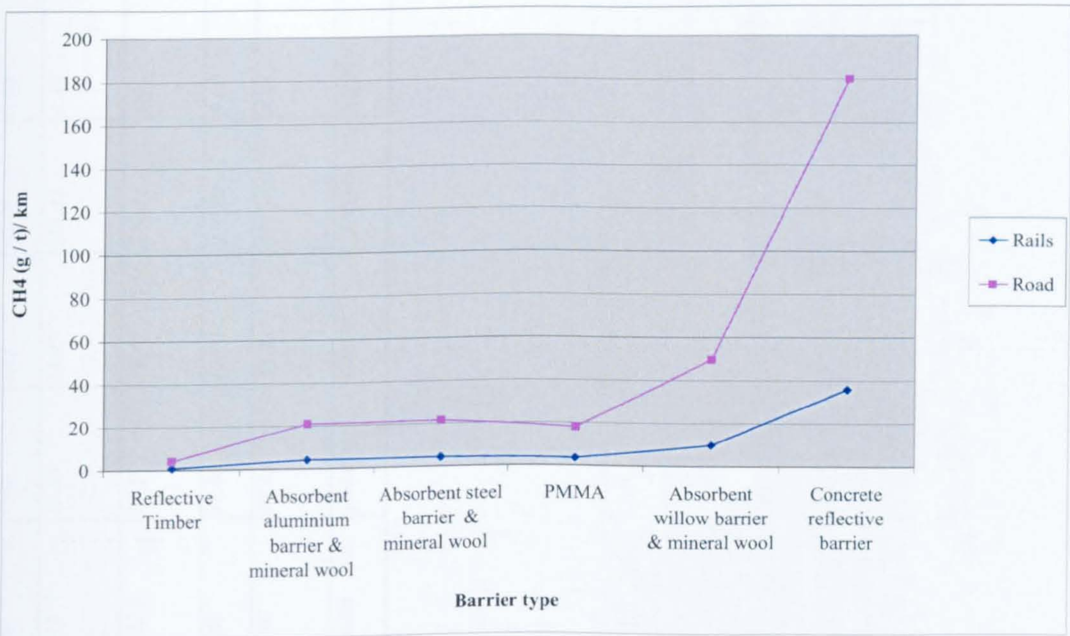


Figure 7.5 (f) Transportation emissions of Methane per tonne over 1km

Table 7.12 Embodied energy, CO_2 and Pollutants consumed and emitted per 1km of travel using rail and road.

Barrier Type	Rail - CO_2	Road - CO_2	Rail - CH4	Road - CH4	Rail - NOx	Road - NOx	Rail - CO	Road - CO	Rail- VOCs	Road - VOCs	Rail - Energy KJ	Road - Energy KJ
Reflective Timber	555.14	2802.78	0.81	4.06	2.71	48.74	0.68	32.50	1.08	14.89	9166.58	39130.60
Absorbent aluminium barrier with Stonewool inner core	2863.44	14456.88	4.19	20.95	13.97	251.42	3.49	167.62	5.59	76.82	47281.68	201837.60
Absorbent steel barrier with Stonewool inner core	2951.18	14899.86	4.32	21.59	14.40	259.13	3.60	172.75	5.76	79.18	48730.46	208022.20
PMMA	2460.00	12420.00	3.60	18.00	12.00	216.00	3.00	144.00	4.80	66.00	40620.00	173400.00
Absorbent willow barrier with Stonewool inner core	6810.10	34382.70	9.97	49.83	33.22	597.96	8.31	398.64	13.29	182.71	112449.70	480029.00
Concrete reflective barrier	24600.00	124200.00	36.00	180.00	120.00	2160.00	30.00	1440.00	48.00	660.00	406200.00	1734000.00

The actual values corresponding to the above graphs can be seen in Table 7.12. This enables any distance for the transportation of future noise barrier materials to be inserted to produce results for each of the pollutants and environmental impact parameters for individual scenarios. The reason this data could not be concluded further, was due to the fact that not all construction sites, factories and final disposal sites, would be the same for each material. This would obviously vary immensely both on the geographical location of the noise barrier manufacturers, and on the site of the barriers assemblage. It can be concluded that the greater the mass of the barrier material, the greater the environmental impacts, under a situation where all the aforementioned problems of geographical site variations have been disregarded.

It is accepted, that within an actual case study the barrier would have a geographical location, and therefore the developers and designers of the barrier should always seek to obtain locally manufactured materials as this would usually blend with the character and the vernacular architecture of the area. In addition, the embodied environmental impacts would be reduced dramatically, as one of the greatest increases of embodied energy and pollution comes from transportation.

In a real world scenario LCA it would be necessary to include factors such as HGV size, if this was standard, the barriers needing less material weight and volume would need fewer HGV's, and the impacts of each individual HGV would be reduced, the lighter the load. Also the return journey would have to be corrected for, by assessing each load transported. The BRE have developed a list of assertions to help with the calculation of transportation impacts for an actual case study application, this can be viewed in *Appendix 3E* (Howard, et al. 1999:38)

7.2.7 Barrier costs

The Highways Agency provides a list of comparative costs and maintenance implications in its design guidelines (Highways Agency 1995:9/2). In order to quantify this further noise barrier manufactures around the UK were approached to give a quote for the price of $1m^2$ of noise barriers in the specified materials. The prices given for each barrier material were averaged and the mean price for $1m^2$ of each material is displayed in Table 7.13 below. This enables a complete evaluation of all aspects, related to the choice of noise barrier material, especially considering that cost is probably the main factor that has determined the type and visual character of most barriers found in the UK (Kotzen and English 1999:155)

Table 7.13 Industry Average Barrier Net Costs for 2m high barrier £/ m^2

Material	*Net price of Barriers 2m high per m^2; supplied and installed*
Concrete pre cast (absorptive)	*£180*[1]
PMMA (Plexiglas)	*£128*[2]
ICI Acrylic (reflective)	*£190*[3]
Aluminium (absorptive)	*£175*[4]
Steel (absorptive)	*£100*[5]
Timber (reflective)	*£55*[6]
Timber (absorptive)	*£104*[7]
Willow (woven)	*£120*[8]
Willow (living)	*£120*[9]

7.2.8 Results for embodied energy and sustainability assessment of noise barriers

The purpose of this investigation, as noted before, is not to provide a definitive answer as to which material is the most appropriate to make a noise barrier from, as this is very site and situation dependant. The aim however, was to illustrate a methodology of how to make the most ecological choice, by providing data for determining the environmental impacts of different noise barrier materials, and raising awareness of the importance of the issue of sustainable construction, in the context of noise barrier development.

One of the main reasons this area was highlighted, was to illustrate the various environmental impacts caused by noise barrier development, and illustrate the fact that by preventing one environmental pollutant, 'noise', that it would be unsustainable to create further and worst pollutants, which would impact on many more people and habitats than those the noise barrier is constructed to protect.

Figure 7.6 below offers a flow chart, to be used in the consideration of a sustainable approach to noise barrier design. The values for the 'cradle-to-gate' section can be understood as correct, regardless of where the noise barrier is located. Beyond the gate, information on all the other LCA influences is described, to enable a balanced judgement on a noise barrier's sustainability in a real world scenario. In the event of a real world scenario being assessed, by using the flow chart, it would be possible to use the weighted values to

[1] Sources: Gramm Barrier Systems, UK, ARC Concrete Ltd, UK, Borall Edenhall Concrete Products, UK.
[2] Sources: Gramm Barrier Systems, UK, and Parachemie, Germany.
[3] Source: Gramm Barrier Systems,
[4] Sources: Hill & Smith, Gramm Barriers UK, Industrial Acoustics Company Ltd, UK, Radian Acoustics UK
[5] Sources: Environmental silencing Ltd, UK, Ecometal, UK, Industrial Acoustics Company Ltd, UK
[6] Sources: (Burn fencing Ltd, Buffalo Structures, Gramm Barrier Systems, Charles Ransfords
[7] Source: Gramm Barrier Systems,
[8] Source: ETS: Green Barrier in Woven willow, GSB Holdings Ltd, Tubosider UK Ltd
[9] IBID

determine the environmental impacts in the context of wider environmental problems. By simply multiplying the various values for energy consumption, and pollutants released by the weighted values listed in Table 7.14.

Table 7.14 BRE weightings for environmental impacts

Environmental impact	*Weighting*
Climate change (100 years)	*38%*
Low-level ozone creation	*4%*
Ecotoxicity	*4%*
Acid deposition	*5%*
Human toxicity to air	*7%*
Fossil fuel depletion	*12%*
Water extraction	*5.5%*
Human toxicity to water	*3%*
Eutrophication	*4%*
Minerals extraction	*3.5%*
Waste disposal	*6%*
Ozone depletion	*8%*

The section on transportation illustrated the influence of each materials transportation on a LCA by giving the value for moving the mass of a whole barrier 1km. Again in a real world scenario, the difference in distance between various manufacturers and recycling and disposal sites would vary. Thus, no particular material could be deemed better than another. The purpose of this project was not to advocate one material over the next, but to illustrate how best an individual developer could consider these factors and integrate this into an overall design project. Therefore summary Table 7.15 bullets the essential areas to be considered, and illustrates how this research can inform future decisions, Figure 7.6 provides a flow chart of information on the values to be used.

Table 7.15 An overview of the actions and information sources for a LCA

Stages	Actions
Stage 1-	Determine the mass and density of the noise barrier necessary for the individual case study using Tables 7.1 & 7.2
Stage 2-	Using the weighted ranks in Table 7.8, in addition to specific information on where the site is located to make a choice on which barrier material would be appropriate by offsetting any additional factors such as maintenance, varying transportation distances, and opportunities for recycling as presented in tables 7.9, 7.11, 7.12 and *Appendix 3F*.
Stage 3-	Weight the 'gate-to-grave ' impacts in accordance with the BRE recommendations.
Stage 4-	Make an informed decision based on the most appropriate barrier that is influenced on more factors that financial implications alone.

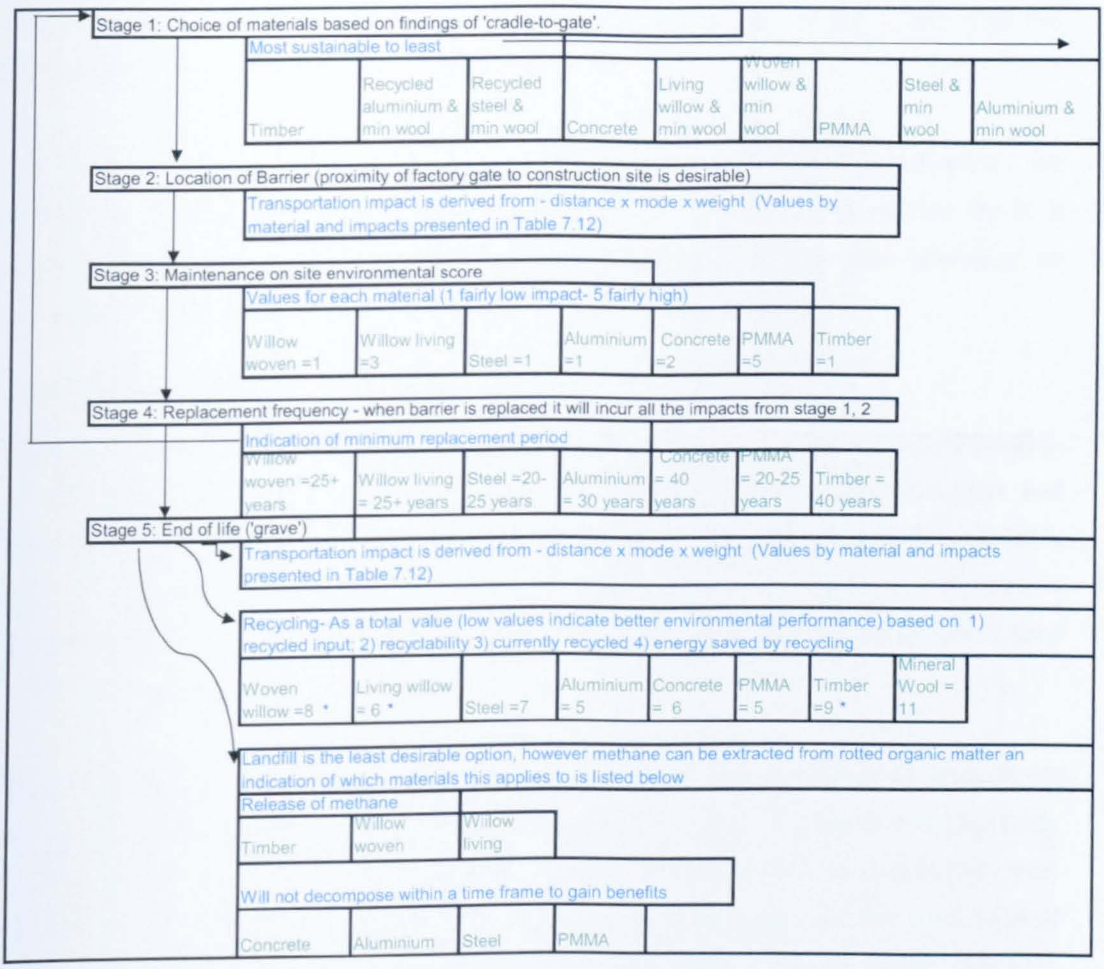


Figure 7.6 Lifecycle assessments of noise barriers. (- Despite carbon neutral status, further benefits can be gained through recycled inputs and composting at end of life)*

The actions described in Figure 7.6 have been formulated into an equation (7.2) to enable the calculation of the environmental lifecycle analysis of a noise barrier, in order for this to apply to a real world scenario the distances between the factory gate and the site for construction as well the distance to the final place of disposal or recycling must be applied.

$$LCA = (w \times T) + (R + D + M + E) \qquad (7.2)$$

where: *LCA= Environmental lifecycle assessment of a noise barrier; w = weighting (Table 7.14); T= Transportation impacts; R= Recyclability; M= Maintenance; D= Disposal of material un-recycled to landfill; E= Weighted environmental impacts from 'cradle-to-gate'*

The higher the value of the *LCA* the less environmentally sustainable that noise barrier material can be concluded to be, this is a useful tool for the comparison of materials on an environmental basis before the final presentation of the choices to the public. The full workings of this equation can be seen in *Appendix 3F.*

In light of the Highways Agency's commitment to sustainable development, the methodology outlined in this research can help the HA achieve these targets, for both environmental and economical accountability for resources, whilst also providing an accessible resource for the community the barriers are designed to protect.

7.3 Discussion and conclusions

Through the extensive reviewing of both the literature, and of the available lifecycle models, a framework has been established to enable the possibility for evaluation of LCA and sustainability of various noise barriers in the future. Prior to this, the only databases available for LCA were specifically designed for assessment of building construction materials. In addition, the models available commercially would only give accurate results when used within the construction of buildings.

As the aspects and criteria of a noise barrier structure and its expectations for its lifecycle are very different from a whole building structure, the data gathered for the purpose of this study was specific to noise barriers. This was achieved as the values used for the calculations were derived from typical noise barrier specifications. As noted throughout the text a full LCA of each of the materials in this study could not be given without a real case study. However, with a real case study, where real values can be attributed to locally produced materials, availability of resources, recycling plants and real transportation distances, they could be incorporated with the data derived for this project and easily converted into the model to give a value for the best available material for a barrier in a specific location.

In effect, if a developer needed to assess which was the best material to use for construction, under both environmental and financial criteria, this data is available with a full methodology to allow for a considered opinion prior to a noise barrier's construction. As the main implementers of environmental noise barriers, the Highways Agency would be able to incorporate individual scenarios into this methodology, to understand the lifecycle costs of the noise barriers under consideration.

The findings of this research also illustrate the importance of selecting materials on a case-by-case basis. Currently the sustainability considerations adopted by the Highways Agency and noise barrier manufacturers relate purely to their impacts from 'cradle-to-gate'. The omission of factors beyond this stage in the 'gate-to-grave' section of the lifecycle, result in a potentially unsustainable option being chosen. The fundamental impacts of transportation and recycling beyond the factory gate can influence the overall embodied energy, and pollutant emissions to the point where a material that has a low impact from 'cradle-to-gate', can become the most unsustainable throughout its overall lifespan, through its impacts to the 'grave'. Therefore all aspects of a noise barrier's lifecycle must be assessed relative to each individual situation in order to provide the most sustainable option.

The model, and the collation of the data to be used are by no means complete, at this stage in the research; to create a model available for commercial use would entail funding. However, the framework and data is established, and this paves the way and highlights the importance of considering lifecycle impacts in a sustainable approach to noise barrier design.

As noted above, the materials investigated here are not the only ones available for noise barrier production, and with advances in new technologies to create noise barriers completely out of recycled materials, such as recycled plastic lumber, the projection for the acceptance of the importance of good environmental design is apparent.

Finally, to orientate this section of work with the rest of the sustainable approach to noise barrier design. It is proposed that the findings of the lifecycle assessment, undertaken as part of the planning process, should also be incorporated into the presentation to the public of the barriers attributes. Thereby giving the public information on, function, form and realistic expectations of the impacts of the barriers development to them personally. This also encourages a wider environmental awareness and responsibility. As noted previously it would be an unsustainable approach, should a micro problem such as noise, which affects relatively few, exacerbate, by consequence of its mitigation, a macro environmental problem such as global warming. Therefore, by informing the public of the wider consequences of their decisions a wider encouragement of social responsibility can be promoted, following the ideology of 'think local; act global'.

The final section of research undertaken in this thesis, determines the importance of the potential for preconceived assumptions on a noise barriers perceived success. An expansion of the lifecycle assessment model presented in the literature review is illustrated in Chapter 9. The model shows how the interconnected nature of each of the constituent parts of the sustainable approach fit together, as an overall method which could be adopted by those responsible for noise barrier design.

Chapter 8 The Impact of Barrier Materials on the Perception of Noise Reduction

Throughout the research undertaken for this thesis, the aim was to uncover, and present an approach for the sustainable design of noise barriers. This final section reveals the importance of perception, and the acknowledgement of preconceptions people have as to how particular materials can attenuate noise, and consequently, identifies the potential for the rejection of noise barriers based on these preconceptions, and how this can undermine the viability and consequently the sustainability of noise barriers.

The issue of subjective impacts has been fundamental throughout this research, as it has been revealed that rarely if ever residents are given the before and after 'objective' values of a barriers ability to attenuate noise. Consequently, their opinions are formed largely on a 'subjective' basis. This fact holds particular importance, when choosing a material for the noise barrier's construction, as if there is a material that incites particular confidence of noise attenuation, without any further quantitative evidence then it may prove a more sensible option to install. Reducing the potential for complaints, and in extreme cases removal, with the sustainability implications this would incur.

The chapter is divided into four sections; the first is a review of the existing literature and experimental approaches that previous researchers have adopted to determine the impacts of intersensory actions on the perception of a noise barrier's effectiveness. The second stage develops the findings of the previous research and adapts them with new technology to illustrate a more effective method for determining the impacts of intersensory actions on perception, the third section presents the findings of the investigation and in the final section the implications of this research is related to the overall sustainable approach to noise barrier design.

8.1 A review of previous intersensory research on noise barriers

There has been much research carried out in the realm of perception of noise, (as reviewed in chapter 2), mainly within the psychology disciplines, therefore, most of the literature is derived from such sources, much of it analysing the phenomenon, and complexities of intersensory interaction. These tests have used many different experimental approaches, however, there is always the risk that controlled experimental designs do not illustrate truly the impact of intersensory interactions in a real world scenario. The definition and explanation of intersensory interaction, occurs when experimental situations are designed to allow only one, or more than one, modality to receive information (for example; eyes or ears). It can be concluded that intersensory interaction has not occurred, if the addition of a second sensory modality does not change a perception, when information is available to a second modality. Often, however, the perception does change when information is available to a second modality, and in such a case it is claimed that intersensory interaction has taken place (Warren et al. 1983).

Viollon (2003), found that when road traffic noises were used as an auditory stimulus, in conjunction with a wooded visual stimulus. The woody visual setting did not exercise a positive influence on auditory judgement, and the explanation for this was that the auditory expectations were not fulfilled, and the sound of road traffic noise was a disappointment (Viollon 2003). These assertions were highlighted in Chapter 4, during the qualitative interviews of this research with the representative of the Highways Agency, who suspected that the perceived judgement of the success of the barrier at attenuating noise was diminished due to high expectations of the residents it was there to protect. Consequently, two factors emerged, the first one being the importance of realistic expectations being relayed to those the noise barrier is being built to protect, this is covered in Chapter 4, secondly, the question was posed of which material induces the perception of greater noise attenuation.

Although both Viollon (2003) and Aylor and Marks (1976) discovered that there was a strong link with regard to audio-visual interactions, and that this link manifested itself in differing ways. As although the visual information did not affect the auditory judgement in the same way, and with the same strength of feeling, neither reported which noise barrier material impacted most upon the perceived noise attenuation. There has been some research within this field by Watts et al (1999), in their paper on 'the effects of vegetation on the perception of traffic noise', they tested the perception of noise reduction through a variety of screens both in-situ and under test laboratory conditions.

The screens used in the laboratory experiment were a willow purpose built noise barrier and a metal noise barrier, a row of conifer trees and an open space, different noise levels were played from behind them throughout the course of the test.

In the in-situ experiments, it was the density of vegetation that was varied, by taking the respondents to various roadsides with both varying traffic flows, and varying concealment of the road by vegetation (Watts et al. 1999). This method presents problems in that during the change of location, the respondents may loose some clarity of thought, on which performed better, consequently resulting in a perception based on memory recall rather than real spontaneous reactions.

The results of these two experimental designs provided a confirmation of the findings of both Aylor and Marks (1976) and Viollon (2003). Where by significant effects were indicated between the differences in the sensitivity to noise, depending on the degree of visual screening, which was largely independent of the noise exposure levels. This was illustrated by the fact that the difference in the noise exposure level needed to incite the same subjective response was 4dB(A), between the site with 30% vegetation cover and 90% vegetation cover, in the direction that the listeners were more sensitive to noise where the screening was highest.

The results from the laboratory test, undertaken by Watts et al (1999), confirmed the effect that listeners gave higher noisiness ratings under the same noise exposure, when the source was obscured by vegetation. In this experiment the noise source took the form of a recording of traffic played behind various screens. It was found that through analysing the effects with actual noise barrier screens, they found that it is the visual screening of the source of sound, and not the other factors connected to the presence of vegetation that is most important (Watts et al. 1999).

Mulligan et al (1987) also confirmed that the assessment of loudness increased as the percentage of vegetation increased, when the ambient noise level was held constant. In this case the sound was a single tone at 500Hz, which was varied between 50dB and 80dB and replayed through headphones (Mulligan et al. 1987).

These varying methods all led to the same conclusion, that some masking of the sound source was beneficial to the perception of the attenuation of noise, but completely obscuring it actually resulted in the perception of a sound increase. Consequently, the question of how this phenomenon impacts upon the perception of purpose built noise barriers arose, and the methodologies of both Watts et al. (1999) and Viollon (2003) were extended, and adapted to test the perception of noise barriers in several standard materials available in the UK, based purely on how they were perceived as noise attenuators.

The key factor being, that noise barriers are developed on the principle of the interruption of the line of site, and with the exception of transparent barriers, most are developed to largely obscure the sound source. Watts et al (1999) did note this possibility and suggested the use of transparent noise barriers or partially transparent barriers as a means of avoiding the problem of false expectations. In addition they asked the respondents which of the four barriers under consideration was the most aesthetically attractive on a 0-9 scale, this was determined as being the willow barrier, which they concluded, 'enforced the impact of appearance on the perception of noise attenuation'.

8.2 Methodology

8.2.1 The methodology of the site recordings

To extend the findings of authors such as Aylor and Marks (1976); Kragh (1981); Anderson et al (1983); Watts and Nelson (1993); Watts (1996); Watts et al (1999) and Viollon et al (2002), a method for determining the extent to which visual stimulus effects the perception of a noise barriers ability to attenuate noise was devised. The difference between this research and that of other previous researchers was that firstly a moving visual stimulus was used under laboratory test conditions, and secondly the audio stimulus was altered to create the illusion that the audio sequence was derived concurrently with the visual stimulus. However, as is explained below the audio stimulus was kept the same for all the barriers. Additional to these factors, the number of noise barriers tested was extended, and the barriers chosen represented a wider variety of barriers than had previously been analysed.

Visiting several noise barriers in-situ throughout the UK enabled the collection of the visual stimulus with a video camcorder. The barriers were chosen as they represented some standard style types available commercially in the UK. The barrier materials were as follows, concrete (reflective), metal (steel) (absorbent), timber (absorbent), transparent acrylic (reflective) and finally a hedgerow of deciduous vegetation (see Figure 8.1 & 8.2). Each barrier was located adjacent to a busy 6-lane motorway at various locations along the M1 and M65, motorways in the North of England (site and barrier descriptions can be seen in *Appendix 4A*).

A suitable and safe position was chosen at each site to record the traffic passing the noise barriers from the non-motorway side, the angle of the cameras view was based on the line of site over the barrier. It was required that the video recording would allow the passage of traffic to be visible, and representative of an average view of the traffic from the ground floor of a property, adjacent and approximately level with the barrier, and low enough to see high sided vehicles, but not so that the barrier was at an angle low enough to see low vehicles, such as cars passing by (for the opaque barriers). This was done to allow a relatively similar comparison between the barriers.

A position of 10-metres away from the barrier was chosen, or as close as possible there to, and the camera was positioned facing straight towards the barrier where possible. However, as the land at the rear of the timber barrier was much lower than the carriageway side, the angle had to be altered slightly to ensure the high sided vehicles passing by were visible, consequently the timber barrier was recorded at an angle of $\approx 45^{\circ}$ to the barrier, looking towards the oncoming traffic of the nearside carriageway (see Figure 8.1 & 8.2, looking towards the source of the noise) (Watts et al. 1999).

The recordings were made using a Panasonic NVDS38 digital video camera, attached to a Manfrotto 055/200 tripod stand, erected between 1.5-1.75m at each site dependent on the barrier heights and angles. A 12-minute recording of the traffic was taken at each site to give enough data to manipulate the recordings.

Figure 8.1. Recording visual and audio sequence and noise levels behind the reflective concrete barrier (Nr Junction 33 Northbound M1).

All of the barriers tested were the same as those tested for their sustainable properties in Chapter 7, with the exception of the line of deciduous vegetation. The lack of willow barriers available in-situ for recording in the UK is allegedly a result of their removal, following problems stemming from both the irrigation requirements and disease[1]. Therefore, for the purpose of this experiment a simple line of roadside vegetation was recorded, this was not an actual purpose built noise barrier, and therefore raised the possibility of recording some interesting results with regard to the perception of vegetation as a noise reducing material.

[1] Source of information Gramm Barriers, UK.

(a) Metal Absorbent Barrier (J27 Southbound M1).

(b) Timber Absorbent Barrier (J27 Northbound M1).

(c) Transparent Reflective Barrier (J7 Eastbound M65).

(d) Deciduous Roadside Vegetation (Nr J33 Southbound M1).

Figure 8.2(a-d) Four of the five noise barriers used in the perception investigation

8.2.2 Methods of constructing the visual stimulus

Several methods were devised to test the participants purely on their perception of the barriers. The original experimental design involved superimposing a noise barrier photograph on top of a moving videoed image of a motorway using Adobe Premiere 6.0 software. However, after piloting this method the results proved to be too unrealistic to successfully test the perception of the respondents on the noise barriers, and as the purpose of this investigation was to improve realism in the intersensory interaction test, the method was abandoned in favour of the video in-situ technique.

The original design of this technique also caused problems, in that the original method was to play the respondents a series of 40-second video clips of traffic passing by a noise barrier, each sample recording was 10 minutes long, which gave the resource of plenty of footage.
This first experimental approach, which was subsequently abandoned, was to interchange the video clips with the sound recordings in order to observe any variation in the respondent's responses when reflecting on how effective each barrier was at mitigating noise.

Unfortunately, the matching up of the different barriers was not very effective, and the risk of the respondents finding the experiment unrealistic made the method unviable. Therefore, the alternative was to choose one audio sequence from one of the recordings and choose a visual recording sample of each of the barriers that could be matched with the audio stimulus by cutting pasting and merging the clips. This was a labour intensive method using both Adobe Premier 6:0 software for the visual samples and Cool Edit Pro software to manipulate the sound wave file. This method, however, guaranteed that when the respondents were tested, there judgement was based on the visual stimulus as the audio stimulus was controlled.

The final tests were designed as follows; the five noise barriers under investigation were videoed and the sounds projecting from over the barriers were recorded as stated above. The 10-minute recordings were then played back using the Adobe Premier 6:0 and Cool Edit Pro 2:0 software, and one 23-second section of the recording of the concrete noise barrier was chosen to be the audio sample. It was chosen, as it contained a section with a frequent flow of large trucks, which could be heard quite clearly. All of the other visual recordings were then played back and sections that fitted the test audio sequence were pasted in together. The end result being that each of the recordings of the audio sequence from the concrete barrier had the visual sequence of each of the other clips pasted over them in order that the audio and video clips were completely synchronised.

8.2.3 The laboratory

The purpose of this investigation was to test the respondent's perceptions of noise attenuation by the barriers, based purely on subjective data, and the preconceptions of the various materials abilities to attenuate noise. Therefore, the experimental design of this investigation utilised the RAVE- Reconfigurable Advanced Virtual Environment suite, known as the REFLEX studio at the University of Sheffield [1].

The files all constituting 23-seconds of traffic flow past each of the five barriers, were projected on to the large screen in the RAVE suite, and the audio sequence was played on four large speakers on either side and behind the screen. This encouraged the feeling of a realistic setting as the sound was coming from the visual stimulus. Although the RAVE facility had the ability to project the sound in surround, it was felt that for greater realism the noise would be projected from the top and bottom, left and right speakers positioned adjacent to the large projection screen (see Figure 8.3).

This facility, developed as a virtual reality interface, had additional foam absorbers attached to all the main vertical walled surfaces, making the sound proofed laboratory partially absorbent, and reducing the impacts of any reflections. The reverberation time of the room was measured as RT30, which is less than 0.2-0.3s at high and middle frequencies, and less than 0.4s at low frequencies. This was an acceptable level, as the test was related to sound pressure levels, and the sound source was directional emanating from the front speakers. The impact of this was a reduction in overall background noise of 2.5 dBA, an acceptable level (Viollon et al. 2002).

A large screen (8ft x 10 ft), capable of projecting 3D images with the use of goggles was positioned to the rear of the room, and took up approximately 2/3rds of the rear wall length. The layout of the room was constructed similar to a cinema, with chairs at an equal distance facing the projection screen (see Figure 8.3).

[1] http://www.shef.ac.uk/reflex

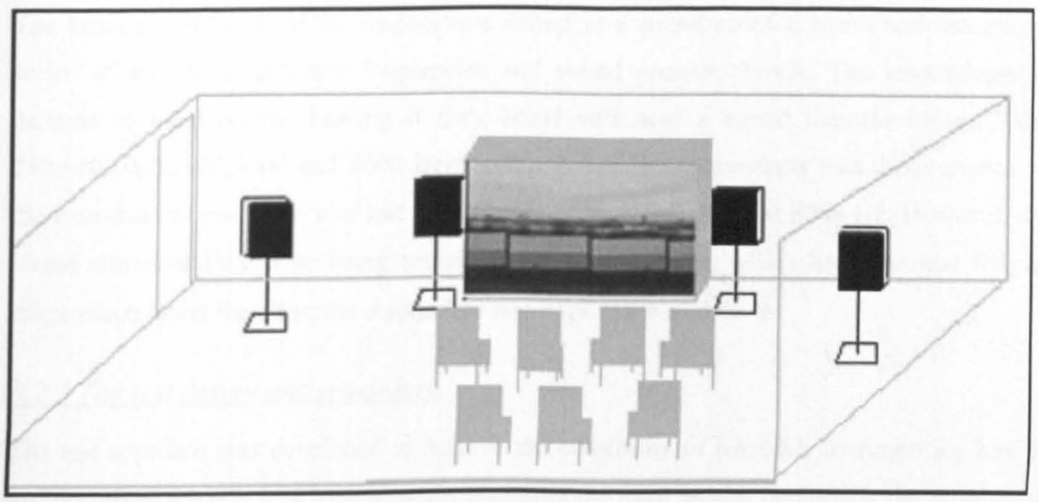


Figure 8.3 Diagram of Reflex Studio with projection of image

8.2.4 Method of sampling volunteers and the characteristics of the sample

The random sample of respondents was chosen from the University population by distributing e-mails to the mail boxes of all 1st, 2nd and 3rd year Architecture students, by posting a request for volunteers on the Chinese Society website, and by distributing posters around the University Union buildings requesting volunteers.

The volunteers were accepted in a 'first come, first served basis', as there was a limited allotment of money to compensate them for their time. The volunteers were made up of 9 males and 14 females with a mean age of 23 years old, with the range spanning from 18-30 years old. The ethnic backgrounds of the group were mixed, but all the respondents originated from 1 of 4 areas. The breakdown of this is as follows: 12 White British /Irish, 1 British Other, 7 Chinese and 3 Taiwanese. The respondents were a mix of Undergraduates, Postgraduates and Postdoctoral researchers from the following departments within the University; Architecture 47.8%, Engineering 13.0%, English & Languages 17.4%, Computer Sciences 8.7%, Psychology / Philosophy 13.0%.

The respondents were allocated to four time slots throughout the test day, to ensure there were no more than 7 people undertaking the test at any one time. This was important due to the size of the room, and screen, as to get the fullest effect of the test the respondents had to be able to see the whole screen, and be inside the speaker positions. To ensure that the respondents all had 'normal hearing', they were all subjected to a hearing test devised by the Computer Sciences Department of the University of Sheffield.

The hearing test involved the respondents sitting in a sound proofed booth and listening to a series of sounds at different frequencies and sound pressure levels. The respondents were deemed to have normal hearing if they could still hear a sound impulse below 20dB at 250,500,1000,2000,4000 and 8000 Hertz (Hz). All of the respondents met these criteria, with the exception of one male who had difficulty hearing below 50dB at 8000 Hz. However, as the sound stimulant they were being tested on was traffic noise, which has a normal frequency range much lower than this, the respondent was kept in the sample.

8.2.5 The test design and procedure

The test approach was developed to remove the possibility of respondents forgetting how they had perceived the previous barrier, when assessing the next, as was potentially the problem with the in situ experiment discussed above (Watts et al. 1999). The objective was to retain as much realism during the experiment, whilst not compromising the controls through the use of a laboratory experiment.

Four tests were developed to assess the objectives of the research, which included theories on the following elements of noise barrier judgement:

- Predetermined assumptions
- The perception of noise attenuation of five standard barrier types when the noise stimulus is kept the same
- The perception of noise attenuation of five standard barrier types at varying sound pressure levels
- The preference of the respondents for each barrier based on its aesthetic qualities

Previous studies investigating the phenomenon of intersensory effects on the perception of soundscapes and noise barriers have used a variety of rating scales, many opting for the use of worded scales such as relaxing/ stressful etc. However, for the purpose of this investigation and in light of the fact that it was not the actual characteristic of the noise that was varying, but the barriers, a numbered scale was used, similar to that adopted by Watts et al (1999), and Aylor et al (1976).

The video clips were played at 5 different sound pressure levels (SPL) increasing by 5dB(A) for each set of 5. By playing the clip and recording the L_{Aeq} for the 23-second duration a recorded base noise level that would reach the respondents was established, this was representative of standing 10m from an average noise barrier adjacent to a busy 6-lane motorway.

Two sets of readings were taken at 2 of the respondent's positions, and gave an average reading of 71.6 dBA, with the variation between the noise levels received at each seat not varying more than 1-2dB. This was judged acceptable as the respondents remained in the same place for the duration of the test, and therefore were always exposed to a comparative noise level. Therefore the five sets of recordings were heard by the respondents at 71.6 dBA, 76.6 dBA, 81.6 dBA, 86.6 dBA and 91.6 dBA, each clip was seen by the respondents with the accompanying audio stimulus 5 times at 5 different noise levels, in ascending order, this made up the sets.

The video clips were incorporated into a computer program designed for the purpose of this research by the Computer Sciences Department (Meredith 2003). This enabled the test to flow uninterrupted and reduced the distraction to the respondents.

8.2.6 A selection of intersensory tests

Test 1 was designed to familiarise the respondents with the procedure; an initial set of each of the visual stimulants were played without the auditory stimulus, and the respondents were told to predict how well each barrier would reduce the traffic noise from behind it. This was achieved by assigning a value between 1 and 5 to each barrier; with 1 representing the quietest (i.e. the response which obtained the lowest values, and was predicted as being the most effective noise barrier) Table 8.1 shows the answer sheet for Test 1.

Table 8.1 Test number 1: (Please predict how well they'll perform by ranking from best)

	Timber	Metal	Concrete	Transparent	Vegetative
(1) Best –(5) worst.					

Test 2 consisted of 5 sets of 5 video clips, increasing in noise level by 5dB(A) at the start of each new set. All the orders were balanced according to a Latin Square experimental design (Dénes 1991) to reduce the effects due to ordering (Watts et al. 1999). The respondents were told to watch the clips, and were then given 5 seconds to note their results, which according to the literature gave enough time to determine their response without forgetting the previous stimulus (Watts et al. 1999). The results of the respondent's perceptions were recorded in a worksheet distributed at the start of the test; a sample from the questionnaire is displayed in Table 8.2(see *Appendix 4B* for full questionnaire). The respondents were given the following instructions, which they read prior to the test commencing:

'This is the main test and you will see and hear the noise barriers in action. You will see that the first barrier to appear is accompanied by the value ***5*** *in the answer table, please give a value relative to this for all the other barriers in that group.*

For example, if you think all the other barriers allow higher noise levels through, give them each values above 5, if you think they are the same you can give them the same value and if you think they are letting less through give them a lower value. Each group of five clips should be judged independently to all the other sets. The values you give must be between 0 – 9, and must be whole numbers'.

The corresponding part of the questionnaire showed a table (5 rows x 5 columns) each row represented a new set, and these were labelled 'sets 1-5', along each row the name of each of the barriers were written in a random order, determined using a Latin Square design to reduce the possibility of ordering. At the beginning of each set, a value of 5 was placed under the first barrier, and the respondents were told that this was the reference noise level, to which all others in that particular set should be judged.

Table 8.2 An example of the questionnaire

	Barrier Types: In the order they will appear. →				
<u>*Set 1*</u>	Concrete	Metal	Vegetation	Timber	Transparent Acrylic
Score 0-9 → Louder	**5**				

The reason for this, rather than a ranking system, was to firstly enable parametric tests to be carried out in the analysis and secondly to reduce the temptation of repeating the replies without proper thought (Watts et al. 1999). The internal consistency of the scales for each of the five sets was tested for reliability. The Cronbach's coefficient alpha value represents a level of reliability in the scale, this statistic provides an indication of the average correlation among all of the items that make up the scale. The Cronbach's Alpha Coefficient value for this test was between .70 and .76, which ensured that the scales were reliable in accordance with the recommendations of Pallant (2001:6).

The respondents were requested not to talk during the test, as there were no right or wrong answers, and were informed that the test aims were to establish their individual personal perceptions. As the respondents were always exposed to the same noise level, a means of reducing the chances of the respondents realising this had to be developed. Therefore, to justify the number of times the tests would be played, the volumes were increased by 5dB at the beginning of each test; however, the increase was identical for each barrier. Following the full description of the test and the hearing test, and when the respondents had been given chance to read through the questionnaire. The respondents were then asked whether they fully understood what was required of them, and whether they had any questions, following this, the test commenced with no further interruption until it was completed. The questionnaire also recorded their age, gender, ethnic background, and department within the University, so that the sample could be tested to see if it was representative.

The objective of Test 1 was to determine any trends in preconceptions on the various barrier materials' abilities to attenuate noise. The objective of Test 2, where the respondents were subjected to the five sets of five recordings at increasing sound pressure levels, aimed to determine whether respondents judge the noise level correctly, 'as all being the same' or whether the visual stimulus of the different noise barriers, meant that some barriers were perceived as more effective than others. This tested to see if any trends remained constant with increased noise levels. The tests included the line of vegetation to assess how effective the respondents perceived this, despite it not being specifically designed as a noise barrier.

The final test, Test 3 asked the respondents to indicate which barrier they found most aesthetically pleasing. This was also tested in conjunction with the results of the acoustic perception, to see whether perception of aesthetics had any links with perception of ability to attenuate noise. The corresponding final section of the questionnaire used a similar procedure as that used in the first section, in that the respondents were asked to use a ranking system, rather than a rating system. They were asked to rank the barriers in order of preference based purely on the aesthetics of the barrier, and as an aid to their decision making, were told to imagine the situation, that a barrier was to be built at the perimeter fence of their house, and therefore they should judge them in terms of what they would like to see.

8.3 Results

8.3.1 The respondents predetermined assumptions of the barriers ability to attenuate noise

The first set of results derived from the analysis of the data, concerned the predictions of how well the barriers would attenuate noise without actually hearing any audio stimulus, thereby analysing the respondent's preconceptions of the barriers abilities to attenuate noise. A Friedman's Test was applied to the data, to determine whether the mean ranks attributed to each of the barriers showed any significant differences. The Friedman's Test is the non-parametric alternative to the one-way repeated measures analysis of variance. It is used when you take the same sample of subjects or cases and you measure them at three or more points in time, or under three different conditions (Pallant 2001: 265).

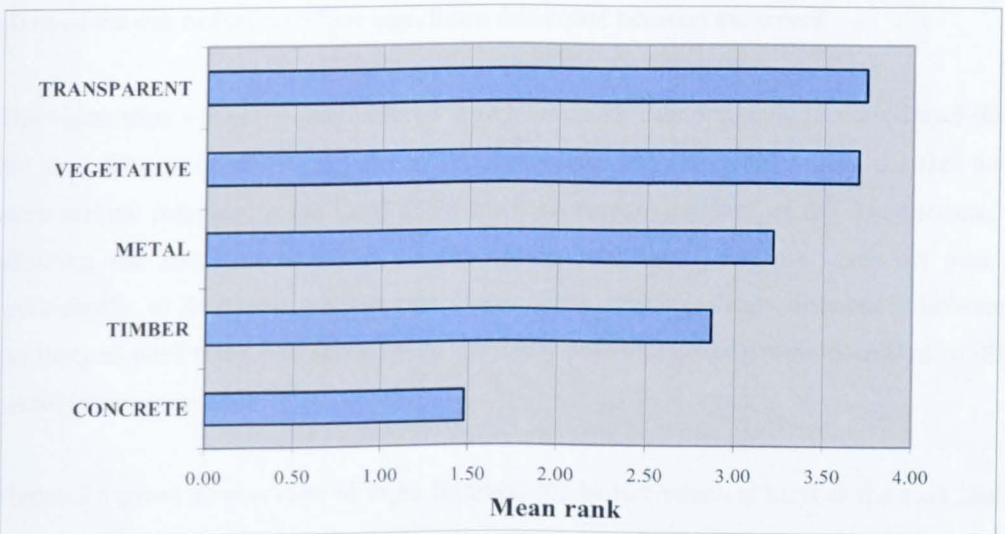


Figure 8.4 Predictions of which barrier has the potential to attenuate the most noise (1 most effective- 5 least effective)
(Chi-square= 31.4; df= 4; p<0. 0005)

Figure 8.4 above, illustrates the findings of this investigation; the values given by each respondent, indicating the frequency of responses from each of the participants, were summed to give the results. The lower the value, the lower the numbers that were most frequently attributed to that barrier type.

Therefore, the respondents predicted that concrete would be the most effective, followed by timber, metal, vegetative and transparent barriers. The results of this test suggest that there are significant differences in the perception of how each of the barriers will perform without listening to them.

8.3.2 Perceptions of the ability to attenuate noise with increasing SPL

The second stage of the analysis investigated the results of Test 2, the null hypothesis developed to test the data therefore stated:

'The respondents will find no significant difference between the barriers ability to attenuate noise, despite the manipulation of the video sequences, to invoke the feeling that the noise levels were changing.'

These results lent themselves to a one-way repeated measure ANOVA test, due to the fact that the data set was made up of one group of subjects measured on the same scale, under five different conditions, with one independent categorical variable (e.g. the noise barriers, 1-timber, 2 -concrete, 3-metal, 4-transparent and 5-vegetation), and one continuous dependant variable (e.g. the rating of the noise level for each barrier 1 quietest – 9 noisiest), the test allowed the determination of any significant difference between the scores.

The video clips were randomly ordered in five sets, with each set being increased by 5 dB(A) at the start. The purpose of this, was to firstly dissuade the respondents from the fact that they were always listening to the same audio track accompanying each of the five barriers, whilst allowing the test to contain an element of repeatability. Therefore, each set was tested individually, to determine whether there were firstly, any significant differences between how the barriers were rated, and secondly, to see if any potential patterns were consistent at different sound pressure levels.

Figure 8.5 gives an overview of these findings, the barrier which is used as the base line noise level for all the other barriers to be judged from, in each particular set can be seen at a constant of 5. The other values within each set are the mean values given by each of the respondents, under each of the different conditions and are illustrated in Table 8.3 along with the number of respondents involved in the investigation and the standard deviation about the means.

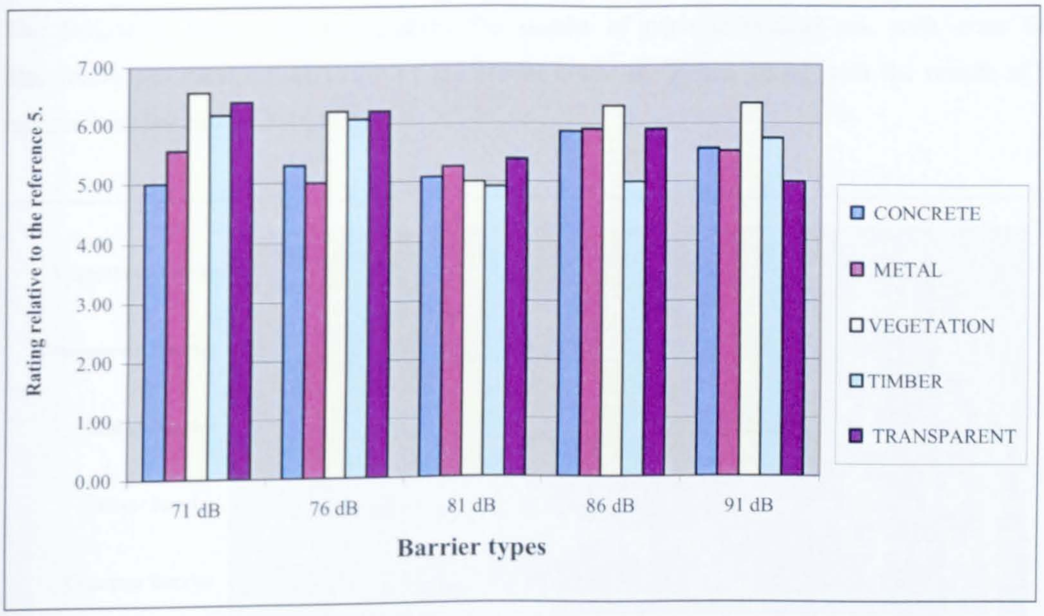
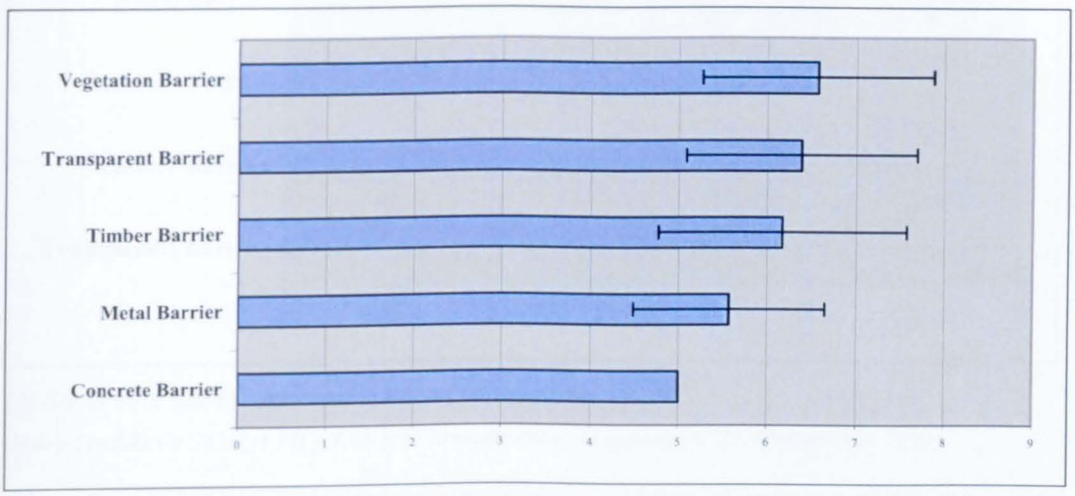


Figure 8.5 The results of the perception exercise at the five different sound pressure levels

Table 8.3 Tabulated results in random order in which they were presented. (n= 23)

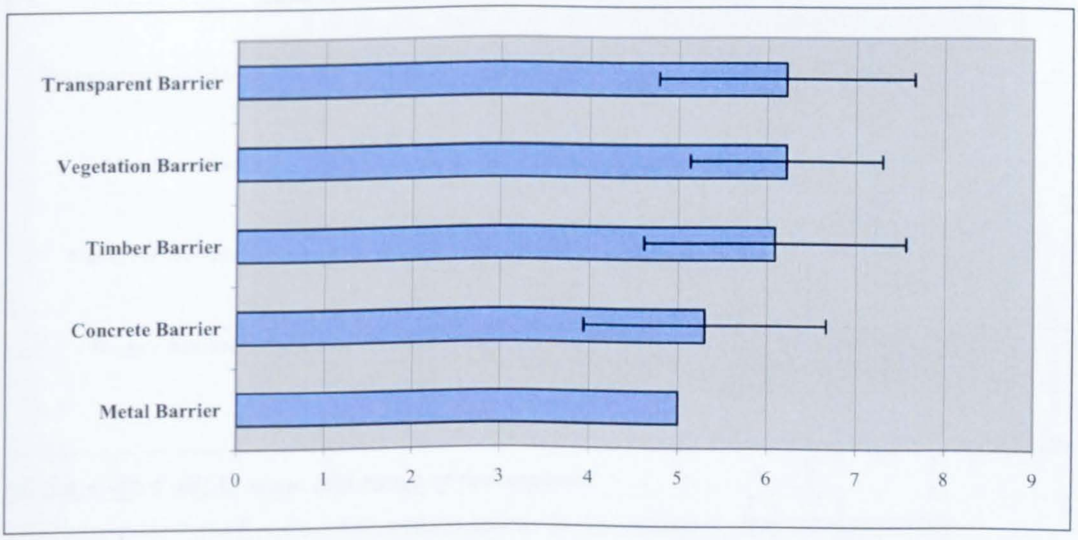
Set and SPL	Barrier type	Mean	Std. Deviation
Set 1 71.6 dB(A).	Concrete	5.00	0.00
	Metal	5.57	1.08
	Vegetation	6.57	1.31
	Timber	6.17	1.40
	Transparent	6.39	1.31
Set 2 76.6 dB(A)	Metal	5.00	0.00
	Vegetation	6.22	1.09
	Transparent	6.22	1.45
	Concrete	5.3	1.36
	Timber	6.09	1.47
Set 3 81.6 dB(A)	Vegetation	5.00	0.00
	Transparent	5.39	1.34
	Timber	4.91	1.59
	Metal	5.26	1.36
	Concrete	5.09	1.31
Set 4 86.6 dB(A)	Timber	5.00	0.00
	Concrete	5.87	1.22
	Metal	5.91	1.44
	Transparent	5.91	1.86
	Vegetation	6.30	1.46
Set 5 91.6 dB(A)	Transparent	5.00	0.00
	Timber	5.74	1.66
	Concrete	5.57	1.53
	Vegetation	6.35	1.37
	Metal	5.52	1.70

The following Figure 8.6 (a-e), show the results of each individual set, with error lines illustrating the standard deviation of the scores about the mean, along with the results of the repeated measures ANOVA test.



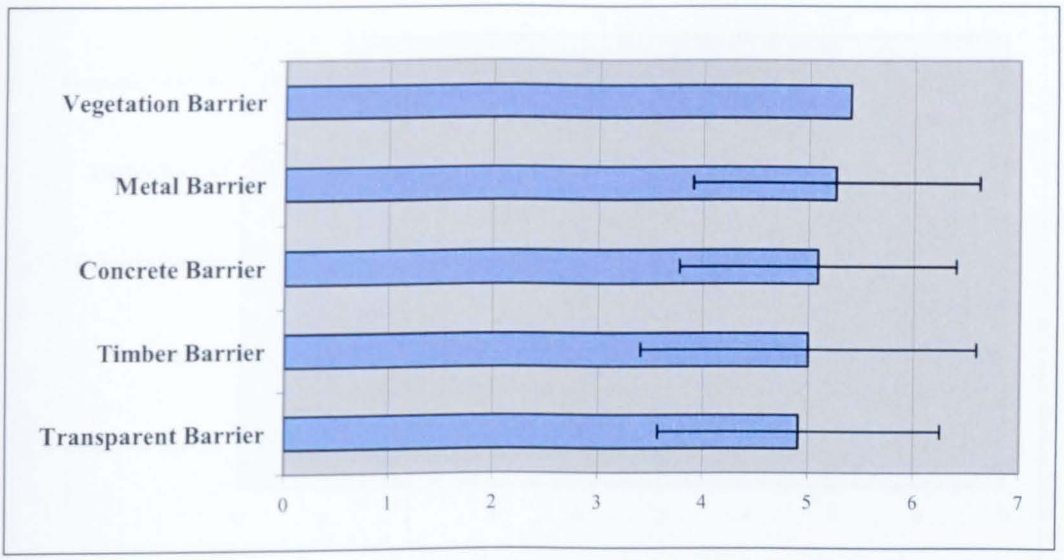
(a) Set 1- 71.6dB(A) Mean and range of perceptions

(Wilk's Lambda =0 .288, F (4,19)= 11.76, p<0 .0005, multivariate eta squared =0 .712(Pallant 2001:229.



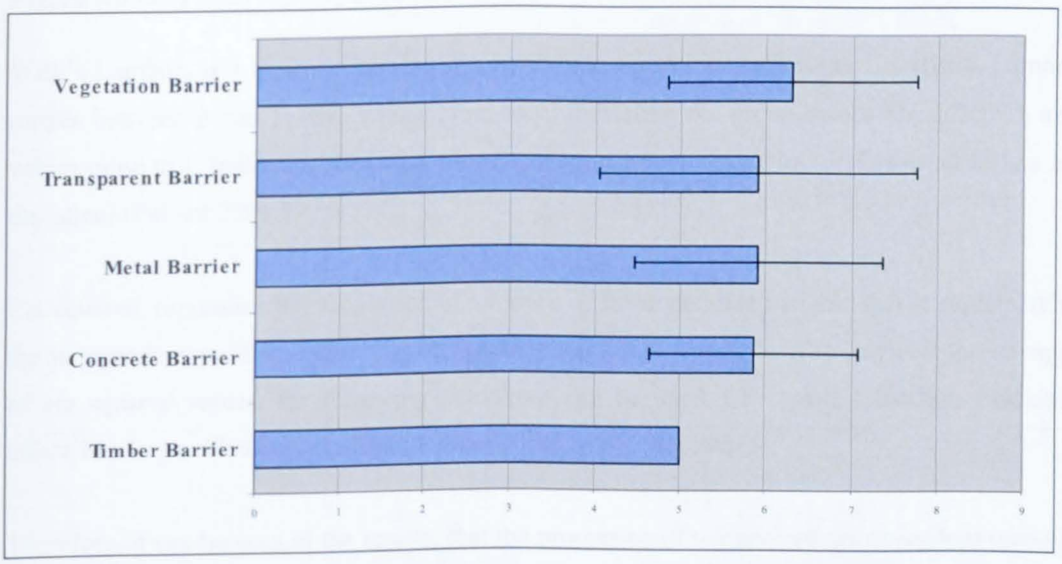
(b). Set 2- 76.6 dB(A). Mean and range of perceptions

(Wilk's Lambda =0 .225 F (4,19) = 16.33, p<0.0005 multivariate eta squared =0 .775(Pallant 2001:229)



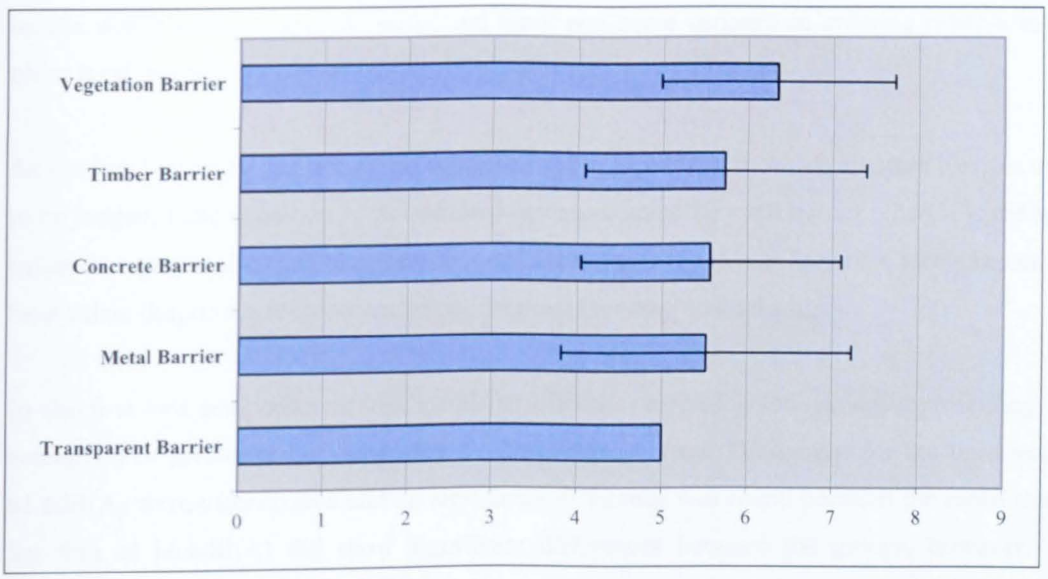
(c) Set 3- 81.6 dB(A) Mean and range of perceptions

(Wilk's Lambda =0 .783 F (4,19) = 1.32, p<0.30 multivariate eta squared =0 .217(Pallant 2001:229))



(d) Set 4 -86.6 dB(A) Mean and range of perceptions

(Wilk's Lambda =0 .466 F (4,19) = 5.45, p<0.004 multivariate eta squared =0 .534(Pallant 2001:229))



(e) Set 5- 91.6 dB(A) Mean and range of perceptions

(Wilk's Lambda =0.410F (4,19) =0 6.8, $p<0.001$ multivariate eta squared =0 .590(Pallant 2001:229)).

Figure 8.6 (a-e) The results of each individual set of results at each noise leve.

Wilk's Lambda, is a multivariate test of significance, sometimes called the U statistic, Lambda ranges between 0 and 1, with values close to 0, indicating the group means are different, and values close to 1, indicating the group means are not different (equal to 1 indicates all means are the same) (Pallant 2001:199).

Eta squared, represents the proportion of variance of the dependant variable that is explained by the independent variable, values for eta squared can range from 0 to 1, to interpret the strength of eta squared values, the following guidelines can be used; 01= small effect.06= moderate effect.14= large effect (Cohen 1988; Pallant 2001; SPSS.com 2001).

Therefore, it can be seen in the results, that the proportion of variance of the dependant variable that is explained by the independent variable, is greatest at the lower noise levels, not relevant as the findings are not statistically significant for 81.6dB(A) set 3, and then moderately effecting the results at 86.6, 91.6dB(A). The lower values are more representative of that which a person standing 10m from a carriageway edge, with free flowing traffic, would be exposed to; this can explain the strength of these statistical relationships.

Figures 8.6(a-e), illustrate that the respondents did perceive the noise attenuating properties of each material differently, despite the fact that they were always listening to the same audio stimulus each time. The use of increasing SPL helped to distract from the fact that each noise source within each set was the same, and there was some variance in ordering relative to the noise level increases.

As the first barrier played in each set was used as the base level, to which all other barriers were to be judged, there is obviously no standard deviation value for each barrier when it is the base value. The graphs illustrate that there was not much tendency to rate the noise levels below the base value, despite the respondents being informed that they could do so.

In the first two sets, concrete and metal consistently received a low rating, representing the perception of greater noise attenuation by these barrier types. The results for the third set, at 81.6dB(A) were inconclusive and no significant difference was found between the mean ranks. Set four at 86.6dB(A) did show significant differences between the groups, however, the strength of this relationship is not as strong as for that presented in the results of the first two sets, nevertheless timber, concrete and metal were still perceived as more effective than the vegetation and the transparent barrier.

The final set, which was played to the respondents at 91.6dB(A), led to the illustration of significant differences between the perceptions of the barrier types, however, this is the only set where the transparent barrier is deemed more effective than the rest. This could however, be influenced by the fact that it was presented as the base value of 5, and therefore the judgements could have been more influenced, than if the barriers were all judged relative to a sound stimulus alone, played prior to the presentation of the audio and video clips together.

The vegetation consistently had the highest or equal highest mean ranking at all the sound pressure levels. This is very interesting, as it is usual that vegetation can give a sense of noise attenuation, despite its lack of actual practical ability to attenuate noise significantly at a depth of less than 20m (Watts et al. 1999). However, it must be considered that some of the sample were architecture students, and so may have had some knowledge on this factor through previous work. Nonetheless, this illustrates that the perception of a purpose built barrier did invoke a greater perception of noise reduction, despite this being based purely on its visual attributes rather than a real reduction in noise level.

The perception of the transparent barrier's inefficiency at attenuating noise, was further compounded by the fact that in all of the tests showing significant differences between 71.6dB – 86.6dB, the transparent barrier was always ranked less effective than the concrete, metal and timber barriers. This finding is in contrast to that of Watts el al (1999), and Aylor et al (1976)

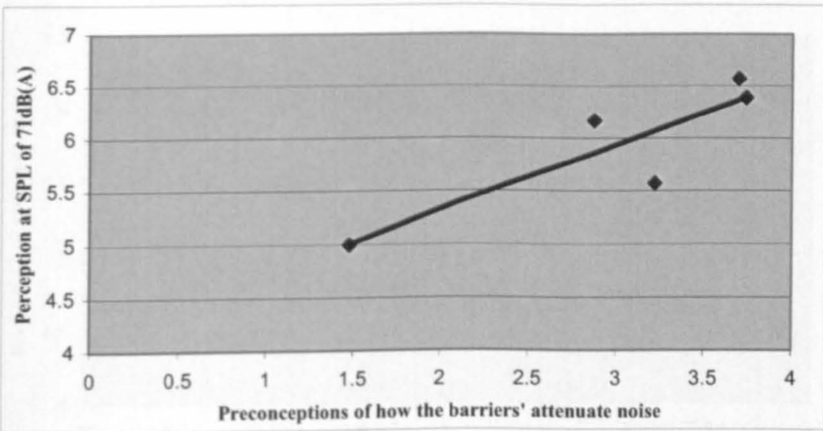
Mulligan et al (1987) who discovered, that when the respondents could see the sound source through the barrier, they actually overestimated its ability to attenuate noise.

They attributed this to a phenomenon described as false expectations, where by when a sound source is visually screened, a listener expects its loudness to be significantly diminished, perhaps in the same manner that light from a source is diminished, when the observer moves into the shadow cast by a fixed source. However, due to sound transmission directly through the foliage of vegetation screens, used in their experiments or significant diffraction of the sound waves around the solid screens, the reduction in noise could be less than expected by the listeners, this would result in the sound source being overestimated in terms of loudness when visually screened (Watts et al. 1999).

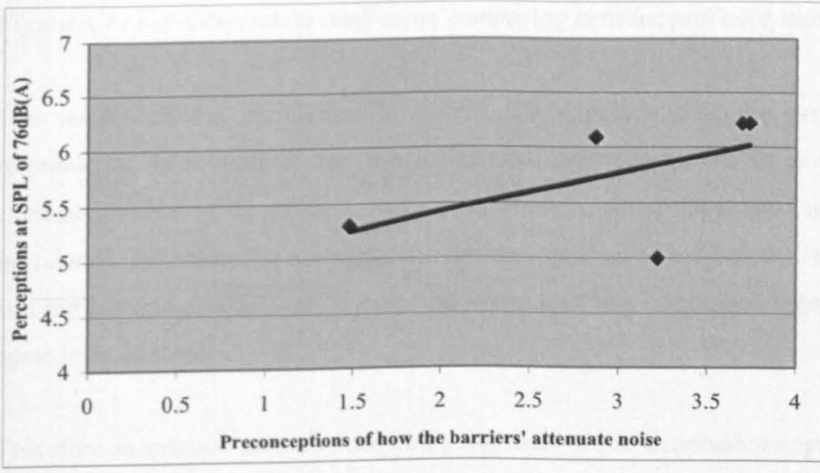
The opposite effect was found by Viollon (2003), who determined that when noise was heard in the wrong context, such as traffic noise in a wood, that the respondents found it more disturbing than in a realistic environment such as alongside a road. Although the respondents in this investigation were not watching a visual stimuli out of context per-se, the fact that the vegetation was present next to the motorway, and it was evident that the recording had been made in a field, could have yielded more negative responses, as the presence of traffic noise close to an area of vegetation was deemed inappropriate.

The repeatability of the experiment did show some patterns, as trends did appear and consequently, it would be interesting to see whether the patterns would be more evident with a larger sample of respondents. Additionally, the method of using a sound stimulus as a tone, played at the beginning of the recordings, without a visual stimulus being shown, could provide a more effective auditory stimulus for the respondents to make a comparison to. In previous studies where the noise levels do vary, such as that undertaken by Mulligan et al (1987), a stimulus tone was played through headphones to the right ear prior to hearing the sound source to be compared through the left ear.

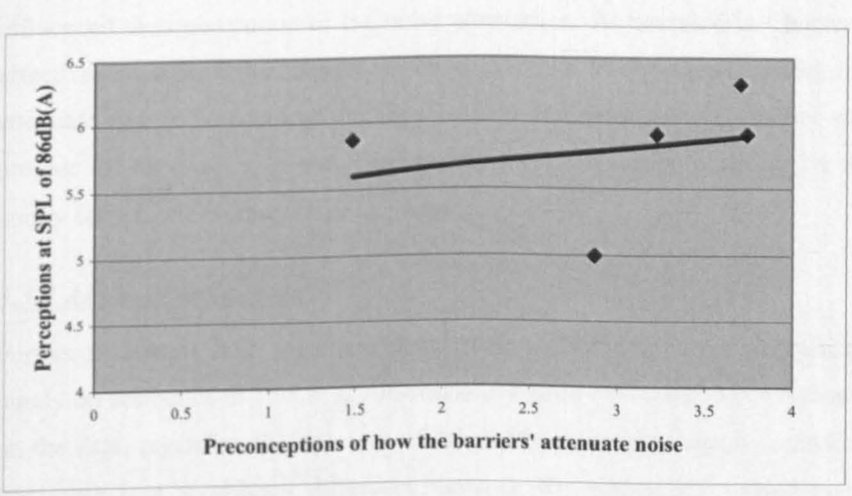
To determine how the respondent's preconceptions had influenced their perceptions of the barriers abilities to attenuate noise, the findings of Test 1, were compared to the perceptions revealed in Test 2. Figure 8.7 (a-d) show the correlation coefficients of the relationships between the Test 1 and Test 2, excluding the test undertaken at 81.6dB(A), as this did not show any significant relationship between the respondent's replies.



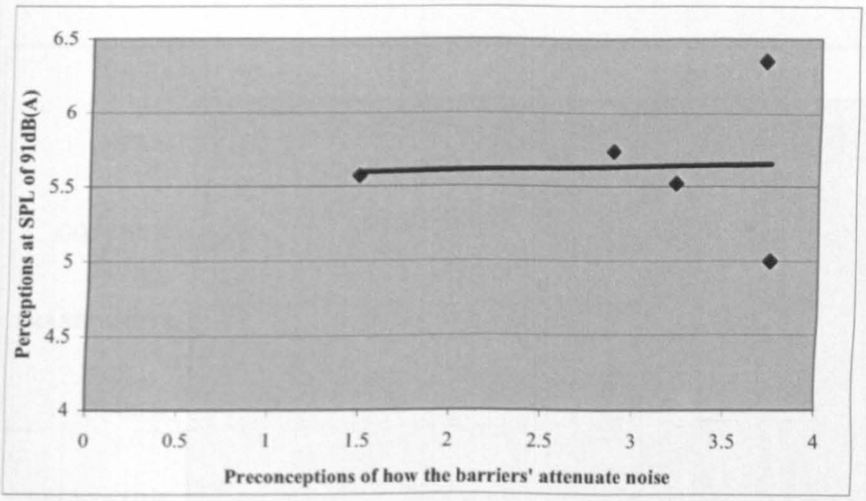
(a) SPL 71dB(A) ($R^2 = 0.6$)



(b) SPL 76dB(A) ($R^2 = 0.3$)



(c) SPL 86dB(A) ($R^2 = 0.1$)



(d) SPL 91dB(A) (R^2=0.003)

Figure 8.7 (a-d) Correlation coefficient, comparing between preconceptions and perceptions.

The results of the correlation in Figure 8.7 conclude that the preconceptions that the respondents' held prior to the test influenced their perceptions of how the noise barriers' attenuated noise, at the lower sound pressure levels, when the second modality of sound was introduced. As before the strongest correlation was shown between the 'preconception' results, and the test run at a SPL of 71.6dB, the strength of this correlation tapered off the higher the noise level became.

Therefore in relation to the wider thesis question of the sustainable approach to noise barrier design, with respect to the perceived effectiveness of a noise barriers ability to attenuate noise, the concrete and timber were the most effective, and the preconceived ideas of the respondents' influenced their perception of the noise attenuation. As revealed in Chapters 4 & 5, perceived effectiveness is as influential as objective evidence on the overall ability of a noise barrier to attenuate noise. Thus, these findings lead to the assertion that timber and concrete would provide the most effective and consequently most sustainable materials for noise barriers based purely on preconceptions and perceptions.

8.3.3 Aesthetic influences

Further to Tests 1 & 2, the respondents rated vegetation as their most preferred barrier based purely on aesthetics in Test 3, as illustrated in Figure 8.8 below. The Friedman's test undertaken on the data, regarding the opinions of the residents on the barriers aesthetic qualities, showed that there is a significant difference between the respondent's preferences of the different barriers based purely on aesthetics, with the choices in terms of popularity being vegetation most, timber, transparent, concrete and least popular metal.

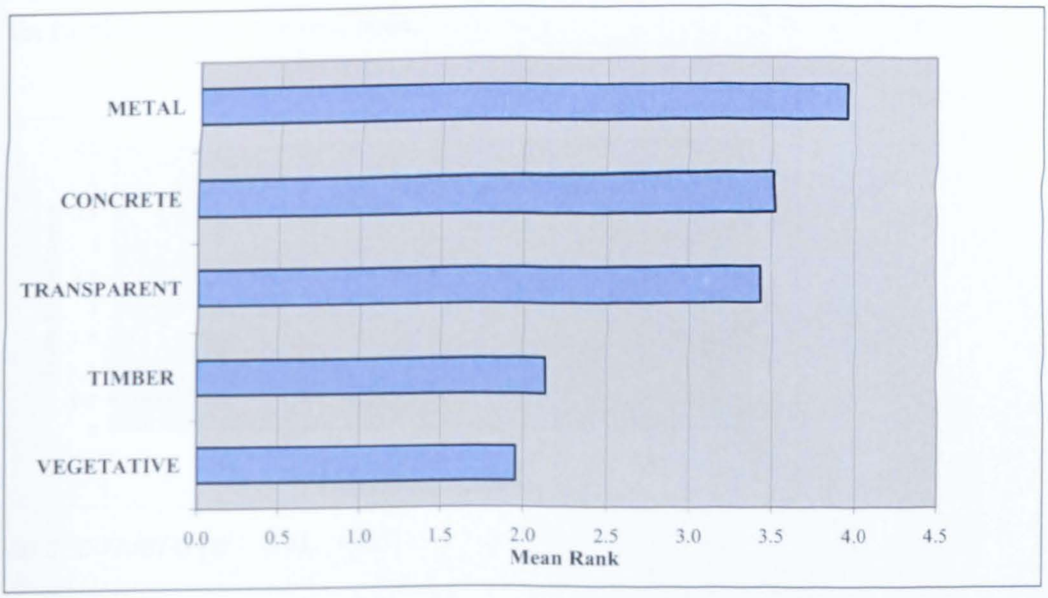


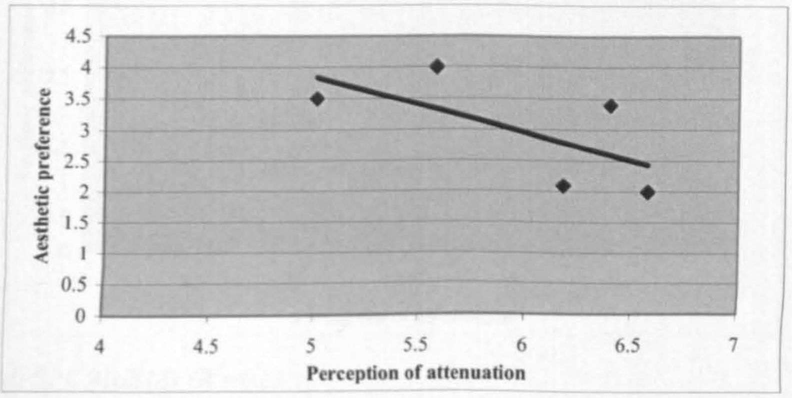
Figure 8.8 Results of respondents preference based on aesthetics alone (1most - 5 least attractive)

(Chi-square = 29.6; df = 4, o =<0. 0005)

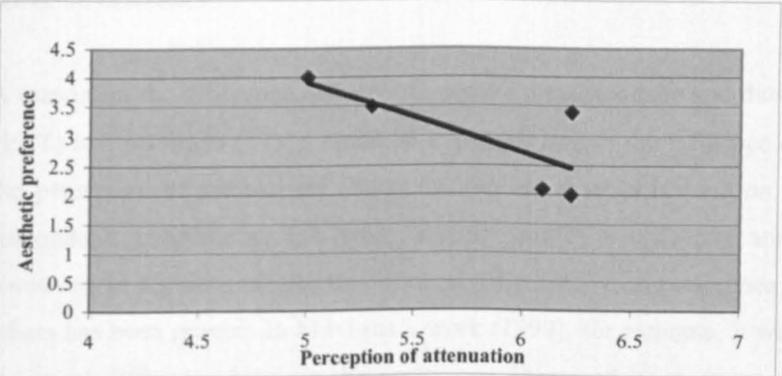
The order, with which the barriers were rated in Test 2, for the judgement of their noise attenuation, shows varying patterns than that of the rated values based on opinions over aesthetics. This is contrary to the findings by Watts et al (1999), that the barriers deemed more aesthetically pleasing to the respondents are perceived as more effective at attenuating noise. They determined that the low noisiness rating given to the willow barrier used under an experimental control was related to the fact that it had been judged aesthetically pleasing by the respondents.

This puts into question the influence of aesthetics on the perceived effectiveness of noise barriers. Figure 8.9 (a-d), tests this influence by correlating the answers that the respondents gave with regard to their preferred barrier, based on aesthetics, against their perception of the noise attenuation at each sound pressure level. The results of which, show that there is a negative correlation at 71.6dB(A), 76.6dB(A) and 91.6dB(A), which means that the most aesthetically pleasing barriers were not perceived as the most effective. The results at 86.6dB(A) are inconclusive as no statistical correlation can be found between them.

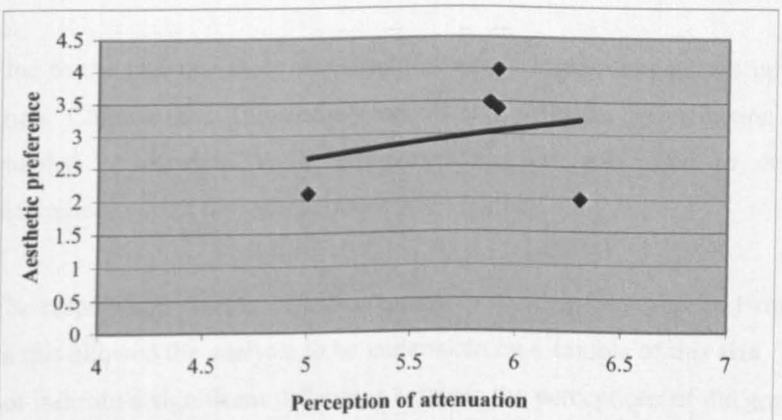
The results demonstrated that the vegetative, transparent and timber barriers were the most aesthetically pleasing, but they were not deemed as effective at reducing noise, relative to the barriers that were deemed less attractive, such as concrete and metal. This further compounds the fact that although aesthetics are important, that they are not incremental in the judgement of the barriers ability to attenuate noise.



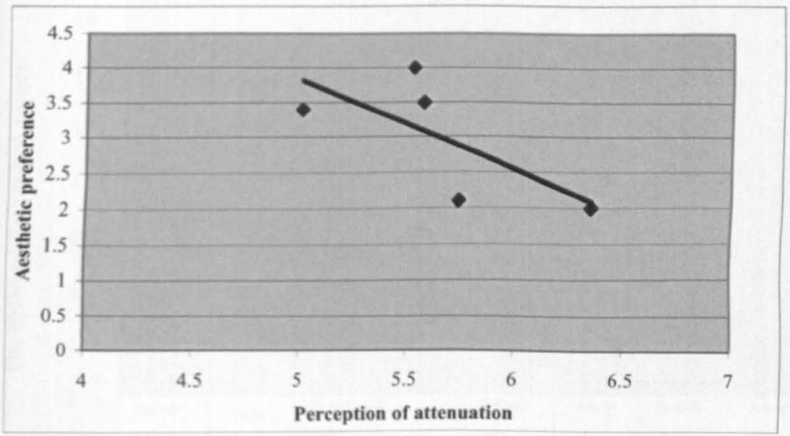
(a) SPL 71dB(A) (R^2 = 0.4)



(b) SPL 76dB(A) (R^2=0.6)



(c) SPL 86dB(A) (R^2=0.06)



(d) SPL 91dB(A) (R^2=0.5)

Figure 8.9 (a-d) Perception of attenuation correlated against ranked preference of the barriers based on aesthetics

A reason for the difference between the results presented here and those of Watts (1996), Aylor (1976) and Mulligan (1987), could be explained due to the influence of ethnic background, on the perception of the barriers ability to both attenuate noise and on its aesthetic appeal. The respondents used during this study cannot provide a definitive answer on this possibility. However, in previous studies the influence of ethnicity on preference for various barriers over others has been proven. In Md-Taha's work (1999), for example, it was found that there was a statistical difference between the preference expressed by a group of respondents of Welsh origin and those of Malaysian origin.

Due to the fact that there was a mix of ethnic backgrounds made up largely of either British/ Irish, Chinese and Taiwanese respondents, a further investigation into this influence was enabled. A Kruskal-Wallis non-parametric test was used to determine any significant differences within the sample under investigation.

The respondents were grouped according to whether they were of British/ Irish origin or Asian, as this allowed the analysis to be undertaken on a sample of this size. The results of the test did not indicate a significant difference between the perceptions of the groups; however, the results indicated by the mean ranks in Figure 8.10 illustrate the trends. These could be further tested on a larger sample, to find if there are any major differences between people of different ethnic origins, however, this is beyond the scope of this investigation.

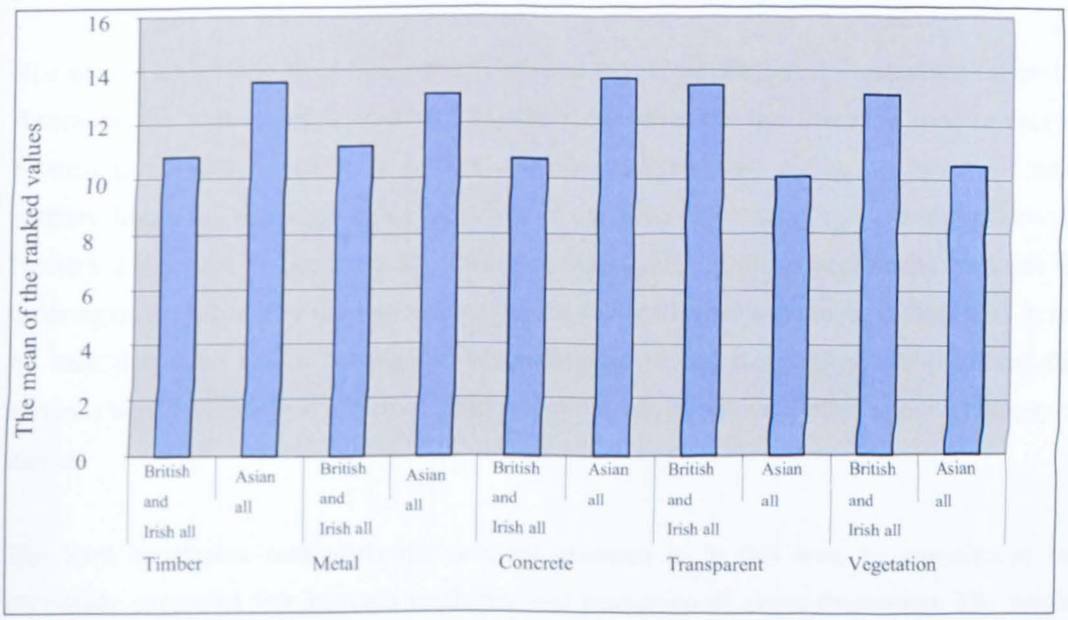


Figure 8.10 The higher the ranked score the more respondents perceiving the barrier as least attractive

8.4 Discussion and conclusions

Three conclusions can be drawn from this research, the first regarding preconceptions, as illustrated in Figure 8.4 indicates that regardless of which noise barrier is presented to the respondents, that preconceptions of a materials' ability to attenuate noise are imbedded. The results showed that the majority of the respondents, based purely on preconceptions, predicted the concrete barrier to be the most effective noise attenuator, followed by metal and timber.

These preconceptions were reflected in the results of the perception exercise as well, with the respondents largely perceiving the more solid looking and opaque barriers as more effective at attenuating noise, despite the noise source being held constant. A strong significant correlation was found between the preconceived ideas and the perceptions at the lower SPL, indicating that preconceptions are influential on perceived noise reductions.

When this fact is considered in relation to the wider question of sustainability, it can be concluded that barrier designers should gauge an understanding of whether preconceptions can be addressed, prior to the ultimate decision on which barrier type to opt for. Both the gauging of how the potential recipients of a noise barrier preconceive certain options, as well as addressing these preconceptions with accurate dissemination of information, could be achieved during the public participation phase of the noise barriers development. Consequently, reducing further the risk of rejection of a noise barrier based purely on perceived ideas.

The second conclusion from this research informs two areas. Firstly, it illustrates a method to determine the impacts of intersensory reactions and develops the literature base to include modern technology by enabling a more accurate understanding of the perception of noise barriers. Secondly, whilst giving an indication of the likely direction of opinion towards certain barriers. Figure 8.4 in Section 8.3.1 illustrates the significant differences found between the ordering of the barriers by the respondents. As the figure illustrates the mean of the ranks, it can be seen that even before hearing the accompanying sound, the respondents predicted that concrete would be the most effective, followed by timber, metal, vegetation and the transparent barrier.

The third conclusion contradicts the previous research in to this area, by questioning the previously suggested link between aesthetics and perception of noise attenuation. The results showed that the transparent and deciduous vegetation barriers, judged most aesthetically pleasing, were inferior to those judged as most effective at attenuating noise (e.g. concrete barriers). A negative correlation was illustrated between the Test 1 and Test 3 results, indicating that this relationship was statistically significant. This is an important factor, as should the previous research have informed decisions about barriers, based on the premise of 'aesthetically pleasing equals an increased perceived noise reduction', then inappropriate barriers may potentially have been adopted for an area.

In relation to the thesis question of determining a sustainable approach to noise barrier development, this investigation proves that there are inherent preconceptions with regard to a noise barrier's effectiveness, based purely on subjectivity. Consequently, it can be predicted that should a choice be made that does not reflect the preconceptions of beneficial materials, then this would transpire to a feeling of disappointment from those the barrier would be built to protect, based purely on its visual and material qualities.

This further illustrates the wide-ranging influences on the success and acceptance of noise barriers, which in turn influences noise barrier sustainability. Previous case studies, as highlighted in the literature review, have proven the strong negative perception that can be held by residents adjacent to a barrier they find visually inappropriate. If this is combined with the potential impacts for perceived negativity through inappropriate public participation procedures, and the potential environmental impacts from a lack of lifecycle assessment utilisation, then the potential for a noise barriers acceptance and consequent overall sustainability can be severely compromised.

The result of this research is a new technique for assessing the impact of intersensory influences on noise barrier perception beyond that developed by previous research. The technique developed here used a more realistic means of undertaking a perception exercise of this type without compromising the controls inherent in a laboratory investigation. Therefore, the findings of this research question that already produced by previous researchers in the field, and illustrate a method, which can be repeated to further qualify the results in future experiments.

Chapter 9 Conclusions and Further Research

9.1 Research findings

The aim of this thesis was to devise and investigate a 'sustainable approach to noise barrier design'. As discussed in the literature, many areas of noise barrier development have been and are currently being researched. Through the extensive review of the literature, it became apparent that the influence of non-acoustic parameters has been researched, but to a lesser extent than other barrier aspects, and consequently the incorporation of these important factors are not integrated sufficiently into real policies in the UK.

This thesis was undertaken to illustrate the importance of sustainability as a key determinant of a noise barrier's success. Presented as five distinct investigations the findings confirmed the importance of public participation (PP) as a means of increasing acceptance of noise barriers', through the demonstration of the impacts of ineffectual PP on a diverse section of the community. The means by which the PP process could be focussed, was demonstrated through adopting and manipulating noise mapping technology, to indicate where resources could be focussed, removing the element of chance, which leads to ineffective PP. Additionally a method for the full lifecycle assessment of noise barriers' was also revealed, which illustrates not only the means of choosing a noise barrier based on sustainable assets, but also the problems of choosing barriers without a methodology to use as a guide. Finally, the thesis concluded with a laboratory experiment that revealed the extent to which preconceptions play a role in the perception of a noise barrier's effectiveness. This in turn enforces the need for effective public participation, which can disseminate information to those that are to receive a barrier. This would be beneficial, as it would give the opportunity to, explain the objective impacts of noise attenuation, whilst also providing a means and opportunity of determining the likely perceptions, prior to a noise barriers construction. A detailed account of the contributions presented in this thesis is described below.

The first section of the research was undertaken through integration with individuals of a community that had recently received a noise barrier. The purpose being, to approach a community for their opinions in an alternative manner, than that which had been undertaken for the barrier projects design. The reason for this bottom up approach, which utilised a semi-structured interview, was that it gave the freedom for opinions to flow, without the researchers preconceived ideas of the situation, clouding the responses.

This approach favoured by feminists, enabled issues that informed opinions to be unearthed, that might not necessarily have been obvious through more traditional means of data collection, such as ordinary questionnaires. Through the application of the grounded theory approach, analysis of the qualitative data was generated into a theory by achieving a close fit between the concepts raised by each respondent.

The theory concluded, it is not only a lack of public participation that can invoke negative perceptions of a noise barrier's effectiveness, but equally influential is the adoption of an inappropriate method, that is ineffectual at accessing and involving all effected members of the public into the public participation process. Of those who attempted to become involved a strong sense of disenfranchisement was apparent, as their opinions were neither actively sort nor adopted.

A positive finding of the research was the overall willingness to become involved in the process, where as the 'public' is often branded as apathetic, the interviews illustrated a keenness and awareness of locally salient issues, and a desire to share responsibility in the processes of addressing them. These feelings were not confined to the individuals that worked within and for the community as volunteers and professionals, but included people of all genders, ages, and ethnicities.

Consequently, the first main contribution emerged with respect to the ineffective use of public participation. The impact of the restrictions imposed by a limited budget on those endeavouring to undertake public participation was also derived through the analysis. These limits restrict the capabilities of Highways Managers to undertake effective PP, and consequently the broad and ineffective methods of information dissemination through public meetings are favoured.

A general lack of trust between the professionals and the public was also highlighted, with the public perceiving their role currently as largely ineffectual, which consequently lead to a general feeling of hopelessness when attempting to integrate. The professionals, on the other hand, perceived the public as largely incapable of grasping the concept of realistic commercial constraints. They see no merits in offering integration when the public will not fully understand these limitations. This problem would be significantly diminished, should methods for effective dissemination of facts be adopted, which impart non-technical and realistic expectations of a noise barrier's abilities.

The findings of the qualitative investigation were developed to determine how this ineffectual public participation had actually influenced the perception of noise reduction. This was undertaken through a 'triangulation' of methods using the qualitative results as the basis for the quantitative investigation.

This was successfully achieved, with all three areas impacted upon both by the barrier and by the public participation process being studied. The findings of this section of the research developed the theory, that a lack of effective public participation negatively impacted on the perception of the barrier's effectiveness at mitigating noise, with 89% of those interviewed either stating 'no change' or 'increases' in noise levels post construction. In addition, the existing method adopted by the Highways Agency for public participation, was found to ostracise large proportions of the community, with 72% of those interviewed revealing that they were unaware of the local forum that had been adopted by the Highways Agency as the focal point of the PP process.

As noted in the literature review, and the findings of Chapters 4 & 5, the use of the traditional patriarchal methods of public participation, associated with a 'tokenistic' approach, are responsible for feelings of exclusion, and disenfranchisement that can lead to a negative perception both of a noise barriers benefits, as well as the souring of the relationship between 'experts' and the public. This loss of influence by the public on projects, which are of great importance to them, has negative repercussions both on the project at hand, and also for future projects. Conversely, with the integration of the public into the decision process, a feeling of ownership can be restored, which would not only manifest itself in improved acceptance of the benefits of a noise barrier but also more widely in social and economic terms.

The importance of PP relative to distance from the noise source was also revealed. Although this seems a likely relationship, the existing method of PP does not fully reflect this. As those most likely to have their opinions heard, were not necessarily those most adversely affected, but those most likely to present themselves at public meetings. It is therefore proposed, that having the ability to attend a public meeting and being amongst the vociferous minority, should not be the qualifying criteria for being integrated into the planning and design process of a noise barrier. The qualifying criteria should be the salience of the problem to the individuals, based on their properties location and received noise level, regardless of ethnicity, language barriers, mobility restrictions, commitments and other potentially limiting factors.

In conclusion, the contribution of this part of the study alludes to a relationship between effective communication and successful noise barrier development. The results also illustrate that one method of participation, does not necessarily suit all members of a community, but that there are correlations in the preferred approach between subsections of the community. Thus, if these subsections were identified prior to participation, then a mixture of methods could be adopted to generate the best outcome.

These findings are very important and relate directly to the ratification of the Arthus Convention, with its requirements for genuinely accessible participation for all members of the public. It will no longer be just an issue of under representation, but a breach of statutory obligations if the public are not fully involved, which in turn impedes the sustainability of a project.

An effective approach of realising a more focussed type of PP within the financial constraints of a public project was illustrated. By revealing how a narrowing of the target for inclusion in the PP approach could be devised. The solution for this was proposed by utilising the new technology of noise mapping.

The areas that had received the noise barriers were noise mapped, and the values of noise reduction at each of the samples' properties before and after the noise barrier's construction were calculated. The findings showed that of the respondents to the qualitative questionnaire, that 24% of their properties had gained a perceivable noise decrease post construction, but of these 81% had perceived either no change, or an increase in noise levels. Therefore, it was concluded that the disparity between the objective reduction in noise levels, and the subjective perception in noise levels, could be related to the consequences of the ineffectual public participation.

Therefore, it is concluded that by using noise maps before the public participation process is undertaken, those who would be directly affected by the barrier installation can be identified. This in turn would enable noise barrier providers to focus their efforts on those for whom the issue is most salient to. Allowing the resources for the process to be more effectively utilised, and remove the necessity to use ineffectual public meetings. This approach could actually reduce the amount of money ordinarily spent on arranging public meetings, as the resources could be focussed into more specific and economically viable solutions, for example, by using the Internet or focussing on directly affected public areas such as local schools, surgeries and shops, for more informal propagation of information and collection of opinions and discussions.

The opportunities to develop a sustainable noise barrier, were further investigated when it was revealed that currently there is no specific methodology for undertaking life cycle assessment's for these particular structures. The choice of preferred noise barriers currently lies foremost on an ability to mitigate the noise problem at the best available cost. This cost is invariably accounted for, primarily as an initial economic one, overlooking largely the potential environmental costs that are also attributed to it. Within the constraints of a commercially viable business this is understandable, despite this the Highways Agency and other noise barrier providers are also obligated to act in an ever increasingly environmentally benign manner, and show commitment to this by subscribing both to there own environmental strategies in addition to those enforced by the Government.

Therefore the lack of an efficient means of assessing noise barriers' sustainability, results in choices being made that cannot fully oblige their objectives of operating in line with good environmental practise. Thus, an approach was devised by adopting the existing frameworks laid out by the BRE, and other lifecycle assessment programs, into a specific methodology for the assessment of the lifecycle impacts of noise barriers.

The result of which, was a comprehensive and systematic list of, the expected use of non-renewable resources, embodied energy and pollutants emitted, from nine of the most commonly available noise barrier materials on the market. The first section of the lifecycle assessment known as the 'cradle-to-grave', gave a full account of the most to least environmentally sustainable materials, weighted in accordance with the impacts on wider environmental problems, such as global warming, atmospheric and water pollution. The findings of the 'cradle-to-gate' concluded, that timber was the most environmentally sustainable material to be used in a noise barrier structure, followed by recycled aluminium, recycled steel, precast concrete, living willow, woven willow, PMMA, un-recycled steel, and the least environmentally sustainable being un-recycled aluminium.

The impacts of material transportation and maintenance beyond the factory gate up to the point of disposal are an equally important factor influencing a material's overall sustainability. An increased release of environmentally harmful pollutants and greenhouse gases, during the processes from 'gate-to-grave', can change the balance from a sustainable material to a relatively unsustainable material dramatically.

Equally, the impacts of recyclability at the end of a barrier's useful life also creates a large determining factor on how sustainable materials can be. The impacts of recycled materials from 'gate-to-grave' show a dramatic influence in the 'cradle-to-gate' analysis, with aluminium and steel changing from one of the least environmentally sustainable noise barrier choices, to one of the most environmentally sustainable based on recycling alone. Equally, the disparity between the environmental claims of the willow barriers, and the reality of the environmental impact caused by the use of the mineral wool inner core, illustrates the importance of noise barrier providers such as the Highways Agency having a method of independently evaluating the real sustainable assets of each available barrier.

This thesis provides an illustration of the recyclable potential of each of the nine pollutants, along with the expected benefit that this recycling would have on the overall sustainability of the materials. As with transportation, the balance of sustainability can be significantly changed with and without recycling, and therefore the opportunity for end of life recycling must be explored in addition to all the other decisive factors that influence a final decision on the most appropriate barrier. The encouragement of end of life recycling is like all other areas of the lifecycle subject to the impacts of transportation. In that, a barrier that is recycled in a vastly different location from that where it was used may reduce its overall sustainability, therefore a noise barrier provider should factor the feasibility of local recycling and or disposal into their decision.

Thus, it can be concluded that a material should be chosen for its sustainable assets based on a full lifecycle assessment, and without this, materials that may seem to be sustainable, may inadvertently result in greater environmental damage. The use of the data set compiled in this thesis, as well as the framework displayed in Figure 7.7, allow the values derived for the hypothetical scenario to be tailored to a real world scenario within the UK. This adaptation can be undertaken by simply altering the values of weight, to reflect individual case studies, and can be used to inform future decisions on noise barriers, that incorporate all of their impacts from 'cradle-to-grave'.

The final conclusions were established using a laboratory investigation, to demonstrate the effects of preconceived perceptions on potential sustainability and perceived effectiveness. The findings of this section were three fold; firstly a new method was established for determining the impacts of intersensory perceptions of perceived effectiveness. This expanded work from previous researchers to increase the realism of the laboratory experiment.

The use of the Reflex studio, demonstrated how respondents could be exposed to noise barriers working in-situ, whilst retaining the controls implicit in using laboratory conditions. To use the Reflex studio in a real world scenario would obviously be impractical, however, the principal of displaying a selection of barriers in-situ, would be possible and effective using a standard film projection. This would firstly give the opportunity to gather information about the community's preferences. In addition, to giving an opportunity for the barrier providers to disseminate information, with regard to realistic expectations of the barrier's potential.

The second conclusion of this investigation, was related to preconceptions, the findings illustrated that the sample had preconceived ideas of how each barrier would attenuate noise. These preconceptions extended to their perceptions of how each barrier worked, with the concrete, metal and timber barriers being consistently rated as better noise attenuators, than the transparent barrier and vegetation, even when the noise source was kept the same. When the preconceptions found in Test 1 were compared to the perceptions found in Test 2, this relationship remained evident, especially at the noise levels most representative of being adjacent to a motorway. This finding should provide barrier developers with two useful pieces of information. Firstly, that effective provision of facts on objective realities should always be given to the public. As well as an indication of how opaque barriers can provide a psychological benefit of perceived effectiveness, even when it is proven that the respondents are exposed to the same noise.

The final conclusion made in the laboratory experiment, disagreed with the findings of previous researchers, that an aesthetically pleasing barrier is perceived as more effective. The sample showed that although they would prefer to have a line of vegetation or a transparent barrier adjacent to their property, that they would not necessarily expect this to provide greater noise attenuation. This is a fundamental finding, as previously aesthetic appeal has been associated with greater perceived noise attenuation, however, the results illustrated that in fact the opposite was true. Therefore, options such as transparent and vegetative barriers should not be chosen for their aesthetic appeal alone, as this may result in rejection by the residents, based on the fact that they perceive it as ineffective.

With regard to the wider sustainability issue, the findings of this research reveal that noise barriers constructed of concrete, timber and metal, will be perceived as more effective at attenuating noise, and consequently will be perceived as more successful in-situ, reducing the likelihood of the residents objecting to the barrier with the associated sustainability impacts that this would entail.

In order to illustrate a method for developing a sustainable approach to noise barrier design, the basic life cycle model presented in the literature (Figure 2.10) has been expanded to incorporate all of the key elements presented in this research. By presenting the model as a lifecycle assessment an effective method for future barrier design, which optimises public acceptance, whilst ensuring a positive impact socially, economically and environmentally is presented.

The current policy adopted by the main providers of noise barriers in the UK prevents the most effective mitigation solution from being achieved. The lack of full realisation of the consequences of in-effectual public participation, including the insufficient provision of information such as realistic expectations, and the negative effects of loss of public ownership of local projects do not seem to be realised. The full extent to the importance of addressing these issues is leading to the loss of opportunities throughout the UK for truly effective noise barriers to be built. The exorbitant cost of noise barrier construction at great expense to the UK taxpayer should be reason enough to adopt better practice, in addition to the prospect that without fully sustainable approach being adopted the actual perceived effects may be significantly jeopardised.

The model presented in Figure 9 can therefore be adopted by future projects to help prevent the shortfalls, which can compromise the integrity of a noise barrier project. The multidisciplinary nature of such projects is also emphasised, and should aid in enforcing the necessity of a fully integrated approach to ensure the longevity, success and sustainability of a noise barrier.

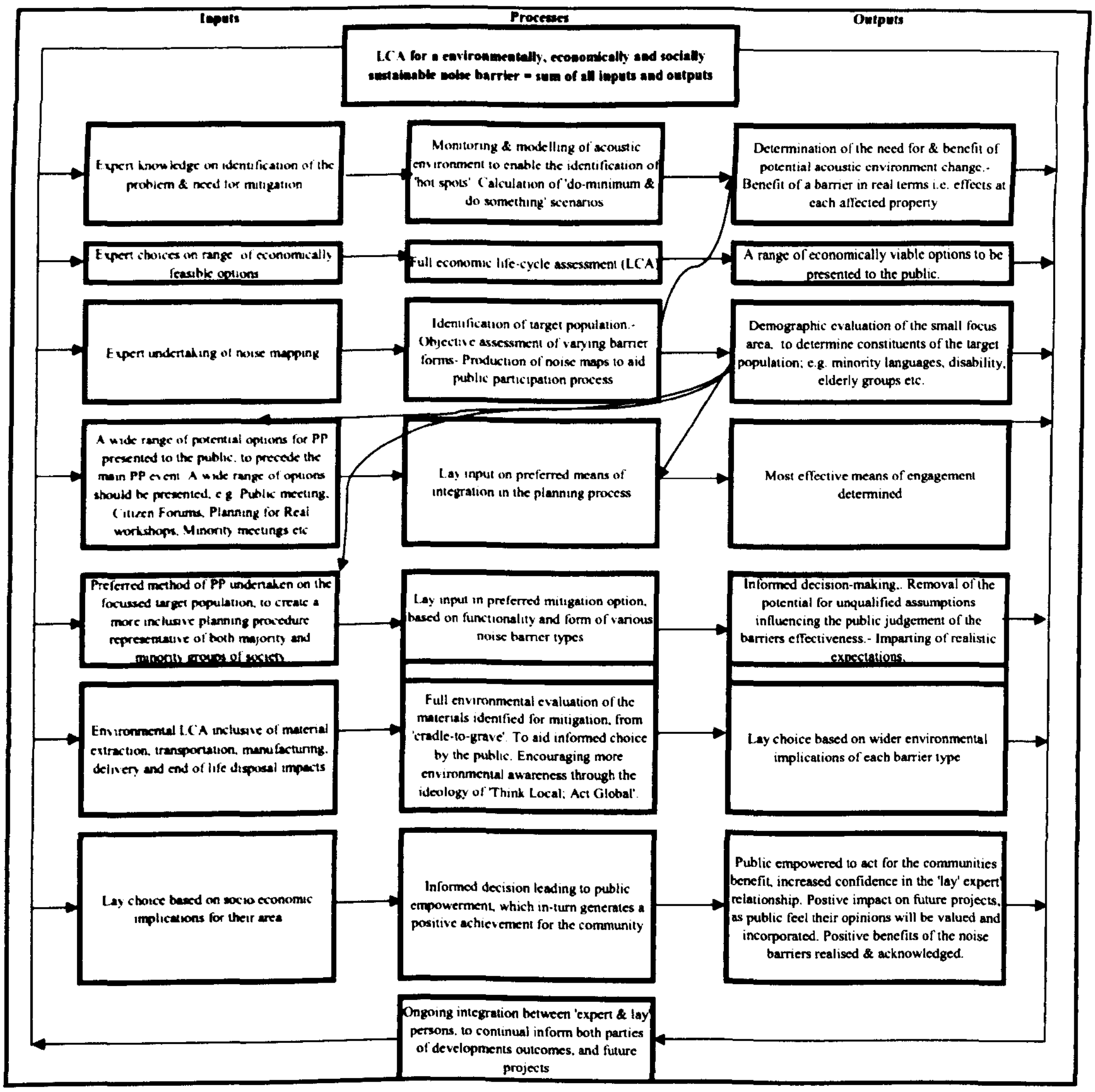


Figure 9 A model of a sustainable approach to noise barrier design

By focusing on several key elements of non-acoustic influence, several contributions to knowledge were made. These present important scientific findings, which can be practically adopted, without excessive financial burdens. These findings are by no means exhaustive, but do illustrate the multi-dimensional approach necessary to develop a successful environmental noise barrier.

9.2 Further research

As noted throughout the thesis, the scope for this project was large, and this project itself helped to uncover many new avenues of potentially interesting future research. These ideas are detailed below:

- The findings of the quantitative and qualitative investigation gave an interesting retrospective view of a noise barrier's design. It would be very interesting to test these theories further, by adopting the proposed PP measures, including the noise mapping of an area, prior and during the process of a noise barrier's installation. To evaluate whether a tangible benefit is observed on the effected publics perception of a noise barrier.
- Additionally, it would be very beneficial to examine further the individual preferences of subgroups on methods of undertaking PP, through obtaining any correlations between minority groups across a stratified sample of society. This could then further reduce any wasting of resources. As the minority groups could be identified in the areas to be addressed for PP, and a tailored method likely to be more inclusive could be adopted from the outset.
- It would be very interesting to develop the life cycle assessment model, based on that presented in this thesis, and compare the outputted sustainable analysis to that which is currently adopted, to assess the benefits of having a specific model for noise barrier assessment.
- Additionally it would be very interesting to see what the financial implications of adopting more sustainable barriers would be on the overall cost of noise barrier development.
- Within the context of public participation, to determine whether the public are affected in their choices on preferred noise barriers based on the criteria of sustainability. For example, would a barrier that is deemed more environmentally friendly than another, be perceived as a more preferable solution.
- The method of testing intersensory interactions could also be developed further, by accessing a sample that represents a wider range of age groups, and/ or ethnicities. In order to determine whether their preconceptions, and perceptions are all alike, or whether there is any variation. Again, this would be useful in defining a mitigation solution for a particular area if the demographics were understood.
- Additionally, the use of projected images within communities as a tool for public participation could be investigated further, again in the context of providing more information on the capabilities of noise barriers, whilst also getting an idea of which barrier would be preferred by those likely to be exposed to it.
- To improve the intersensory test, the use of a base tone played prior to the presentation of each of the barriers in-situ, rather than the use of one of the films clips as a reference, could remove the tendency to always judge the base clip as the most effective attenuator.
- The areas investigated within this thesis were only representative of some of the non-acoustic parameters that determine a barrier's effectiveness. Therefore, it would be interesting to undertake investigations on the impacts of noise barriers on light and view reaching the receivers, and how this impacts on perception, as well as economics, and variations within and between countries.

- Finally as touched upon in the literature review, the impact of barrier tops on the perception of a noise barriers ability to attenuate noise would also be useful, this could be achieved using a similar test to that devised in the intersensory section of this thesis.

9.3 Limitations of the research

A list of the limitations of this research is explained below. The limitations are presented for the main research chapters.

Chapter 4

- The researcher had a bias towards the opinions of the respondents, as they had been excluded in the Highways Agency's patriarchal method of public participation. Therefore to address the initial bias present in the noise barrier's production, the results favoured the opinions of the publics, in both interpretation, as well as the numbers of representatives of the lay and expert groups interviewed.
- Additionally, the results are limited in their potential for wider extrapolation, as the interviews and the resultant theory were used as a basis for further qualification, rather than as a full description of the reality, except for those interviewed.

Chapter 5

- It is accepted that the errors altered after the pilot study remained in the questionnaires translated into foreign languages. However, to alter these would have been financially unviable within the constraints of this study at £100 per language. It is accepted in hindsight that the translations should have been carried out after the initial piloting of the questionnaires. However, there was a time constraint on the translations, as they had to be ordered 3 months in advance of delivery.
- A limitation was caused by the potential for representation of the minority groups such as those with ethnic backgrounds other than British, despite the sample being representative of the area when compared to local census data. Due to the limited resources the sample size was not sufficiently big to be as representative of these groups as if a larger sample had been addressed. There could have been the option of choosing the clusters by targeting places where people of minority groups could be accessed in greater numbers, i.e. at the local mosque, the over 75's social events etc. However this would have biased the results and the potential for generalising to the area would be diminished.
- A further bias could have occurred in the questioning of the respondents on their preferred method for public participation. Due to two limiting factors, firstly, the respondents all indicated that their most preferred method of PP would be through 'a

questionnaire in the home'. However, as the respondents were undertaking a questionnaire in the home at the time this could have biased the results. Secondly, the respondents were asked whether they would opt for 'another' means of public participation other than the simplified methods given as options. It is accepted that the respondents may have had a limited knowledge of other options that could be available to them such as planning workshops, and citizen forums, and had they been aware of these options it could have altered the results. However, the question paper was limited in size and to present these options verbally to the respondents may have influenced them further, in that they may have felt it was, the 'desired answer' by the researcher.

Chapter 6

- The number of reflections and the absorption coefficient levels modelled in the noise maps were restricted to 1 this was due to the limitations inherent in the noise modelling software, as well as that resultant of the increased calculation time necessary for a model of such a large area, with the level of detail input.
- There were also limitations inherent in the validation of the 'no barrier', scenario, due to the barrier already being constructed and their being no official before measurements for comparison. The validation with the measurements against the 2m barrier model outputs was comparable enough to assume that the model was sound.

Chapter 7

- There were some limitations in the results due to the problem of missing data. This was unavoidable due to the fact that the data had to be provided from many different sources and although they all adhered to ISO14040: 1997, The Life-Cycle Assessment framework, for some of the parameters the data was either not present or given as a total without the breakdown that would have been necessary for a full comparison.
- Other limitations impacting upon this investigation were that not all possible noise barrier materials could be evaluated and entered into the database at this stage. For example for the impacts of materials noted in the literature review such as recycled plastic lumber, recycled plastics, recycled aggregate concrete barriers and recycled rubber more widespread evaluation of their environmental impacts and benefits need to be recorded before they can be inputted into the database. However As new technologies develop and the wider spread use of these recycled materials occur the data needed to evaluate both cradle-to-gate and cradle-to-grave can be added creating an even wider reaching resource.

- The other remaining limitation noted during this investigation was the lack of enquiry into mixed barriers i.e. barriers constructed of more than one material. The exception of this was the absorbent noise barriers with an inner stone wool core. These could be integrated as data was available for the standard volume of absorbent core needed for each of the barrier types, but as of other mixed barriers such as those combining transparent and concrete panels as a design feature the impacts would vary according to the design used. However, should the volumes of material needed to create a mixed barrier for a specific case study be known in a future project the information in the database could be used successfully to give a complete LCA.

Chapter 8

- It is accepted that the sound recording on a camcorder can be distorted internally during processing. Therefore, the sound may not have been as representative of the noise situation adjacent to the carriageways as would be possible with a DAT recording. However, as the respondents were always exposed to the same sound recording for each barrier this limitation should not impair the results.
- A further limitation has been identified due to the potential for, a 'temporary threshold shift' of the hearing of the respondents. The shift occurs when the ear is exposed to a sudden loud noise, the hearing normalises over a time-curve until it returns to normal, which could in effect make the respondents perceive the first noise as the loudest. This however, was not observed in the results with the respondents consistently reporting the first noise recording as the quietest. Additionally, the use of the Latin Square Design approach ensured that the barriers were all played as the first in the set at least once, and despite this limitation the trends remained strong throughout.

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Appendix 1:

From Chapter Four

1A	Preliminary Format Of The Qualitative Questionnaire
1B	Symbols Used For Concepts Of Open Coding
1C	Photographs Representing Several Different Barrier Forms Presented To The Respondents.
1D	Grounded Theory Of The Expert Opinions

Appendix 1A Preliminary Format Of The Qualitative Questionnaire

In you opinion, what are the most important environmental and social issues in Tinsley?
- Employment, crime, transport, education, environment or any other
- Is this different for men and women, how?

Does the environment in Tinsley affect your quality of life?
- Would you describe the environment as beneficial to you, why?
- What are the best features of Tinsley?
- What are the worst features of Tinsley

How long have you lived here, have you seen an improvement or decline in the areas environment, by this I mean presence or improvement of pollution. How?

Why do they live here?
- Job, family, nice area to live, safe, good transport links other

How long have you lived in this house?
- Is it private rented, council rented, privately owned, other?
- If owned, has the house risen in value since you bought it, or stayed the same, dropped?
- If renting, would they consider buying in this area, why?
- Where else would they consider living in Sheffield, Why?

Are they're any health related benefits or problems associated with living in Tinsley.
- Have you ever visited a doctor for any problem, which you feel, is related to where you live, what was it?
- Why did you think it was related to where you live?
- What did your doctor suggest you do?

Have you ever complained or been tempted to complain about any issues in your area, what were they.
- Who did / would you approach to complain to and why?

Do you sleep at the front or the rear of you house?
- Which side does the noisiest road run to your house?

Have you ever complained about noise?
- Why did you complain, were you woken up at night, disturbed whilst reading or watching T.V
- If you have ever felt like complaining, what stopped you?
- Fear nothing would be done, or benefits would be reduced etc?

How does noise affect your daily life, -
- For example do you feel stressed or are you use to it,
- When you are on holiday or away from Tinsley do you feel that it is too quite, or is it a huge relief or do you not really notice the difference
- Do your visitors who don't live in Tinsley ever comment on the noise here
- Do they stay indoors/ or go out and about more than they would without these issues affecting them. Explain for each.

At what time of the day or week are you most disturbed by noise? What is the usual cause of the noise? Tyres, Sirens, accelerating cars, decelerating cars, or does vibration effect you more.
- Why does this disturb you more than other things, when are you least disturbed by noise

Are you aware that a noise barrier has been built in your area,
- If yes, how did you hear about it?
- Was this before or after it was constructed?
- Did you feel that you were involved in the noise barrier project?
- What did you do?
- How did this make you feel?
- How important do you think your input was?
- Do you think you have some suggestions for say location, or form?
- Were these suggestion's used?
- If another big project was to be outlined for your area would you like to be involved in the planning and design stage, and comment on the final design before construction, or do you prefer to leave that to the experts
- If no, do you think you should have been made aware of it?
- Do you think you would have had some valid input into the planning, as a resident of Tinsley.
- For example do you feel you are better placed to comment on something in your area than an expert in design.
- Or should it be left to the experts, why?

Do you feel that you would like to have contributed to a discussion on environmental issues in your area and in particular on noise.

If yes, what would be your suggestions for improvement?

Do you think the noise in the area affects you children?

How?

Tired due to lack of sleep,

Or woken up in the night

Have they ever complained of being frightened by the noise, which noise in particular

lack of concentration,

makes them noisy from shouting,

any health effects that you believe are related to where you live, why do you think this?

Have they seen the barrier?

If no, is this because you don't use the motorway,

Or, do use the motorway but hadn't noticed it?

If yes, was this from the motorway side or the residential side or both,

Do you like the design, why? (show picture)

Do they think the materials used reflects Yorkshire particularly Sheffield, (if haven't seen it show a picture)

In you opinion is it more important to have a barrier designed well on the residential side or traffic side or both, why?

If you were to design a barrier for Tinsley what would be the most important feature

Aesthetics, so whether it looks good

To be made of a solid material such as concrete or metal, or to be more incorporated into the environment, by using natural materials

Do they think that its important to have a contemporary design or would a more natural approach be suited to this area, for example using trees

If you were to rate the importance of noise reduction against form (what the design is like) which would you consider to be the most important

Have you noticed an improvement in the noise pollution since the barrier was built?

Does the barrier work?

How much of an improvement has the barrier made to your life,

What actual improvements can you identify (sleep, rest, concentration, health ill effects improving

Or have there been no improvements, or worsening situation,

Do you feel the barrier is at the right height or too low, high? Why do you think this?

Do you think the barrier is in the right place, if not where else should be protected

What would you change about the barrier if you had the chance?

Have you noticed a change in community spirit since the barrier was built, have you seen more or less interaction or is it the same as before.

As a Woman/ Man- Do you feel you have more / less or the same opportunity for your say about local issues. How?

Are you aware of The Tinsley Forum have you ever or would you ever attend a meeting, what for? why?
Finally show pictures of a few different types of barrier ask which they prefer and why, and which is worst, and which they think would be the most effective at reducing noise.

Appendix 1B Concepts And Accompanying Symbols

Environment affects quality of life	X	*Environment doesn't affects quality of life*	√	*Lack of belief/ trust in experts & professionals*	*	*Trust and believe experts as they improve and benefit the area.*	#
Acceptance of Situation	*	*Rejection of situation*	#	*Evidence of hearing problems*	♪	*No evidence of hearing problems*	♫
Abandonment & Severance	X	*Inclusion & Acknowledgement*	√	*Residents priority*	▮	*Residents unimportant*	▮
Disappointment	*	*Approval*	#	*Lack of hope*	*	*Hopeful*	#
Informed	≈	*Uninformed*	∞	*Would like involvement*	≈	*Wouldn't like involvement*	∞
Disenfranchised	*	*Included*	#	*Causes positive aspects and opportunities for community*	▮	*Causes negative aspects and opportunities for community*	▮
Defiance	●	*Disillusionment*	■	*Improvements*	*	*Decline*	#
Barrier is good/ success	√	*Barrier is bad/ failure*	X	*Act to stop it*	≈	*Don't act to stop it*	∞
Lack of trust	*	*Trustworthy*	#	*Optimism*	$	*Pessimism*	£
Language barrier problem	X	*Language is no barrier/ problem*	#	*Complained (or prepared to)*	+	*Not complained (not prepared to)*	-
Illness	*	*Wellness*	#	*Bothered*	+	*Not bothered*	-
Ability to have say	*	*Suppressed*	#	*Aware of forum*	●	*Unaware of forum*	■
MI/Traffic heart of areas problems	*	*Other factors cause problems*	#	*Public participation is very important*	*Pp*	*Public participation isn't very important*	*N.Pp*
Affected by noise	*sss*	*Not affected by noise*	*xx*	*Barrier looks good*	☼	*Barrier looks bad*	▼
Barrier natural & Blended	≈	*Barrier Contemporary & Eye catching*	∞	*Men's opinions most salient*	*M*	*Women's opinions most salient*	*F*
Suggestions for improvements	+	*No suggestions for improvement*	-	*Main problem environment*	Δ	*Main problem social*	*O*
Aesthetics important	≈	*Aesthetics unimportant*	∞	*Self reliant*	*SR*	*Wait for external help*	*XH*
Equal opportunities in the community for PP	√	*Unequal chances for PP*	X	*Like living here (or would (will) like to move in)*	*MI*	*Dislike living here (would like (will) move away*	*MO*
Fearful	*O*	*Not fearful*	□	*Time away from area is better for me*	☼	*Going away makes no difference*	▼
Aware of barrier prior	●	*Unaware of barrier prior*	■	*External exaggeration of problems*	■	*Problems are as bad as made out*	●
Barrier choices important	√	*Barrier choices unimportant*	X	*No environmental problems*	*NEP*	*Environmental problems*	*EP*
Sceptical of how well barrier works	≈	*Un-sceptical of how well barrier works*	∞	*Noise reduction over aesthetics*	●	*Aesthetics over noise reduction*	■

Appendix 1C Grounded Theory: For The Expert Interviews.

Key Phrases, to be open coded.

TR "He sort of championed it on they're behalf, and he asked whether we'd consider it and clearly we were, provided that it didn't cost us more money, and it didn't delay it because we had this Hansard list and we had to deliver it within a certain time, and it was a rolling programme so obviously the following year there wouldn't qualify for this money, and really that's how it began that we were really prepared to take on board with it being a gateway project and it was what design Yorkshire wanted was something that stood out and said you are entering Yorkshire".

High expectations due to non-expert involvement of organising committees.

TR "It was very much our project and my colleagues down the corridor who are the project deliverers it was up to them to deliver the project and they delivered it through what they call their term contractors they're managing agents, they were put on a three year project. But that's about to change so its basically what we call an environmental scheme and a network management scheme, and, which we delivered through a managing agent. So it was up to the managing agent to carry out, or get the work carried out. They prepared the contract up for us, and let the contract documents to the main contractors (I cant remember what they're called), and really essentially we have a specification for noise barriers its basically an end product specification it has to have a certain performance. So really the only criterion was that provided that what ever noise barrier was put forward by Design Yorkshire met with our noise barrier specification, was fine, because at the end of the day if they can show us that it will cost the same amount of money whether it was a wooden fence or what ever else it was providing it met our specification, i.e. an end product specification then that was fine. So that was the trick, the trick was trying to get the design to meet the specification because its an enormous document our noise barrier specification".

Reduced control, delegated responsibilities, restrictions of design controlled by official noise barrier design specs.

TR "It had to be yes, primarily it had to be an effective noise barrier, and it had to be no worst than we would have got with a standard noise barrier fence, oh sorry the noise barrier we usually get as a consequence of our specification, because all the suppliers out there are geared up to our specification so basically off the shelf there are half a dozen firms that contractors go to, so "how much will you provide this fence for"? So it's just a case of cost really, you go to all these suppliers and say I want a barrier to HA specification. But this was new and in a way it would essentially y cost a little more because it was a gateway project, and people have to create moulds or what ever, as it was a one off. But in terms of a gateway project we have to bear a little bit, for the intention of all gateway projects".

Upfront cost is deciding criteria, as all noise specs are conformed with naturally, Planning not a consideration when part of existing works (as is inclusive).

TR "OH no if its part of the highways its part of the works, so you don't have to have a separate planning permission, but err the recommendation was when we first went out with our consultants and we were looking at the hotspots, it was one of the recommendations, what is the most cost effective barrier, no sorry, what is the most cost effective noise mitigation method, noise barriers over resurfacing, so the recommendations were that we should construct a two meter high barrier so that what we went ahead and did. A two-meter high barrier doesn't warrant planning permission".

Upfront cost is deciding criteria, as all noise specs are conformed with naturally,

TR "Its certainly effective in parts, erm, I think that peoples perception is that's it's a noise removal measure, rather than a noise reduction measure, and people have written saying its not very good we're only getting 3dB reduction, and that's quite a success. If I thought that I had achieved that I would have said I've succeeded. And anything over that is a bonus and I think there are quite a few properties that are still in the shadow. Those properties where the roads high and they're below the level I think we were looking at, hopefully looking at 10 dB (A), because they were actually in the shadow obviously those that get 2-300 meters away, by definition are not going to get too much reduction, which is why we'd rather go for low noise surfacing which attacks the source so everyone gets the benefit. There are areas where it isn't effective because it needs to be continuous because where the road dips and you've got properties in what they called the arena type effect, if you can see the vehicles you can hear them, because it a direct line to source. So there were some people who were upset because the road dipped at the embankment and the barrier followed it, that again needs to be a continuous barrier. Otherwise the effectiveness is lost upstream and downstream".

Realistic expectations, Arena effect should have been explained, Realistic alternatives.

TR "You have to have, the end effects of the barrier if you have a property here, and one over here, and you want to protect them then you have to take the barrier considerably past to ensure you stop the end

effects of noise, and by the time, if you want to stop it by the time you stopped the end effects your just making one continuous barrier. So there are locations where it does appear low, its basically a very pretty wall because all the properties are up here, but by definition if you wanted to protect those you'd have to have a four or five meter high barrier. And then you run in to all manner of construction difficulties".
Limitations.
TR "I think it was Yorkshire Designs idea, I think they've done similar things, and the barrier was just one of their initiatives, I think they had an evening and a presentation at Design Yorkshire, of the successes they had had, and this was just one of them, they wanted to involve both the private sector and the public sector".
TR "The tendered items, if it had gone out to one of our normal suppliers they would have got a wooden fence. And that's exactly what Yorkshire Design wanted to get away from they wanted something that wasn't a wooden fence. And they wanted innovation, and so, we support innovation, that's one of our strands, we will always support innovation, providing that it means the same end product at the same end product at the same end specification, providing it does the job its meant to do, then if there's a better way of doing it, so much the better we will embrace it".
Realistic alternatives
TR "It's provided us with what we consider to be an effective noise barrier I know that sound bland but, that's what we are charged with. If those who received it think its better than a wooden fence then its been a success. If they'd rather had a wooden fence then it's a failure, I think there were some people who thought it could have been better, it hasn't come out as good as they thought, you know the colour wasn't as good, so it could have been better, so there are lesson to be learnt. It could have been better".
Acceptance of failure to some degree.
TR "And some of the curvatures were lost due because of existing services and the like. A normal fence is easy you just drill some holes and put a fence pole up, this is slightly different".
Limitations.
TR "No, no it was a compromise, it was meant to be a series of curves, which is fine, but in a highway verge that's only 3.5m high if there were services, then there's the safety element problem. It's a safety fence problem, so in the end it was a case of trying to make the very best, it was a good idea. And we shouldn't be dispirited but it wasn't as good as people wanted. And that what happens when you put the pure and the applied together".
Limitations.
TR "Oh yes it is important that we do get aesthetics right, I mean people have to live with it. And its high on the agenda, but it was more costly in the end, properly the next time round it would be cheaper, because of the moulds would be made. But aesthetics is very important as we are charged with enhancing the natural environment, that's one of our objectives. So we wouldn't want to put up a bright orange plastic fence".
Aesthetics important.
TR "They were involved, through a lobby. Tinsley was one of three, as I say there was Tinsley, Brinsworth that actually went out as one and there was one at Alltoffs, and they all went out as one contract and because the Altoffs was the first meeting, and another MP got involved. Bill .... Who was championing the course so our liaison officer went along with the agents with a diet chart if you like, 'this is the sort of barrier we're wanting to put up what do you think'? And they thought it was fine, and they actually picked the colours, the Green and the Terracotta".
Public participation incomplete at Tinsley, situation was explained not determined at the forum. The importance of public participation is accepted and acknowledged.
TR "Yes, so then we went to Tinsley Forum, which is a fairly active group in Tinsley and we told them that this is what we were going to do. That was more a 'this is what were going to do what do you think about it?' And if anyone was violently opposed to it then , we just said these are the two colours that Altoffs have decided on the Red for the Urban and the Green for the more rural sections. And they seemed content with that".
Public participation incomplete at Tinsley, situation was explained not determined at the forum.
TR "Certainly Tinsley forum, has been pressing for a noise barrier, so in away, it was going back to tell them that a) they'd been successful, and that Tinsley had got this money out of this ring-fenced £5 million and b) that it was going to start soon, and this was what we were proposing, so it was a presentation as a consequence of a direct source. It is a good representative body, and they are a very active body, and they had been campaigning for one for a while, there are a couple there that think it could be better".
Project regarded a success due to realistic expectations by experts.
TR "If were doing new works we certainly like to consult with people and again, we consult with groups all the time, you know make them aware of what we're doing, there's environmental group there's lots partnerships now that are going on, so that people are kept constantly aware, and we used to go out and

talk to parish councils on a regular basis and asked them if they had any problems, it is about engaging the public because at the end of the day they are our customers, our customers are not just road users they are also the people that are effected by the route, so were just about to embark on a route management strategy for the M1 so again we'll be engaging communities through their local representatives or local groups, and in some way were going to try and engage them".

Public participation incomplete at Tinsley, situation was explained not determined at the forum.

TR "because the barrier goes up in highway land, its basically an improvement to an exiting highway and that included under a general improvement order, we don't have to consult on it, it's a case of improving the highway under our general power. But we do engage people purely on this cross load of information".

P/P was not an obligation; the importance of public participation is accepted and acknowledged.

TR "Public consultation is inherent in our process, you know it's a usually tied, with any project you would look at feasibility and it depends on the scale of the project if it was a brand new route then you'd consult on having to find the route. We'd have public consultations before you announce the preferred route because the public consultation would be taken into account when deciding which route we choose. You then have to look at the consultation at the order stage, having decided the route you get to the stage where you can publish any statutory orders".

The importance of public participation is accepted and acknowledged.

TR "Its usually not over powered by public interest but again its targeting your audience if some of these projects coming in such as multi-modal studies, is about widening the motorway you would have to have the consultation period even though if you widened on line again its within the landscape so if its something with a major impact we would want peoples opinions about landscaping and other interests. So public consultation is always in the loop but it's the level of that if it's a noise barrier to protect A and B, its very dangerous, we went to Altoffs and we went to Rotherham and they asked for it to be increased in length slightly but that's the problem you get is that, I don't think a barrier will ever be too long they're will always be someone on the end of it. It is a case we've got |£5 million across the country year on year".

Fear of consequences of too much control through P/P.

TR "WE certainly tweaked it a bit at Altoffs, and we tweaked it a bit at Tinsley Brinsworth".

TR "NO, we went to the Tinsley Forum, because they were right on the forefront, and the were the most vociferous and I mean that in the nicest possible way, but you did get the impression that they had Tinsley at heart and they weren't interested in either side, so I did feel I was getting a good focus. Because it is well represented, well structured and well supported".

TR "Which is the best method of involving the public do the Highways Agency favour public meetings over exhibitions, or more hands on approach to participation.

Its horses for courses really, it depends, you've got to add value so if your going to have public consultation there's no point going over there if the people are affected. We use a whole range we've got a 'bendy bus' that we drive around",

JJ "A bendy Bus?"

TR "Its an exhibition that we actually drive around so we can drive to villages and park in pub car parks. It is difficult, because although the public want to be involved its up to them and its difficult to get someone to drive ten miles to go to an exhibition, its on their terms as it were. So we have exhibitions were quite happy to go and give presentations to groups we go to councils and take our presentations, we try and engage everyone as at many levels as we can we try and draw as many partnerships as we can so we can influence or involve or what ever it is. There's a whole raft of measures we take the public consolations exhibition is just one form it's a fairly common form on a big scheme we also have a websites".

Awareness and attempts at alternative means of P/P, just not used here; responsibility of PP lies in the hand of the public, Despite best effort not everyone can be engaged, damage limitations are practised by spreading the word.

JJ "What provision is made for minority groups such as ethnic minorities and disabled people to be able to become involved in projects?"

TR "Were usually aware of what the community groups are through local authorities, they have local partnerships and there's so may of them I cant remember what they are, have these forums, so we become very aware of what they are and almost through local authorities we can get representation of all these groups, if anyone wants to come along to an exhibition we say no to nobody. We do have lists of groups and clearly when we are consulting then we have statutory consul tees and non-statutory consul tees and at the bottom there is any other interested parties, and it really is trying to get a handle on who those other interested parties are. Were involved with LSP Local Strategic partnerships, they have close leads, and again they're involved with all these local groups and we get the contacts with the local groups. So it cascades through".

Despite best effort not everyone can be engaged; damage limitations are practised by spreading the word.

JJ "Is it actually the Highways Agencies responsibility to involve making sure that everyone is represented or is it someone else's responsibility?"

TR "Well its, we need to be in a position where we can't be criticised for over looking, its very difficult to be very explicit because by definition if your very explicit then you can make yourself more exclusive. Because the more you try and be prescriptive the more you miss somebody and then you'll be accused. We do try and look broad brushed so we can engage at least one group that can be seen to represent certain groups, so if you go to CPRE or Friends of the Earth then chances are that they will represent TART, which is the environmental groups. And they have a group themselves so if you invite one then you spread the word. So that's what we try and do, we try and ensure that we don't miss anybody so at the end of the day we can't be criticised that 'we weren't consulted', and so when you say who did you consult, its other interested parties. There are clearly statutory ones involved and then they're stipulated, and then there's the non-statutory consul tees, and then there are the other groups which we try and engage. So we'd invite them to everything we can say an exhibition or send them brochures".

Despite best effort not everyone can be engaged; damage limitations are practised by spreading the word. Awareness and attempts at alternative means of P/P, just not used here;

JJ "So you think the current measures are adequate to involve everybody?"

TR "Well were continuously doing this, we have a PR group who is constantly trying to find ways to engage them and that's the aim of the game. We are a customer based service now we are a network operator and we have customers, so we have to improve our customer service".

Despite best effort not everyone can be engaged

JJ "Would it be the highways agencies responsibility to provide information on the plans, it was actually your responsibility rather than your choice to do it, through public demand".

TR "Yes it was ultimately our project so it was ultimately it is our responsibility so in a way that was one of the tests of all the entries, was maintenance. Did it have high or low cost maintenance, because clearly it becomes ours to maintain. So its maintained at the public expense".

Accountability.

TR "We have one or two, we've had a couple saying Thank you and a couple saying it could be better".

TR "Altoffs certainly did there's one just up the M62 they've been very appreciative, but again its slightly on an embankment of course, they've noticed the difference. As I say Tinsley's difficult because we took it down the slips, and it's a very wide motorway, and when you've got a wide motorway and slips the effective height of the barrier gets reduced. Perhaps we'd have to look at the effective height of the barrier, because you say a 2metre high barrier but you can loose a foot by the time you get top the back of the verge".

Greater P/P at Altoffs influenced acceptance.

JJ "Noise can be measured in to different ways, in how the public perceive it and how you actually empirically measure it, how successful is the barrier on both of these".

TR "We haven't gone back and measured it, although someone else has claimed they have, I think that was the school or something. And that's when they said its only gone down three to five dB, and I said that's pretty good. No we work on the prediction method, we have started to look at other sites as part and parcel of this ring-fencing, I think Bath University were engaged to do a 'before and after' which would have been very useful, but we didn't do it on Tinsley we just missed it. So we don't have a before measure, its purely predictive".

Realistic expectations. Should have been imparted

TR "There is nothing more emotive than noise and the sadness is that £5million is not a lot of money, for lots and lots of motorways, but if you can reduce noise from 78 to 74 dB that's a big reduction in traffic and energy, but in terms of, 74 is still very loud. And that's the sadness. In a way you almost give with one hand and take away with the other because you raise peoples expectations, there getting a noise barrier and they think its going to be great, " well I cant notice the difference" but 3 or 4 db A is only just perceptible anyway. So we are tinkering on the margins. As I say if we get 5, like with some of this low noise resurfacing we say its 3 to 5 but in some cases its been as much as 8 which is massive but its still 80 down to 0, and its still loud at 70".

Realistic expectations. Should have been imparted

TR "Well, if you ask the question, people never say thank you or give you the good news, if you go and ask the question all you will get is the negative you very seldom get the positive, I think by definition because you put up a noise barrier two meters high although some people wont benefit as much as others some will, we know by definition, especially where the motorways on an embankment we know that people will have benefited. Because we know how it works, but they may well not have perceived it or appreciated it and that's why we do it".

Realistic expectations. Public were unrealistic.

TR "Well stainless steel was expensive! It turned out to be an expensive project because it was innovative and it was a gateway, which accepted in a sense it would be I think if I did it again, I would look at it being slightly higher in terms of its effective height. Because I think we tend to loose in the detail, when we say a 2 meter high barrier, but of course 2 meters is always measured from ground level, i.e where you start building the barrier from. And because noise are always related, well the calculations are always from source it depends where the source is the effective height, should be measured from the noise source so if its lane one then it easy to loose if your not careful, all the calculations are based on 2 meter high its important that the 2 meter high is actually the same as it was in the calculation because if your not careful you'll get the hard shoulder and then there 's the first lane and then you find that because of stats or because you've got to put the barrier at the back of the verge, if you're not careful you'll virtually reduce your effective height. With noise you get a big difference with a 1.8m barrier than a 2m barrier, and that little can make quite a big difference. And I think perhaps the colouring could have been slightly better".

In hindsight would have increased height

TR "I think it could have been bolder".

Misconception of public opinion due to lack of communication; opposing views, illustrating bad communication.

TR "I think we took some unfair criticism that it was bland, and someone accused us of 'Bastardising it.' Which we did, the idea was a good idea but at times we couldn't attach together the flowing curves".

Applied V Pure; curvatures of the design lost.

JJ "Do you ever look to Holland who are way ahead of anyone with barriers, and the Japanese as well, do you ever look overseas to get inspiration or even commission one, or is it just too expensive?"

TR "Well sadly yes, our hands are tied by best value and we have to have these continual value measurement exercises, and we look at projects and ways to make best use of money and that's one of the saddest things. If you want to go for a gateway project then you value manage it as a gateway project , not just as a project, and when we get calls form overseas recommending that we should have nice structures and so on for the future that we've got to make sure that its identified and its necessary to be a feature otherwise it will get value managed as a utilitarian product which is essentially, you could get someone in Cornwall who gets upset that your providing noise barriers at three times the cost and its coming out of their taxes".

Accountability; upfront cost is deciding criteria, as all noise specs are conformed with naturally.

RB "About 3 years ago the government said two things that they would cover all concrete roads with low noise surfaces and they would address noise mitigation on their network. We have now have a rolling program of surfacing concrete roads and then we carry out on behalf of the highways agency what we call Sift studies. That's where a property lies within sight of the motorway, where if the noise requirements of the sift study are met there is a possibility of doing a study for that property and the provision of a noise fence. So we end up doing lots and lots of sift studies through out the network"

Reactive solutions are the norm not proactive.

RB "They are done on complaints, going to the client (highways agency) and the client requests us to do a study".

Reactive solutions are the norm not proactive.

RB " A competition that actually decided which noise fence to be put up".

RB "The question is then where do you stop, it is a degree of cost, and the degree of benefit. Its designed as a structure, if you've any concept of structural elements. The taller they are the bigger the foundations have got to be. We've actually constructed this structure adjacent to a live motorway, most of the width available to construct it in, is between one and half and two meters wide, and also the two meters are full of drainage trenches and communications cables, because it's a structure, it has to be protected against the impact of vehicles. So you have to have a safety fence in front of it as well all in this very narrow width, so everything is a compromise.

Yes we could have gone for a three-meter high barrier, at a considerable amount of cost, there would have been a few more, properties receiving benefit. But on a cost benefit ratio two meters came out as the highest cost benefit ratio".

Applied V Pure; Limitations. Realistic expectations.

RB "No they were all as equally effective, if they could conform to the HA document".

upfront cost is deciding criteria, as all noise specs are conformed with naturally.

JJ "So then it was down to aesthetics".

RB "It was down to aesthetics, the market scheme, longevity, maintenance anti-graffiti, to some extent it was a compromise between making it visible and making it attractive, and not causing distraction. So if you've seen the scoring criteria you would have seen it was quite a complicated scoring criteria? Did Terry talk to you about the design process, the design competition and the scoring?"

Potential for public integration unused; Unclear how to engage properly;

RB "I think you would have got, define better, I think you would have got more fence for the same money using a conventional design".
Realistic alternatives.
RB "Engineering success, yes, it went up well; it was constructed well, and touch wood it seems to have its longevity. But that could have equally been achieved by conventional methods".
Project regarded a success due to realistic expectations by experts.
JJ "So would you say the edge then over a conventional fence would be the public perception".
RB "Yes, the public perception and participation in the design. If you go south of us junction 25 of the M1 they've put up a three meter timber fence that looks nothing, its just a big timber mass, at least ours has a little bit of form, structure, and colour about it".
Misconception of public opinion due to lack of communication.
RB "Yes we met with design Yorkshire, we met with the local Mp we had this design competition. We also did a section on the M62, (Altoffs) John Bagualey Terry Rogers boss at the time, myself and Terry all met with the residents. Gave them a sort of winning design gave them a selection of colours, and said what colour do you want it. And they were keen to influence the colour. That was up at Altoffs.
Here we met with the Tinsley Forum. Terry and I did, who weren't really bothered about the design. But I met with Colin Rose at the site, and he said he wanted that bit red and that bit green, So that's how we proceeded".
Public participation incomplete at Tinsley, situation was explained not determined at the forum.
RB "Not really we tend to deal again reactive. Nobody has complained so we assume there happy with it".
RB "Erm, very difficult, retreating into my engineering background, if you involve the public they want the earth, they see no reason why we cant have noise barriers 5 meter high the length of the M1. Coming forward into some sort of caring organisation if we'd have just gone in there and out up the bog standard timber fence, I think we would have had complaints. They would have said well, why have you just stuck up a Timber fence couldn't we have had something a bit more aesthetically pleasing. It's a difficult one, halfway house, do you have full public consultation do you tell the public what's happening it lays somewhere in between".
Fear of consequences of too much control through P/P.
JJ "So what you say is the best method of approaching the public is through the use of forums?"
RB "Yes,"
Forum deemed only/ best means of engaging the public.
JJ "And would you say you got everybody in from the community?"
RB "No, we got views from interested people, if their interested they didn't turn up and they didn't give their views".
Misconception of public opinion due to lack of communication; Opposing views, illustrating bad communication.
RB "The residents of Altoffs and the Tinsley Forum invited US, I believe they'd heard about the noise barrier was happening, and they wanted to know, it was an exchange of information. They wanted to know what form the barrier took, when it was going to go up and where it was going to go".
Public participation incomplete at Tinsley, situation was explained not determined at the forum.
RB "Yes, we do nothing until the client asks us to do it, so if the client asks hasn't received the complaint and asked us to do something we won't do anything. We are a commercial organisation unless we get told to do something we don't get paid".
Reduced control.
RB "concrete one only requires minimum maintenance and it should require not a lot in the future. Other designs that were perhaps higher in maintenance were marked down and didn't win. So it was taken into account in the design competition".(Consideration for Ch: on embodied)
Maintenance costs were considered.
RB "You can't all the designs complied with the acoustic attenuation requirements, so providing it met that the aesthetics were judged on their own merits. So any of the designs in the competition should have met the requirements of the noise competition. And it was purely marked on looks".
Potential for public integration unused.
RB "Yes, it was always intended to be discussed with the residents. And I have the difficulty of defining whom. Tinsley and that area have a forum, so you can talk to those. Brinsworth has no sort of local authority or parish council that we could talk to. Altoffs just had interested residents".
Unclear how to engage properly; the importance of public participation is accepted and acknowledged.
RB "Yes they have to request meetings or what ever".
Delegated responsibilities.

JJ "And do you have any sort of guidelines in terms of Public Participation, is it your responsibility or is it solely their responsibility".
RB "No we react to the client. If the client (HA) wants us to go we will go, if the client doesn't wants us to go we wont go".
Reduced control.
JJ "Would you see any sort of way, as not everybody knows about local forums and stuff, in terms of involving those people, minority groups and disabilities and things?"
RB "Yes, how do you involve them? Difficult one that, let me put one of my other hats on I look after major maintenance works on the motorway and to inform people that we are actually going to perform the work, we would do a letter drop at the addresses. Perhaps here if the client wanted it, we could have actually done a letter drop, for Brinsworth saying that we are going to put this Fence up and there is a public exhibition at the local library if you want to come and look at it. Something of that ilk, but that wasn't done".
The importance of public participation is accepted and acknowledged.
JJ "So its not the residents who's job it is to get themselves into a forum it's the Highways Agency to let them know that you are going to do It
Awareness and attempts at alternative means of P/P, just not used here.
RB "I believe it is yes. I think here the Highways Agency, Terry Rogers, could have actually gone to the local residents or the parish council of Brinsworth and said were going to put this noise fence up are you interested?"
Delegated responsibilities.
RB "No we had one or two comments saying why didn't we take it further, why didn't we go over Tinsley Viaduct, why didn't we go South things like that, one or two people have commented on the colour the aesthetics things like that, but nothing that has said we didn't need it we didn't want, couldn't it have been higher anything like that".
Misconception of public opinion due to lack of communication; Opposing views, illustrating bad communication.
RB "I think that would be inappropriate because the you suffer a lot with driver distraction. Perhaps on a lower speed urban road, not the M1".
Fear of consequences of too much control through P/P.
RB "I think its been quite a success, I can tell you what the noise reductions have been, they are very much in line with the design ones. So that obviously says the barrier has been a success. Regarding the public perception of it, we've had no real adverse comments so by inference it must be a success".
Project regarded a success due to realistic expectations by experts
RB "The barrier itself, probably ran out at something like £200 a metre".
RB "Well two things there, we wouldn't procure them we would go to a main contractor to procure them. European Union rules say we accept anything form anywhere. So if the contract came up with some fancy Scandinavian one that met all the criteria. Yes no objection. But that's not personal choice that's legislation".
Restrictions of design controlled by official noise barrier design specs; Upfront cost is deciding criteria, as all noise specs are conformed with naturally.
JJ "If the barrier was commissioned again, you use the same public participation approach?"
RB "Yes".
Wouldn't change PP method with hindsight
RB "The action of actually involving the design competition, the assessment of the submitted designs, actually delayed the imposition of this barrier possibly by three to four months. If we were going to do it again I would take that into account in the programming, but that's all".
RB "Not significantly, but I think a noise map, like a before and after survey, I could sit here more confidently and say that property has given x dB reduction. Rather than a little bit of theory. So yes before and after should have been done".
Wouldn't change actual method of design with hindsight, accept for including a before and after survey.
RB "The problem you've got is with us being a commercial organisation. Were here because we one this commission by competitive tender. Therefore unless its in our tender we don't do it, unless were paid extra to do it. A lot of what you've discussed today, we'd love to do but we can't afford to".
Accountability.
RB "It comes back down to the central control where THE HA is the owner and have the run of the roads.
Lets talk about the noise fence itself, its 2 metre high its concrete panels, each panel weighs approximately 2 tonnes and there are 4 panels in the 2 metre high so each one is 1/2 a metre.

It weighs two tones, so this is where the actual cost comes into it, a fairly simplistic timber fence would probably only weigh about ½ a tonne but it would serve the same job. It would fail a little bit on longevity because it rots, its susceptible because it can be burnt down".

Reduced control; Delegated responsibilities.

Axial Coding Categories:.

Limitations.

Accountability.

High expectations due to non-expert involvement of organising committees.

Reduced control.

Delegated responsibilities.

Arena effect should have been explained.

Applied V Pure ~ Curvatures of the design lost.

~ Acceptance of failure to some degree.

~ In hindsight would have increased height

The nature of the PP method.

Public participation incomplete at Tinsley, situation was explained not determined at the forum.

~ P/P was not an obligation.

~ Fear of consequences of too much control through P/P.

~ Forum deemed only/ best means of engaging the public.

~ Wouldn't change PP method with hindsight

The importance of public participation is accepted and acknowledged.

~ Awareness and attempts at alternative means of P/P, just not used here.

~ Responsibility of PP lies in the hand of the public.

~ Despite best effort not everyone can be engaged.

~ Damage limitations are practised by spreading the word.

~ Unclear how to engage properly

Reactive solutions are the norm not proactive.

o *The nature and consequences of the experts perceptions and actions*

Potential for public integration unused.

Greater P/P at Altoffs influenced acceptance.

Realistic expectations. ~ Should have been imparted

~ Public were unrealistic.

~ Project regarded a success due to realistic expectations by experts.

Realistic alternatives.

Misconception of public opinion due to lack of communication.

~ Opposing views, illustrating bad communication.

o *Design choice influences.*

Restrictions of design controlled by official noise barrier design specs.

Upfront cost is deciding criteria, as all noise specs are conformed with naturally.

Planning not a consideration when part of existing works (as is inclusive).

Aesthetics important.

Maintenance costs were considered.

o *Future measures derived from this experience.*

Wouldn't change actual method of design with hindsight, accept for including a before and after survey.

Other mitigation strategies would have been wider felt, i.e. Low noise surface.

In hindsight would have increased height

Appendix 1D Photographs Representing Several Different Barrier Forms Presented To The Respondents For Opinions.

a)

b)

c)

d)

c)

e)

f)

Pictures from SLC. Japan

Appendix 2:

From Chapters Five & Six

2A	**Demographic Profile & Social Deprivation Indicators**
2B	**Letter For Residents**
2C	**Calculation Of The Standard Error Of The Mean Of The Cluster Samples**
2D	**A Copy Of The Questionnaires Issued**

Appendix 2A Demographic profile & social deprivation indicators

Tinsley

Housing condition - the quadrant contains some of the poorest quality private housing in the city;

Social and economic factors – rates of ill-health and unemployment are amongst the highest in the city;

Links to other programmes – the North East Quadrant is part of the Round 4 Single Regeneration Budget area, enabling housing and regeneration activity to complement each other; (Sheffield City Council 1999)

Population Statistics & Households

Based on the 1991 Census, the tenure breakdown of those households in Tinsley in relation to Sheffield as a whole was as follows:

Owner occupied 72% Tinsley - 57% City

Council rented 11% Tinsley - 33% City

Housing Association rented 6% Tinsley - 3% City

Private rented 11% Tinsley - 6% City

Other 1% Tinsley - 1% City.

People

The total population of Tinsley in the year 2000 was 3640. There are an above average proportion of children, balanced by a slightly lower proportion of people of working age.

As noted in (Partnership 2000) the population was made up of:

23% - 0-15 years old

61%- 16-64 years old

16%- 65 and over.

Ethnic Origins

Tinsley has a large number of ethic minority residents in comparison to the rest of the city, ethnic minorities make up just 5.1% of the total city wide population, where as in Tinsley they make up more than a third of the population, most of these being Pakistani. The statistics break down as follows 65.5% of the population of Tinsley is White British/ Irish, 2.9% is Black Caribbean, 0.1% Black African, 1.2% were other Asian, 28.5% were Pakistani (Partnership 2000).

Income Support

More than a quarter of households in the area were receiving Income Support in December 1998 (430 households).

Almost half of the households on income Support were families with children aged 0-15 (190 households) (Partnership 2000).

Local Economy:

Index of Local Deprivation (ILD)

The Tinsley Area has an ILD score of almost double the city average. The actual ranking of the ward of Darnall of which Tinsley makes up a proportion is 561st out of 8414 English wards, which is much lower than the ranking given for the ward Brinsworth, Catcliffe and Treeton, which was ranked 1843rd. It must be acknowledged however that the ward of Darnall is much larger than Brinsworth, Catcliffe and Treeton with 6,300 more in the population (Partnership 2000).

Unemployment

Official unemployment statistics are available to electoral ward level only. The most recent unemployment rates for the Darnall Ward indicate that in July 1998 that 9.6% of the population were unemployed as compared to 8.3% of Sheffield's overall population. Of those unemployed 50% had never had a job. And of the 50% that had previously had a job 67% had been unemployed for over 12 months (Partnership 2000).

Health

- The most reliable health data is available at ward level.
- The all causes rate for men in Darnall ward has deteriorated significantly
- Cancer SMRs for women in Darnall have remained consistently high
- Heart disease, stroke and related SMRs have deteriorated to almost double the national average
- Suicide rates for men are high (Partnership 2000).

Crime & Community Safety

Levels of crime, both real and perceived, have a debilitating effect on communities. One of the most commonly quoted factors when describing the desirability of an area is the level of crime and how safe people feel.

The Tinsley Area's overall crime rate is relatively low at 8.3 %

The main problems are criminal damage and car crime

Housing

Confidence in an area is generally reflected in the private housing market and in the level of demand for and satisfaction in its Council housing.

House prices

The average house prices for the period 98 for terraced housing in the area compared with a city average. Is £23,020 to £40,239 respectively. Terraced housing only has been selected as an indicator because it varies less form area to area than other types of housing. Average prices for all housing are dependent upon the housing mix as well as the popularity of the area (Partnership 2000).

Miscellaneous facts.

Together with Darnall, Tinsley has the highest proportion of people with low or no qualifications and of people who had never used a personal computer (53 %).

Brinsworth & Catcliffe

Treeton is included in the statistics as it is a part of the same ward as Brinsworth and Catcliffe, despite not being directly used as a part of the study sample it runs parallel to the areas of Brinsworth and Catcliffe and statistics are not available separately.

Population:

The resident population of Brinsworth, Catcliffe and Treeton in mid 1998 was 13100 people, 5 per cent of the population of Rotherham local authority. 21 percent of Brinsworth, Catcliffe and Treeton's population in mid 1998 were aged under 16, 61 per cent were aged between 16 and 59 and 18 per cent were aged over 60. This compares with 21, 59 and 20 per cent respectively for Rotherham as a whole.

Vital Statistics:

A total of 165 live births to mothers usually resident in Brinsworth, Catcliffe and Treeton and 89 deaths of residents of this ward were registered in 1998. These represented crude rates of 13 births and death per thousand residents compared with 12 and 10 respectively across the whole of Rotherham local authority.

Employee jobs:

There were 12000 employee jobs in Brinsworth, Catcliffe and Treeton at September 1998, 2 per cent of the Rotherham total.

Income support.

In August 1998 there were 680 income support claimants in Brinsworth, Catcliffe and Treeton. This represents 7 per cent of the resident population aged 16 or over. For Rotherham the proportion was 10 per cent compared with an average 8 per cent for Great Britain overall.

Indices of Deprivation.

The indices of Deprivation 2000 (with rank 1 being the most deprived ward in England) gave Brinsworth, Catcliffe and Treeton the rank 1843 out of a total of 8414 English wards. (Statistics 1998)

Appendix 2B Letter for residents

June 26th 2002

Dear Resident

I am conducting a survey in the Tinsley, Catcliffe and Brinsworth areas as part of my research for a Ph.D. thesis, for the University of Sheffield. Your house was randomly selected from a map of the area due to its close proximity to the M1. The survey aims to investigate the effects of noise on residents, and the level of public participation available for you the residents, to raise your concerns about protecting the local area.

I will be calling at your house between Tuesday the 25th and Friday the 28th, to drop off a questionnaire it is available in the following languages English, Urdu, Bengali and Somali, and large print for the partially sighted. The questionnaire is very short and simple and should take no longer than 10 minutes to complete. Any personal information asked for will be used solely by the researcher for the purpose of data handling, and to ensure a representative response. In accordance with the Data Protection Act 1998. All other responses will be presented purely in graphical and statistical form for the purpose of the Ph.D. research.

At your convenience I will return the following day to collect your completed questionnaire, and answer any questions it may have raised.

I wish to thank you in advance for taking the time to assist me with my research, as I believe your views are essential for the success of future projects both in this area and for other projects around the country.

If you have any queries concerning this study please contact Jennifer Joynt on 0114 222 0370/ 0114 268 0069 or alternatively Dr Jian Kang on 0114 222 0325.

Thank you very much

Yours Faithfully

Jennifer Joynt & Dr Jian Kang
(Postgraduate) (Reader)

Appendix 2C   Calculations of the standard error of the means of the cluster samples

$$\bar{x} = \sum_{k=1}^{K}\sum_{i=1}^{M_k} x_{ki} \Big/ \sum_{i=1}^{K} M_i$$

$$s_{\bar{x}} = \Big[(1 - K/A)\sum_{k=1}^{K}\frac{(\bar{x}_k - \bar{x})^2}{(K-1)K}\Big]^{1/2} - (1)$$

$$s_{\bar{x}} = \Big[(1 - K/A)\frac{1}{\bar{M}^2 K}\sum_{k=1}^{K} M_k^2 s_k^2\Big]^{1/2} - (2) \qquad (5.2)$$

where K: number of clusters selected Mk: cluster size $s\bar{x}$ *is standard error;* a *is number of clusters selected; A is total number of clusters in a population;* xa *is a cluster mean, and* $\bar{x}$ *is the overall mean;* *(1-K/A): finite population correction*

Standard error calculation for cluster samples (Henry 1990: 108).

Three Clusters Tinsley, Brinsworth and Catcliffe.

Tinsley	Brinsworth	Catcliffe
$\frac{67}{5} = 13.4$	$\frac{75}{5} = 15$	$\frac{46}{5} = 9.2$

The overall mean = 62.7 $\bar{x}$

$sx^2 = [(13.4 - 62.7)^2 + (15 - 62.7)^2 + (9.2 - 62.7)^2 / (2) * (3)$

$sx^2 = 7568.03 / 6$

$sx^2 = 1261.3$ $\qquad s_{\bar{x}} = 35.52$ **Standard error of the mean.**

Five clusters of the fifty m bands (0-50), (50-100), (100-150), (150-200), (200-250).

0-50	50-100	100-150	150-200	200-250
$\frac{20}{3} = 6.7$	$\frac{35}{3} = 11.7$	$\frac{65}{3} = 21.6$	$\frac{37}{3} = 12.3$	$\frac{30}{3} = 10$

The overall mean = 12.46

$sx^2 = [(6.7 - 12.46)^2 + (11.7 - 12.46)^2 + (21.6 - 12.46)^2 (12.3 - 12.46)^2 + (10 - 12.46)^2 / (4) * (5)$

$sx^2 = 123.29 / 20$

$sx^2 = 6.16$ $\qquad s\bar{x} = 2.5$ **Standard error of the mean.**

Although there seems to be a representative sample of each of the different ethnic minorities with relation to the wider census data, a weighting was calculated to test whether when applied to the statistical analysis there was any change to the data. This would help identify any under representation of a section of the population in the event of the weighting not influencing the outcome it can be presumed that the population was representative.
The weighting equation is as follows.

$w = Pp / Ps$

Where *Pp is the population proportion, and*
Ps is the sample proportion.

Ethnic Background	*Weighting*
White British	*0.875*
White European	*1.889*
Asian	*1.471*
African	*11.11*
American/ Caribbean	*75*
Non response	*N/a*

Appendix 2D Copy Of The Questionnaire In English, Versions Were Also Available In Urdu, Bengali And Somali

Questionnaire Spring 2002

For office use only: version 2

Part I: Environmental Pollution

1. Please circle the number which represents how you feel about each of the following issues in your area: **(1 indicates no problem - 6 indicates severe problem)**

a.	Road Traffic Noise	1	2	3	4	5	6
21.	Aircraft Noise	1	2	3	4	5	6
22.	Air pollution	1	2	3	4	5	6
d.	Water pollution	1	2	3	4	5	6
e.	Graffiti	1	2	3	4	5	6
f.	Litter	1	2	3	4	5	6

2. *Does road traffic noise directly affect you, when you're in your house or outside in the garden/yard?*

Yes □ (please Answer question 3) **No** □ (please move on to question 4)

3. *If yes, please indicate how it affects you, by ticking any of the boxes, which relate to how road traffic noise affects you.*

	Yes	*No*
a. Disturbs indoor leisure activities; i.e. reading, watching T.V	□	□
b. Prevents the use of outdoor space; i.e. using garden/yard	□	□
c. Prevents windows being opened	□	□
d. Makes you feel tense, tired and irritated	□	□

e. Has contributed to illness. (Please state) ______________________

f. Other (please state) ______________________

4. In your personal opinion, has the level of noise pollution decreased in your area in the last 12 months?

Yes □ (please answer question 5)
No □ (please move on to question 6)

5. *Please write below, a brief reason for the improvement in noise pollution in the last 12 months.*

6. Is there anything in-between your house and the motorway, please tick any of the following

a) Scheme of planting, trees or bushes □
b) Earth bank □
c) Wall (e.g. retaining wall, stonewall or brick wall) □
d) Building (houses, offices, factories, shops) □
e) Timber Fence □
f) No protection □
g) Others, please state: ______________________

7. Which side of your house is in the direction of the motorway?

Front □
Back □
Side □

8. Is your bedroom at the front or the back of the house?

Front □

Back □

9. Do you have double-glazing at all?
Yes □ No □ Partial □ }Bedroom □
}Living Room □

10. Do you think that noise from the traffic is a problem, / nuisance in this area?
Yes □
No □
Use to it □

11. Have you ever complained about road traffic noise?
Yes □ (Go to Qu. 12) No □ (Go to Qu. 13)

12. If yes to who have you complained? Is it…?

	Yes	No
a) Environment Agency	□	□
b) Town council/ County Council	□	□
c) Highways Agency	□	□
d) Local Forum	□	□
e) Environmental Health Department	□	□
f) Newspaper or other media	□	□

g) Other, (please state):______________________

Part II: Your thoughts on the new road traffic barrier

13. Are you aware that a noise barrier has been built alongside the M1 to reduce the noise pollution problem in your area?
Yes □ (go to question 14) No □ (go to question 15)

14. How did you find out?
a) Newspaper □ d) Through the local school □
b) Local Forum □ e) Through the Church/Mosque □
c) Word of mouth □ f) other (please state) ____________

c) Please indicate your agreement or disagreement with the following statements by circling the response that most nearly coincides with your own.
SA = Strongly Agree; A = Agree; U = Uncertain;
D= Disagree; SD = Strongly Disagree.

c) Public Participation in the design process was very effective, all the Residents had the opportunity to make their suggestions. SA A U D SD

b) I felt very involved in the barrier project due to good information availability for the local residents. SA A U D SD

c) The barrier has reduced the noise significantly SA A U D SD

d) The barrier is a success because local residents were allowed to make suggestions over its height and location SA A U D SD

16. Would you have liked to be more involved in the designing of the noise barrier on the M1?
Yes □ No □ don't know □

17. Residents should be made fully aware of projects before they are commenced?
a) I strongly agree □
b) I agree □
c) I'm not bothered □
d) I disagree □

e) I strongly disagree □

18. Please circle how you feel about the following methods of involving the public in the design of a noise barrier. **(1= best - 5= worst)**

a) Questionnaire in your home	1	2	3	4	5
b) Local public meeting	1	2	3	4	5
c) Using the Internet	1	2	3	4	5
d) Public exhibition to view the finalised plans	1	2	3	4	5
e) Questionnaire after the barrier is constructed	1	2	3	4	5

19. Since the barrier's construction in spring 2001, have you noticed a difference in the noise levels at your house?
a) Decreased noise □
b) Increased noise □
c) No change □

c) What do you think are the most important functions of a noise barrier?
(1 Most Important - 5 Least Important).

a) Reduction in noise	1	2	3	4	5
b) Looks good for the residents	1	2	3	4	5
c) Looks good for the motorists	1	2	3	4	5
d) Blends in with the environment	1	2	3	4	5
e) A contemporary design	1	2	3	4	5

21. Do you use the Internet; please indicate where.
a) No □
b) Work □
c) Home □
d) Library □
e) Other, please state; ______________________________

22. Do you feel you would participate in more local planning issues if;

		Yes	No
1.	You could do it over the internet	□	□
2.	If meetings were more frequent	□	□
3.	Meetings were arranged for different groups of the community	□	□
4.	If meetings were better advertised.	□	□
5.	Other (please state) ______________________________		

23. Have you ever attended a meeting of the Local Community Forum?
Yes □ (go to Qu. 25) **No** □ (Go to Qu. 24)

24. If no, please indicate which of the following statements most closely resembles why not
a) I've never heard of the Community Forum □
b) I feel intimidated by large groups □
c) I feel I won't get my say anyway □
d) Nobody listens to what the Forum says □
e) I'm afraid I won't be able to hear □
f) I'm restricted by mobility □
g) Local issues don't interest me □
h) I don't have time □
i) Other reason please state

25. Do you personally feel you have an opportunity to have your say about local issues, in your area;
Yes □ No □ if not please state why?

____

Part III: Personal Information- All personal information will be held in the strictest confidentiality, it will be viewed solely by the researcher for the purpose of data handling and to ensure a representative sample has been studied.

26. Please indicate your gender

- Male ☐ b. Female ☐

27. Please indicate which age group you fall into

- 18-24 ☐
- 25-34 ☐
- 35-44 ☐
- 45-54 ☐
- 55-64 ☐
- 65-74 ☐
- 75 + ☐

16. Please describe your ethnic background

____

29. Please describe the standard of English language you use

- Fluent ☐
- Conversational ☐
- Basic ☐
- No English ☐

20. What is your first language?

____

21. Are you registered disabled?

Yes ☐ **No** ☐

32. If you suffer from any of the following complaints, please tick.

		Yes	No
❖	Permanent deafness	☐	☐
❖	Mild ear problems (wax build up)	☐	☐
❖	Tinnitus (ringing in the ears)	☐	☐
❖	Angina/ High blood pressure/ heart disease	☐	☐
❖	Insomnia (unable to sleep)	☐	☐
f.	Other (please state)	☐	☐

____

33. Please estimate in an average 24-hour period how long you spend in your house?

Weekday (in hours) Weekend day (in hours)_______________

Thank you very much for your cooperation.

If you would like to add any further comments about any of the issues covered in this questionnaire, please use this space and the back of the page.

Appendix 3:

From Chapter Seven

3A	Web Links From Barrier Manufacturers
3B	Relevant BS, ISO And Other Material Standards
3C	The Calculations Of The Mass Of Each Of The Hypothetical Noise Barriers
3D	Sound Reduction Indices – For Materials
3E	Methodology For Calculating Transportation Fuel Use
3F	Expansion of the LCA Equation 7.2.

Appendix 3A Web Links From Barrier Manufacturers

Mineral wool	http://www.rockwool.co.uk/sw7046.asp accessed 09/06/2003
Transparent	www.plexiglas.de/
Various	http://www.urbantransport-technology.com/projects/hong_kong/hong_kong8.html
Various	http://www.cmit.csiro.au/research/papers/abstract.cfm/294
Willow	http://www.etsluk.com/Green%20Barriers/living_technical.htm
Various	http://www.tamu.edu/univrel/aggiedaily/news/stories/archive/082697-5.html
Various	http://www.lucid-communications.co.uk/section/2/
Concrete	http://concreteproducts.com/ar/concrete_sound_investment/
Timber	http://www.buffalostructures.com/
Timber	http://www.ransfords.co.uk
Various	http://fhwa.dot.gov/environmnet/noise/5htm
Various	www.grammbarriers.com
Various	www.hsipg.co.uk/companies/hands.html

Appendix 3B Relevant BS, ISO And Other Material Standards

Reference No	Title
BS EN ISO 14040:1997	Environmental management- Life cycle assessment – Principles and framework
94/2/EEC	Eco labelling
93/5068/EEC	Construction products directive
594/91/R	The banning of Chlorofluorocarbons
75/442/EEC & 91/156/EEC, 81/972	Reuse, recycling and the recovery of energy from materials
HA 66/95& 96	Design Guidelines for Environmental Barriers./ Environmental Barriers. Technical Requirements
MCHW Vol 1, Sec 2504	Manual of contract documents for highway works
BS 1722/7: 1999	Fences. Specification for wooden post and rail fences
BS EN 1793: 1998	Road traffic noise reducing devices. Test method for determining the acoustic performance. Intrinsic characteristics of sound absorption
BS EN 1794-2:2003	Road traffic noise reducing devices. Non-acoustic performance. General safety and environmental requirements
BS 5756:1997	Specification for visual strength grading of hardwood
BS 8110-1:1997	Structural use of concrete. Code of practice for design and construction
BS 5950-3.1:1990	Structural use of steelwork in building. Design in composite construction. Code of practice for design of simple and continuous composite beams
BS 8118-1:1991	Structural use of aluminium. Code of practice for design
BS 5400-6:1999	Steel, concrete and composite bridges. Specification for materials and workmanship, steel
ZTV Lsw88	Guidance for transparent materials (Germany)

Appendix 3C- The Calculations Of The Mass Of Each Of The Hypothetical Noise Barriers

The calculations of the mass of each of the hypothetical noise barriers in Kgm²

Steel & Aluminium both come as 14-18 Gauge = 75-100mm. Weight of 75mm barrier = 17/18 kg/m² for a fully constructed barrier with air gap and rock wool absorbers

All metal noise barriers are typically in the range of 18-22 gauge, which is 0.79mm and 1.27mm for steel and 1.59, and 6.35 for aluminium[1]

Timbers minimum thickness is 24mm thick Douglas fir timber = 15 kg/m². According to the main importers of foreign timber and producers of UK sawn timber[2].

Transparent noise barriers that are non-glass are mainly made out of Plexiglas (Perspex and Glass). The minimum width for a noise barrier is 15mm, however the average of the three commercially available sizes is 20mm, and the weight of a barrier 20mm wide is 23.7 kg/m². Therefore this will be taken as the standard in accordance with ISO 1183:1987 (Plastics -- Methods for determining the density and relative density of non-cellular plastics).

Concrete pre-cast panels are confined to 4.5m lengths, and the minimum thickness is usually directly related to the amount of concrete required to cover the reinforcing bars or mesh. Buts its typically about 100mm plus an additional 25mm in total to allow for the reinforcing and any surface texture[1]. The average density of the concrete is 2400 kg/m²in accordance with BS1881-114 1983 'Density of Hardened Concrete'.

Willow barriers come in two main varieties live willow noise barriers and willow weave noise barriers. Both types consist of 240mm thickness of soundproof stone wool. This is compressed stone wool of greater than 35 kg/m2 of constructed barrier. The density of the wool required must be greater than 140kg to give it the insulation properties required to meet the Highways Agency standard. The willow section of the barrier consists of 60 rods per linear metre of barrier with a diameter of approximately 30mm. The dry weight of each linear metre is 50kgs 2.

[1] Data calculated from the average value according to Environmental Silencing Ltd and the Federal Highways Agency.

[2] Charles Ransfords and Calder's and Grandidge

[1] Federal Highways Agency

[2] Bowles, A. (2003). Carbon Analysis for Green Barriers. Joynt.J. Sheffield, ETS Ltd.

Appendix 3D Sound Reduction Indices – For Materials

Sound Reduction indices										
Material and Construction	Thickness								Rw	Ave.
			125	250	500	1k	2k	4k		SRI
Single sheet materials	mm or swg	Weight Kg/m^2								(100-3150Hz)
Aluminium, corrugated, stiffened	20	2.44	33	31	33	33	42			
Steel sheet 1m x 2m	16g	12.9	16	20	27	32	37			
Ditto	1	11							29	26
1.2mm steel sheet	18g	10	13	20	24	29	33	39		26
Steel sheet 1m x 2m wih stiffeners	16g	12.9	17	18	23	30	36			
20 g galvanised sheet steel	0.9	7	8	14	20	26	32	38		
18 g galvanised sheet steel	1.2	10	13	20	24	29	33	39		
T & G timber boards, joints sealed	25	14	21	17	22	24	30	36		25
Hardwood (mahogany) panels	50	25	19	23	25	30	37	42		
fibre covered by 22g perforated steel										
As above, but 16g steel replaced with 5mm p	100	50	34	35	44	54	63	62		
190mm Dense concrete block	190	215	39	41	45	49	56	60		
100mm dense concrete (2300Kg/m^3)	100	230	37	39	45	52	58	62	47	
150mm dense concrete	150	345	29	39	45	52	60	70		
150mm dense concrete (2300Kg/m3)	150	345	40	43	48	55	59	63	53	
200mm dense concrete (2300Kg/m3)	200	460	42	46	50	57	60	65	55	
300mm dense concrete (2300Kg/m3)	300	690	40	45	52	59	63	67	56	
100mm Reinforced concrete	100	230	38	38	41	48	57	65		
Glass bricks	200	510	30	35	40	49	49	43		
T & G boards, wood joists joints sealed	21	13	21	18	22	24	30	33		
Single glazed windows										
13mm acoustic laminate	13		30	32	37	41	39	46	39	
16mm acoustic laminate	16		29	31	38	40	39	50	40	
Double glazed windows										
6/12/11 acoustic laminate			26	28	38	47	43	51	41	

Appendix 3E Methodology For Calculating Transportation Fuel Use BRE

Road

The assumptions to be used for Road Transport are listed below

A Annual Delivery Quantity *This is taken to be the annual input quantity of the product into the process, even where more or less product has been delivered in the given period than has been used, due to stockpiling, or no quantity is given Transport is considered for all given inputs into the process, including fuels such as diesel and LPG.*
B Gross Laden Weight of Vehicle *Where data is given on the size of vehicle, it is taken to mean the GLW of the vehicle. The maximum size of vehicle permitted on UK roads until 1999 was 38 tones, except for travel to or from a railhead. Therefore, unless details of rail transport are also given, the maximum size of vehicle is assumed to be 38 tones.*
C Average Delivery Load *Where the average delivery load is not given, then it is calculated from DETR UK Transport Statistics for the Gross Laden Weight of the Vehicle as given and for the type of load it is carrying figure (taking account of part load % if necessary). If neither an Average Delivery Load nor a Gross Laden Weight of Vehicle are given, then the Annual No of Deliveries is used to calculate the Average Delivery Load. The Gross Laden Weight is then estimated from this. If no Annual No of Deliveries is given either, then the most common form of transport for that commodity is taken from UK Transport Statistics3.*
D Annual No of Deliveries *Where this information is given, it is used to calculate the Average Delivery Load (A/D). Where either the Gross Laden Weight of the Vehicle or Average Delivery Load have also been given, then it is checked that the calculated average load agrees with the given average load. If it is not given, then it is calculated (A/C).*
E Delivery Distance *If this is not given, then it is taken as the "average haul" from the UK Transport Statistics for the given vehicle type and commodity transported.*
F Full or Part Load *Where the delivery is a full load, e.g this is the only delivery made on the outward trip, then the load is 100%. Where the delivery is a part load, we have presented the information as the percentage of the load taken by the given delivery. If no percentage has been given, then it has been assumed to be 25%. For a part load, the fuel consumption is calculated inexactly the same way as for a full load, but only the given percentage is allocated to the product.*
G Return Trip Empty or Full *Where no data has been given, the return trip has been assumed to be Empty.* *For Empty trips, then the delivery distance is doubled to give the total distance traveled per delivery. Part Loads are taken to be Empty Returns. For Full trips, then the delivery distance is taken to be the total distance traveled per delivery.*
H Total Distance Traveled *If the Return Trip is Full then Total Distance Traveled = Delivery Distance (E). If the Return Trip is Empty or the delivery is Part Load, then Total Distance Traveled = 2* Delivery Distance (2E).*
J Fuel Consumption *Taken from DETR UK Fuel Statistics for each class of vehicle (B), and converted to liters/km.*
*Fuel Used = No of Deliveries * Distance Traveled * Part Load % * Fuel Consumption = D * H * F * J*

Fuel Consumption Figures: 1997 DETR Correspondence

	Rigid <7.5t	*Rigid 7.5-14t*	*Rigid 14-17t*	*Rigid 17-25t*	*Rigid 25t+*	*Artic <=30 t*	*Artic 30-33t*	*Artic 33 t*
Miles Per Gallon	*11.8*	*10.7*	*8.9*	*6.8*	*6.5*	*7.9*	*7.9*	*7.2*
Kilometers Per Gallon	*19.0*	*17.2*	*14.3*	*10.9*	*10.5*	*12.7*	*12.7*	*11.6*
Liters Per Kilometer	*0.2394*	*0.2641*	*0.3175*	*0.4155*	*0.4347*	*0.3576*	*0.3576*	*0.3924*

Rail

The various types of information which have been provided for Rail Transport are listed below:

A Annual Delivery Quantity: *This is taken to be the annual input quantity of the product into the process, even where more or less product has been delivered in the given period than has been used, due to stockpiling.*
B Type of Rail Transport *This is taken to be a Western European mix of Electric and Diesel. All rail travel is assumed to be containerised.*
E Delivery distance *A Delivery Distance must be obtained for rail transport.*
J Fuel Consumption *0.15MJ/t.km electricity* *0.1466MJ/t.km Diesel*
Train Electricity consumption = A x Ex J (0.15) *Train Diesel consumption = A x Ex J (0.1466)* Both of the above calculations should be carried out for each train journey

Shipping

The various types of information which have been provided for shipping are listed below:

A Annual Delivery Quantity: This is taken to be the annual input quantity of the product into the process, even where more or less product has been delivered in the given period than has been used, due to stockpiling, or no quantity is given
B Type of Ship Where data is given on the type of ship, fuel consumption data for that type of shipping will be used. Otherwise it is assumed that containerised shipping is used and this fuel consumption will be used.
C Average Delivery Load Where the average delivery load is not given, then it is assumed that it is equal to the Annual Delivery Quantity (A).
D Annual No of Deliveries Where this information is given specifically for shipping, it has been used to calculate the Average Delivery Load (A/D). Otherwise it is assumed to be 1.
E Delivery distance
A Delivery Distance must be obtained for shipping transport.
G Return Trip Empty or Full Where the return trip is given as empty, then the distance traveled is taken to be double the delivery distance. Otherwise, shipping is assumed to be containerised with a full return trip. J Fuel Consumption Tonne-km fuel consumption has been used of 0.0038 kg Diesel/ tonne-km for Containerised Shipping and 0.0018 kg Diesel/tonne-km for Inland Navigation.
Fuel Consumption = Annual Delivery Quantity * Delivery Distance * Annual Number of Deliveries * Fuel Consumption = A * E * D * J

Appendix 3F Expansion of the LCA Equation 7.2.

$$LCA = (w \times T) + (R + D + M + E) \quad (7.2)$$

where: *LCA= Environmental lifecycle assessment of a noise barrier; w = weighting (Table 7.14); T= Transportation impacts; R= Recyclability; M= Maintenance; D= Disposal of material un-recycled to landfill; E= Weighted environmental impacts from 'cradle-to-gate'*

The higher the value of the *LCA* the less environmentally that noise barrier material can be concluded to be, this is a useful tool for the comparison of materials on an environmental basis before the final presentation of the choices to the public.

$$T = (Co + Nox + VOCs + Co2 + CH4 + e)g / t / km \quad (7.3)$$

As the value for all of the pollutants with the exception of Embodied Energy (e) are in the unit of grams, the value of energy has to be converted from kilojoules (KJ) per tonnes (t) of material transported 1 kilometre (km) to grams (g) per tonne (t) of material transported per kilometre (km). In order to accomplish this a value of the equivalent amount of fuel used to produce the same amount of energy in kilojoules has to be established.

Using the value of tonnes of oil (TOE) equivalent allows this conversion to be undertaken as follows:

1 TOE = 10^7*KCal*
1 KCAL= 4.187KJ

Thus, for an energy value of *n* kilojoules (KJ) to be converted to grams (g), the following calculation must be undertaken. where n = the energy value to transport 1 tonne of material by road or rail over a specified number of kilometres.

$$n(KJ)/4.187 = n(Kcal)$$
$$n(KCal)/10^7 = n(TOE)$$
$$n(TOE)x1000 = n(kg)$$
$$n(kg)x1000 = n(g)$$
$$n\ (g) = e\ (Energy\ in\ g/t/km) \quad (7.4)$$

The value for *R* can be determined from table below, for each of the main noise barrier materials.

Barrier Material	Concrete pre cast	PMMA	Aluminium	Steel	Living willow	Woven willow	Stone Wool	Timber
R= Sum of recycling values converted from BRE data	6	5	5	7	6	8	11	9

The value for *M* is derived from the environmental score given to each of the barrier materials based on having 1 (fairly low) maintenance requirements 5 (fairly high) maintenance requirements, as presented in the table below.

Barrier Type	Environmental Score
Timber	1
Concrete	2
Metal	1
Transparent	5
Willow weaved	1
Willow living	3

The value for D is the final weight of material that will be sent to landfill in . Although it is accepted that there may be some further benefits derived from the creation of energy from landfill gases this is not explored further here.

Appendix 4:

From Chapter Eight

4A **Sites Of Data Collection For The Perception Exercise**

4B **Questionnaire For Test Of Perception Of The Attenuation Of Noise**

Appendix 4A Sites Of Data Collection For The Perception Exercise

Site 1. Reflective Metal Barrier.

Junction 28 Southbound of the M1 nr. Nottingham, Nottinghamshire. Accessed from the Marriott hotel gardens. Approximately 10metres from the Northbound carriageway and slip road.
The section of the M1 through J28 currently carries 97,000 vehicles to the south. Heavy goods vehicles account for 18% of this traffic.
Weather overcast, and dry, no wind.

Site 2. Absorptive Timber Barrier

Junction 28 Northbound of the M1 nr. Nottingham, Nottinghamshire. Accessed from local fields data recorded approximately 13m from the carriageway on a 45° angle due to the height of the barrier and topography of the land. Had the recordings been carried out straight on from the barrier the traffic would have been obscured reducing the visual stimulus.
The section of the M1 through J28 currently carries 119,000 vehicles per day to the north. Heavy goods vehicles account for 18% of this traffic.
Weather overcast, and dry, no wind.

Site 3. Reflective Acrylic Transparent Barrier.

Junction 4 M65 Southbound nr. Blackburn. Lancashire. Accessed from local residents garden. Data recorded approximately 10m from the carriageway facing the barrier directly.
Weather overcast and dry, slight wind.

Site 4. Reflective Concrete Barrier.

Nr Junction 33, M1 Northbound in Catcliffe. Accessed through local landowners field. 10m from the barrier looking up towards it. This section carries 57,613 vehicles per day to the north. Heavy goods vehicles account for 18% of this traffic. Weather fine and sunny, slight wind.

Appendix 4B Questionnaire For Test Of Perception Of The Attenuation Of Noise

Test of perception of the attenuation of noise-by-noise barriers made of various materials.

Date: Wednesday 17th/ December/ 2003.
Location: RAVE Computer Sciences Department.
Time of session_______
Seat position number________.
Researchers. Jenny Joynt and Meng Yan: School of Architecture. University of Sheffield

Your Details

Age

Gender

Ethnic background

Department

Any hearing problems

Main tests. Please take some time to read this before the test.

The test consists of 3 sections, the first shows a set of video clips with no accompanying sound and you are asked to make a prediction of how well the barriers will attenuate noise by raking them from best (1) to worst (5). Test 2 involves you seeing five sets of films, each set containing five video clips of traffic passing some noise barriers, and you will be asked to judge how much noise you can hear from behind each barrier.

This is the main test and you will see and hear the noise barriers in action. You will see that the first barrier to appear is accompanied by the value **5** in the answer table, please give a value relative to this for all the other barriers in that group.

For example if you think all the other barriers allow higher noise levels through give them each values above 5, if you think they are the same you can give them the same value and if you think they are letting less through give them a lower value. Each group of five clips should be judged independently to all the other sets. The values you give must be between 0 – 9, and must be whole numbers.

Finally please do not talk while the test is underway, we are interested in your own personal opinions and whether there are any trends so please evaluate the sounds by yourself.

Test number 1: Please predict how well they'll perform by ranking from best

(1) Best – (5) worst.	Timber	Metal	Concrete	Transparent	Vegetative

Test Number 2: Each test will take approximately 2minutes to complete; with a few minutes in between to vary the volumes therefore the whole process should take no longer than 30-minutes.

	Barrier Types: Louder In the order they will appear. →				
Set 1	Concrete	Metal	Vegetatio n	Timber	Transparent Acrylic
Score →	5				
Set 2	Metal	Vegetatio n	Transpare nt Acrylic	Concrete	Timber
Score →	5				
Set 3	Vegetatio n	Transpare nt Acrylic	Timber	Metal	Concrete
Score →	5				
Set 4	Timber	Concrete	Metal	Transparent Acrylic	Vegetation
Score →	5				
Set 5	Transpare nt Acrylic	Timber	Concrete	Vegetation	Metal
Score →	5				

Key to scale
5= base line, 6= very slightly louder, 7= slightly louder, 8= louder, 9= much louder

Test Number 3: Please rank the barriers in order of attractiveness from most 1 to least 5. (To help you decide on this imagine you live next to a motorway or main road, which barrier would you most like to see from your house?)

Barrier	Timber	Metal	Concrete	Transparent	Vegetative
Ranking of attractiveness					

That's the end of the test, thank you very much for participating if you would like to find out about the outcomes of the research please write your contact details below and I will be happy to send you a copy in the New Year.

If you would like to make any comments or suggestions about the research please feel free to use the space below and on the reverse.

Thanks again
Jenny Joynt and Meng Yan (Mary).
Post Graduates
School of Architecture