Interaction and integration of visual and noise impacts of motorways

Like Jiang

September 2015

Thesis submitted for the fulfilment of the degree of Doctor of Philosophy in Architecture

School of Architecture
The University of Sheffield

Acknowledgements

I would like to give thanks to my first supervisor Prof. Jian Kang who led me into the world of acoustics and more beyond, and offered continuous guidance, support and encouragement throughout the work to complete this thesis; and to my second supervisor Dr. Olaf Schroth for his interest and guidance on this inter-discipline work.

The thesis would not have been completed without helps from the members of the Acoustic Group in the University of Sheffield. Particularly, I am greatly thankful to Dr. Östen Axelsson, for his helps on recording and guidance on experimental design and statistics; to Dr. Francesco Aletta, for his helps on lab setting-up and guidance on audio signal processing; and to Dr. Yiying Hao, for always being available for inquiries in the initial stage of my PhD.

My thanks also goes to the friendly people in Sheffield where I had a lot of good memories during the four years. Special thanks to John Richmond for his multi-helps on things from daily hassles to PhD work, and, including him, people in the Hallamshire tennis club where I enjoyed great fun of tennis.

I would also like to thank the acoustic group in the Second University of Naples for offering me the opportunity to explore further after my PhD, and their understanding and support in the past two months for me to finalise my thesis.

Finally, I want to express my deep sincere thanks to my parents, who have always been there to support me for my pursuits, and been tolerant for my being far away apart for so long. Wherever I go, there is always a place I can call home.

Abstract

This study aimed to achieve a better understanding of the visual and noise impacts of motorways and their integrated impact on the environmental quality via an aural-visual interaction approach, to contribute to more reliable and efficient assessments of the impacts. The study was based on perceptual experiments involving human participants using computer-visualised scenes and edited audio recordings as experimental stimuli.

Factors related to road project characteristics and existing landscape characters that potentially influence the perceived visual impact of motorways were first investigated on without considering the impact from moving traffic. An online preference survey was conducted for this part of study. The results showed substantial visual impact from motorways especially in more natural landscapes and significant increase in the impact by opaque noise barriers. Map-based predictors were identified and a regression model was developed to predict and map the perceived visual impact in GIS.

The second part of the study investigated the effects of traffic condition, distance to road and background landscape on the perceived visual impact of motorway traffic, and the contribution of traffic noise to the perceived visual impact. A laboratory experiment was carried out where experimental scenarios were presented to participants both with and without sound. The results showed significant visual impact from motorway traffic which was higher in the natural landscape than in the residential counterpart, increased by traffic volume and decreased by distance. Noise increased the perceived visual impact by a largely constant level despite changes in noise level and other factors.

With findings on visual impact from above studies and knowledge on noise impact from current literature, the third part of this study, with a second laboratory experiment, investigated on the perceived integrated impact of visual intrusion and noise of motorways, and explored the predictability of the impact by noise exposure indices. The results showed that traffic volume expressed by noise emission level

was the most influential factor, followed by distance and background landscape. A regression model using noise level at receiver position and type of background landscape as predictors was developed, explaining about a quarter of the variation in the perceived impact.

Concerning the acoustical and visual effects of noise barriers found on perceived environmental quality, the fourth part of the study focused on mitigation of the integrated visual and noise impact by noise barrier. A third laboratory experiment was conducted and the results showed that noise barriers always had either beneficial or insignificant effect in mitigating integrated impact, and the effect was largely similar to that of tree belt. Generally, barriers varying in size and transparency did not differ much in their performance, but there seems to be some difference by barrier size at different distances.

Lastly, using the above findings of this study, impact mappings as possible prototype of more advanced tools to assist visual and noise impact assessment were demonstrated.

CONTENTS

List of Figures

List of Tables

List of Abbreviations

2D:	Two Dimensional
3D:	Three Dimensional
AB:	Amount of Buildings in the Viewshed
ABB:	Amount of Buildings in the Viewshed in Background
ABF:	Amount of Buildings in the Viewshed in Foreground
ABM:	Amount of Buildings in the Viewshed in Midground
ANOVA:	Analysis of Variance
APE:	Area of Potential Effect
AT:	Amount of Trees in the Viewshed
ATB:	Amount of Trees in the Viewshed in Background
ATF:	Amount of Trees in the Viewshed in Foreground
ATM:	Amount of Trees in the Viewshed in Midground
dB:	Decibel (unweighted)
dB(A):	Decibel (A-weighted)
CNOSSOS-EU:	Common Noise Assessment Methods in Europe
CRTN:	UK's Calculation of Road Traffic Noise
DEM:	Digital Elevation Model
GIS:	Geographic Information System
HGV:	Heavy Good Vehicle
IEMA:	Institute of Environmental Management & Assessment
IL:	Insertion Loss
$L_{A10, 18h}$:	The 10-Percent Exceeded Level during the 18 hours using A-weighting

L_{Aeq}:	Equivalent Continuous Sound Pressure Level using A-weighting
L_{den}:	Day-evening-night Equivalent Level
L_{night}:	Night Equivalent Level
PB:	Percentage of Buildings in the Viewshed
PBB:	Percentage of Buildings in the Viewshed in Background
PBF:	Percentage of Buildings in the Viewshed in Foreground
PBM:	Percentage of Buildings in the Viewshed in Midground
PCU:	Passenger Car Unit
PT:	Percentage of Trees in the Viewshed
PTB:	Percentage of trees in the viewshed in background
PTF:	Percentage of Trees in the Viewshed in Foreground
PTM:	Percentage of Trees in the Viewshed in Midground
SLPavg:	Average slop of visible land
SLPstdv :	Standard deviation of the slops of visible land
SPL:	Sound Pressure Level
URL:	Uniform Resource Locator
VIA:	Visual impact Assessment
ZTI:	Zone of Theoretical Influence

Chapter 1 Introduction

1.1. Research background

Visual impacts are changes in visual landscape quality brought about by developments in association with human experience of the changes, and are required to be assessed as an essential component of the Environmental Impact Assessment by EU regulations (Landscape Institute and IEMA, 2013). Transport infrastructures can always have strong visual impact, adversely or positively. While some well-designed projects may contribute to enhanced landscape quality, projects like motorways always tend to impose negative visual impact, judged with general aesthetic appreciation, due to their massive scales and the large volume of traffic they are to carry. The specific methods and processes of motorway visual impact assessment applied in practice vary in different countries and regions and from different agencies (Bureau of Land Management, 1984; Federal Highway Administration, 1988; Highways Agency, 2010; Roads and Traffic Authority, 2009; U.S. Forest Service, 1974 & 1995). Generally, the assessment takes into account factors associated with three main components: the project, the existing landscape, and the viewer, and obtains judgement for steps related to the three main components either according to prescribed classification criteria, or by individual expert judgment, or by a combination of both. This type of expert-based approach is efficient (Lothian, 1999) but is criticised for the inadequate levels of reliability and precision (Daniel, 2001). On the other hand, research studies on visual landscape assessment on broader topics have drawn on perception-based approach to obtain more precise and reliable judgement (e.g., Anderson & Schroeder, 1983; Bishop & Miller, 2007; Buhyoff, & Leuschner, 1978; Louise, 1977; Schroeder & Daniel, 1981; Shafer, 1969). This approach, usually by the mean of a preference survey, derives visual quality of the landscape or visual impact on it as perceived by a sample of actual or potential viewers on site or by presenting surrogate media (Daniel, 2001). However, empirical research of this type on visual impact of road projects is very limited in literature, despite some effort made early in the 1970s (Gigg, 1980; Huddart, 1978; Hopkinson & Watson, 1974). On the other hand, new technologies have been developed in recent decades which can optimise the perception-based assessment. Some perception-based visual landscape studies integrated their prediction models derived from preference surveys into a geographic information system (GIS) by using map-based measures as predictive factors (e.g., Bishop & Hulse, 1994; Grêt-Regamey et al., 2007; Hadrian et al., 1988; Schirpke et al., 2013), to improve the predictiveness and achieve more efficient application of the models as planning tools. However, the potentials of this integration have not been explored for the assessment of visual impact of road projects.

Noise impact is another environmental impact that can be induced by motorway projects, which can have serious detrimental effects on human health and wellbeing. Methods and procedures for the assessment of road traffic noise impact have been well developed, as compared to the case of visual impact. Typical approaches of the assessment are based on noise exposure measure and/or calculation, to reflect the quality of noise climate or changes in the quality (Highways Agency, 2011; Federal Highway Administration, 2011). Attempts to measure noise nuisance have also been made by exploring the relationships between noise exposure and human responses which include annoyance, sleep disturbance, speech interference, performance, heart rate, etc. (Fidell et al., 2002; Knall & Schuemer, 1983; Tulen et al. 1986; Wilkinson & Campbell, 1984). Exposure-response curves developed from meta-analyses (e.g., Miedema & Vos, 1998; Miedema & Vos, 2007) can be applied in noise impact assessment to assess the harmful effect of noise on populations (EU, 2002a; Highways Agency, 2011).

Recently, research in environmental psychology has emphasised the multisensory nature of human perception (Cassidy, 1997). Multisensory approach, especially addressing the aural-visual interaction, has been applied in many studies aiming to gain deeper understanding on environmental perception and develop human-centred methodologies for soundscape and landscape assessment. It has been shown that sound environment perception is influenced by visual settings (e.g., Anderson et al., 1984; Mulligan et al., 1987; Viollon et al., 2002), and vice versa judgment on visual landscape quality is affected by sound environment (Anderson et al. 1983; Benfield et al., 2010; Hetherington et al., 1993). Many studies have also shown their interactive effects on perception of the overall quality of the environment (e.g., Carles et al, 1999; Hong & Jeon, 2013; Pheasant et al., 2008). The interaction is particularly important for assessment of motorway projects, as noise and visual impacts of motorways are very often symbiotic and can both be serious where the baseline environment is tranquil and of high scenic quality. Potential advantages of assessing visual and noise impacts in an integrated approach is also revealed as research suggests that assessing the overall environmental quality is easier and more natural than assessing environmental qualities of each individual sensorial modality (Nilsson et al., 2012). However, there is still a lack of systematic investigations to understand how identified factors which are influential on visual and/or noise impacts contribute to their integrated impact, and effort to explore possible assessment methods for the integrated impact.

1.2. Aims and objectives

The aim of this thesis is to achieve a better understanding of the visual and noise impacts of motorways and their integrated impact on the environmental quality via an aural-visual interaction approach, to contribute to more reliable and efficient assessments of the impacts. The detailed objectives are:

Objective 1: Investigate the effects of project related factors including the appearance of roadways, noise barriers, tree screen and distance to road on the perceived visual impact, explore the mathematical relationships between map-based measures of existing land covers and landform and the perceived visual impact, and consequently develop a GIS-based model to predict the impact. At this stage the potential visual impact induced by moving traffic was not considered.

Objective 2: Investigate the effects of traffic condition, distance to road and background landscape on the perceived visual impact of motorway traffic, and the contribution of traffic noise to the perceived visual impact.

Objective 3: Investigate the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of noise and visual intrusion of motorways, and explore how indicative noise exposure is to the perceived impact.

Objective 4: Investigate the overall performance of noise barriers in mitigating the perceived integrated impact of noise and visual intrusion of motorways, given different barrier characteristics, traffic levels, receivers' distances to road and background landscapes.

Objective 5: Demonstrate possible mapping applications concerning visual impact and the integrated impact based on the findings of this study, with comparisons to noise impact maps.

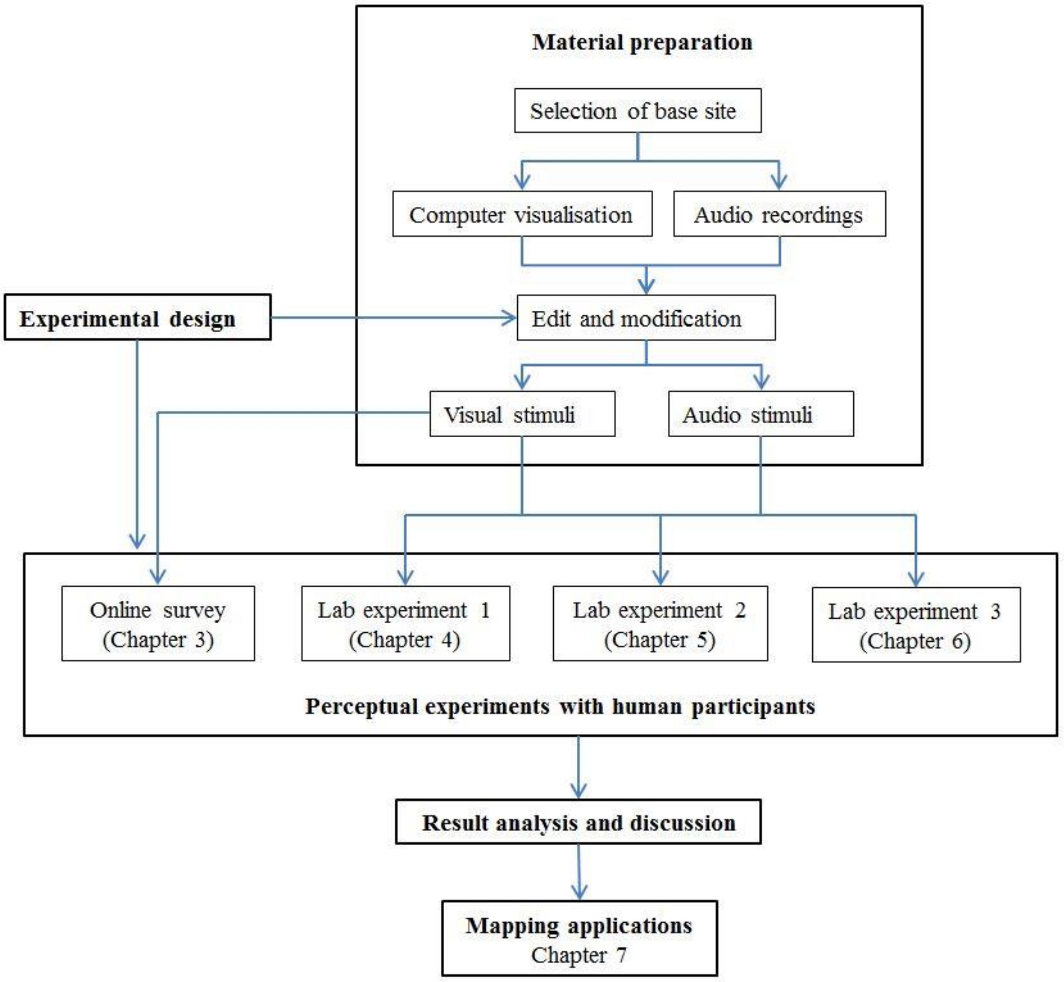

Figure 1.1. The overall methodology of this study

1.3. Research methodology overview

This study was based on perceptual experiments involving human participants using computer-visualised scenes and edited audio recordings as experimental stimuli. Figure 1.1 illustrates the overall methodology. A 2500 m × 2500 m site along a segment of the UK M1 Motorway was selected as the base site for computer visualisation and audio recording, with GIS data of the site derived from Ordnance Survey. The 3D mode and recoding files were then modified and edited for each experiment according to the specific experimental design. Sound pressure levels at receiver positions for scenarios where noise was presented was calculated in CadnaA. Four experiments, including one online survey and three laboratory experiments, were conducted for this study. Data obtained from the experiments was analysed using IBM SPSS Statistics 21. Possible GIS applications of the research findings were explored and demonstrated in ArcGIS 10.1.

1.4. Thesis structure

Chapter 1 briefly introduces the research backgrounds for visual impact assessment and research, noise impact assessment, and aural-visual interaction in environmental perception, followed by the aim and objectives of this study, and an overview of the research methodology. Finally, the structure of the thesis is listed.

Chapter 2 presents reviews of current literature on visual landscape and impact assessment in practice, visual landscape and impact research, noise impact assessment in practice, and research on aural-visual interaction in environmental perception. Firstly, visual landscape and impact assessment in practice is reviewed by giving out an overview of the issue, and the general method and procedure of the impact assessment for road projects. Then a review is made for research on visual landscape and impact, categorised into studies based on objective visibility measures and studies based on subject human perception. The third part of this chapter reviews noise impact assessment in practice by first giving an overview of the issue of environmental noise and then the general method and procedure of the impact assessment focusing on road traffic noise, followed by an extended review on noise barrier. Finally, research on aural-visual interaction in environmental perception is reviewed, covering topics of effect of visual settings on sound perception, effect of sound on visual perception, and the interactive effects on overall environmental perception.

Chapter 3 investigated the effects of the characteristics of the road project and the character of the existing landscape on the perceived visual impact of motorways without considerations of moving traffic, and developed a GIS-based impact prediction model based on the findings. An online preference survey using computer-visualised scenes of different motorway and landscape scenarios was carried out to obtain perception-based judgements on the visual impact. Motorway scenarios simulated included the baseline scenario without road, original motorway, motorways with timber noise barriers, transparent noise barriers and tree screen; different landscape scenarios were created by changing land cover of buildings and trees in three distance zones. The landscape content of each scene was measured in GIS. Results of the survey were analysed and 11 predictors were identified for the visual impact prediction model which was applied in GIS to generate maps of visual impact of motorways in different scenarios.

Chapter 4 investigated the effects of traffic condition, distance to road and background landscape on the perceived visual impact of motorway traffic, and the contribution of traffic noise to the perceived visual impact. Computer visualisation and edited audio recordings were used to simulate different traffic and landscape scenarios, varying in four traffic conditions, two types of landscape, and three viewing distances, as well as corresponding baseline scenarios without the motorway. Subjective visual judgments on the simulated scenes with and without sound were obtained in a laboratory experiment. Results of the experiment were analysed and discussed.

Chapter 5 investigated the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of visual intrusion and noise of motorways, and explored how indicative noise exposure is to the perceived impact. Six traffic conditions, consisting of three levels of noise emission × two levels of heavy good vehicle (HGV) percentage in traffic composition, two types of landscape and three distances to road, as well as corresponding baseline scenes without the motorway, were designed as experimental scenarios and created using computer visualisation and edited audio recordings. A laboratory experiment was carried out to obtain ratings of perceived environmental quality of each experimental scenario. The results were analysed and discussed.

Chapter 6 investigated the overall performance of noise barriers in mitigating the integrated visual and noise impact of motorways, taking into consideration their effects on reducing noise and visual intrusions of moving traffic, but also potentially inducing visual impact themselves. A laboratory experiment was carried out, using computer-visualised video scenes and motorway traffic noise recordings to present experimental scenarios covering two traffic levels, two distances of receiver to road, two types of background landscape, and five barrier conditions including motorway only, motorway with tree belt, motorways with 3 m timber barrier, 5 m timber barrier, and 5 m transparent barrier, as well as corresponding baseline scenarios without the motorway. Participants' responses were gathered and perceived barrier performance analysed.

Chapter 7 demonstrates some possible mapping applications using the results of this study. Maps of visual impact of motorways, including impact from moving traffic, were produced combining the results of Chapter 3 and Chapter 4. Maps of the integrated impact of visual intrusion and noise were generated based on the results of Chapter 5 and Chapter 6. For comparison, maps of noise impact were also produced, using noise exposure maps produced by commercial noise analysis software and exposure–effect transformation developed by other studies.

Chapter 8 concludes the thesis, summarising the research findings and discussing some limitations with future work to improve.

Figure 1.2 shows the relationship of the main chapters, Chapter 3, 4, 5, 6 and 7, with the research objectives. Original research work solely on noise impact, as should ideally be side-by-side with the presented work on visual impact, was not carried out in this PhD study, since knowledge on related topics is already broad and deep in existing literature, and noise impact assessment system is already well-established in practice. This thesis was not intended to make further contribution to noise impact research, rather, it was conceived to draw up a more complete picture, to compare, to relate, and to combine the impacts of noise and visual intrusion of motorways.

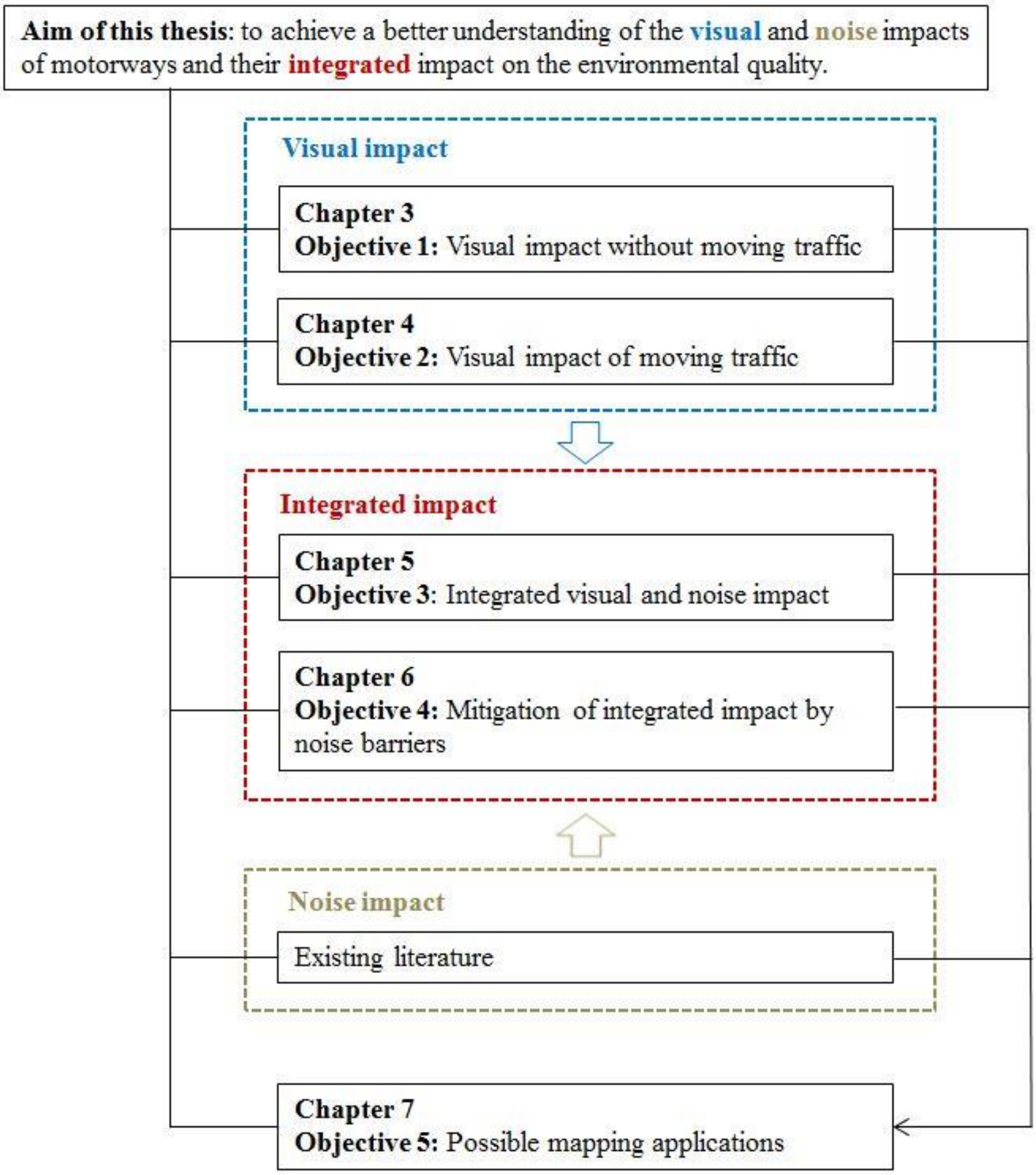

Figure 1.2. Relationship between the main chapters and the research objectives.

Chapter 2 Literature review

This review is split into four main sections, including review of current literature on visual landscape and impact assessment in practice, visual landscape and impact research, noise impact assessment in practice, and research on aural-visual interaction in environmental perception. Firstly, visual landscape and impact assessment in practice is reviewed by giving out an overview of the issue, and the general method and procedure of the impact assessment for road projects (Section 2.1). Then a review is made for research on visual landscape and impact, categorised into studies based on objective visibility measures and studies based on subject human perception (Section 2.2). The third part of this chapter reviews noise impact assessment in practice by first giving an overview of the issue of environmental noise and then the general method and procedure of the impact assessment focusing on road traffic noise, followed by an extended review on noise barrier (Section 2.3). Finally, research on aural-visual interaction in environmental perception is reviewed, covering topics of effect of visual settings on sound perception, effect of sound on visual perception, and the interactive effects on overall environmental perception (Section 2.4).

2.1 Visual impact of road projects

2.1.1. An overview of the issue of visual impact

The concept of visual impact has long been shaped in the landscape academia and practice since landscape is by and large perceived visually. A quality visual environment can enhance individuals' physiological and psychological experience while unpleasant scenes detract from their quality of life or opportunities for development. The visual impact or the quality of available views can be a significant concern in a various types of projects, from the top grade urban flats featured by magnificent views to the though small and closed landfills in rural areas, and the debated Eiffel Tower in the late 19th century to the giant energy facilities today.

The term "visual impact" here refers to the visual effect which is delivered by development or alterations in a certain context setting and generally regarded as negative or intrusive. An effect being negative or intrusive is the result of both objective and subjective factors which can be summarised as three types of scenario components: the object, the receptor and the environment (Hadrian et al 1988; Danese et al. 2009). The object is usually the development projects which will induce significant change in the physical appearance of the existing landscape and the visual effect of which is to be assessed; the receptor is any individuals or groups who can be visually affected by the object; the environment is the landscape settings where the objects and receptors located and those far behind the objects as far background, including every landscape element within the area and the atmospheric conditions. The properties of the object will determine the proposed visual changes which itself is very objective in nature (e.g., loss or addition of elements in the views). The properties of the environment will determine the sensitivity to the visual changes of the current context settings. In most cases, visual impact is more likely to arise when there is a sharp contrast between the object and the environment in terms of colour, line, and texture (Rogge et al. 2008). And the properties of receptors will have an effect on the way that the resulted impact is perceived and how it is responded to. Judging the significance of visual impact should take into account the receptor sensitivity which is dependent on the expectations and activities of the receptors and the number of people likely to be affected (Landscape Institute & IEMA, 2013).

While visual impact was not much a widely noticeable issue in traditional societies due to the slow pace of development and coherent adherence to vernacular design, technological and economic progress in the past century had introduced enormous and rapid changes of visual resources into our landscape, as well as raised people's awareness on the importance of scenic beauty (Smardon et al, 1986).

The National Environmental Policy Act of 1969 in US declares that the federal government is responsible for assuring safe, healthful, productive as well as aesthetically and culturally pleasant surroundings for the citizens. A great number of development projects and studies carried out in the 1960s and 70s, from national to site scale (e.g., river basin planning, power transmission lines, coal development, urban development, waterfall management), had shown concerns to aesthetic resource and visual impact, the work of which included landscape inventory, generic impact assessment, detailed visual impact assessment and mitigation, depending on the project scales and the potential significance of the impact (Smardon et al, 1986).

Rather than as a pure aesthetic issue which was usually dealt with in “design” approach, visual impact during that period, with the upsurge in sustainable development and rational planning, had already been and proposed to be addressed in a systematic framework along with considerations of other environmental impact. Methods to better achieve this were envisaged which proposed to integrate visual impact assessment into four general stages of environmental decision making: (1) environmental inventory; (2) policy formation; (3) program planning or project design; (4) postimpact evaluation (Smardon et al, 1986). In EU, visual impact assessment is carried out as part of the Environmental Impact Assessment which is an iterative process in project development (Landscape Institute & IEMA, 2013). Visual impact assessment is needed or will be helpful in several steps in the development process including site selection, design option comparison, design modification and monitoring after the completion of the projects (Landscape Institute & IEMA, 2013).

Typically, visual impact assessment, along with visual landscape quality assessment, have been approached on the basis of two contrasting paradigms, i.e., the objectivist and subjectivist paradigms (Lothian, 1999). The objectivist paradigm considers visual landscape quality as inherent in the biophysical features of the landscape, underlying surveys and classifications of landscape features for visual landscape and impact assessment. On the other hand, the subjectivist paradigm accepts that visual landscape quality derives solely from perceptual/judgmental processes of the human viewers, underlying surveys and studies of viewer preference for visual landscape and impact assessment (Daniel, 2001; Lothian, 1999).

Both of the two paradigms have limitations and either of them along cannot be correct. Visual landscape and impact assessment in practice and in research usually combine the two paradigms with different emphasises. Approaches with more emphasis on the objectivist paradigm are generally known as expert-based approach, and are dominant in environmental assessment and management practice (Churchward et al., 2013; Daniel, 2001). The expert-based approach derives objectively-measurable indicators of visual landscape quality from classical model of human perception and aesthetic judgement, and assesses visual landscape quality against the indicators calculated by measuring biophysical features of the landscape (Daniel, 2001). Expert-based approach is efficient and the use of measurable indicators is favoured in the systematic framework of environmental impact assessment. However, the indicators used can often be questionable for their validity in reflecting actual visual landscape quality as judged by the affected community (Daniel, 2001; Lothian, 1999).

On the other hand, approaches with more emphasis on the subjectivist paradigm are generally known as perception-based approach, and are dominant in research (Daniel, 2001). The perception-based approach employs community response to visual landscape, with the biophysical features of the landscape as stimuli, to determine the visual quality of the landscape (Daniel, 2001). Perception-based approach is seen to be more reliable than expert-based approach, since it derives visual landscape quality directly from the affected community, or from samples of affected community with the use of surrogate visualisation instead of real landscape as stimuli (Daniel, 2001; Lothian, 1999). However, perception-based approach is expensive, time-consuming, and not always available (Schirpke et al. 2013). To achieve higher efficiency, some shift towards the objectivist end has been made and measurable indices of perceived visual landscape quality are developed by correlate biophysical features of landscape to human preference to the landscape (e.g., Dramstad et al., 2006; Hunziker & Kienast, 1999; Palmer, 2004). The key difference of such indices from those used in expert-based approach is that they are evidence-based and are derived from empirical studies.

Detailed description of the expert-based approach particularly in practice of visual impact assessment of road projects is presented in Section 2.1.2; a review of studies on objective measures of visual impact is made in Section 2.2.1; and a review of perception-based visual impact studies is made in Section 2.2.2.

2.1.2. Assessing the visual impact of road projects

Guidelines for the assessment of visual impact caused by road projects have been developed by transport departments or other related government agencies in many countries. In the UK, the guideline was developed by Highways Agency (Highways Agency, 1993 & 2010) based on the general guideline for landscape and visual impact assessment published jointly by The Landscape Institute and the Institute of Environmental Management and Assessment (2nd ed, 2002), which differentiates the concepts of landscape and visual effects and separates the assessments. In the US, the Federal Highway Administration developed a set of guidelines for the assessment of visual impact caused by federally funded highway projects in response to the National Environmental Policy Act (Federal Highway Administration, 1988). Some states adopted the guidelines, while others adjusted them or developed their own (Churchward et al., 2013). Guidelines for visual impact assessment have also been developed outside of transport departments (e.g., Bureau of Land Management, 1984; U.S. Forest Service, 1974, 1995).

Generally, in these guidelines, visual impact is recognised as difference between visual quality of the landscape without and with the proposed projects. Most of them consider visual quality an intrinsic property of the landscape and largely rely on expertise for the evaluation. Although the specific assessment procedures vary, as well as the terminology, some common tasks are involved in the procedures proposed in these guidelines.

A baseline condition needs to be established at the outset of the assessment, by desk study and field survey, to understand the landscape and visual context upon which the proposed project may have an effect. This part of work documents the existing landscape character, usually by deconstructing landscape character into separate landscape components, e.g., landform, vegetation, water, manmade structures, with a description of some perceptual element such as scale, form, naturalness, etc. Area of Potential Effect (APE) (Churchward et al., 2013) or Zone of Theoretical Influence (ZTI) (Landscape Institute & IEMA, 2013) needs to be defined to determine the extent of potential impact and area to be assessed. This can be done manually on maps or digitally by viewshed analysis. The baseline study also needs to identify the potential receptors: people within the defined area who will experience changes in views caused by the proposed project.

Having established the baseline condition, a depiction of the visual appearance of the proposed project and comparing it with the character of the baseline landscape can reveal the degree of changes in visual quality of the landscape caused by the project. In the UK, the term “magnitude” is used for this part of assessment. Magnitude of the impact concerns the contrast of the proposed project with the baseline landscape in terms of form, scale, line, height, colour and texture, and the space and time scales of the resulted impact. In the general guideline (Landscape Institute & IEMA, 2013), magnitude of the impact, or more precisely, magnitude of the visual impact, is more of a neutral description; while in the guideline specifically for highway projects (Highways Agency, 2010), magnitude of the impact also considers the quality of the impact, i.e., whether it is adverse or beneficial. Usually, expert judgments are employed for this part of assessment in both the UK and the US procedures. 3D computer visualisation and/or 2D photo montage are commonly used to depict future landscape scenarios with the project to assist the evaluation as well as to communicate with the public.

The significance of impact is determined not only by the magnitude of the impact, but also the sensitivity of receptors to the impact (Churchward et al., 2013, Landscape Institute & IEMA, 2013). Here the receptor means the particular person of group of people likely to be affected at a specific viewpoint. The sensitivity is mainly a function of the receptor activity and awareness. Receptors with high sensitivity are likely to include residents at home, people engaged in outdoor recreation involving appreciation of views of the landscape, visitors to heritage assets, etc. Cultural and historical significance and local values attached to the views can also affect the sensitivity of receptors to the change in views. The categorisation of receptors into different sensitivity groups should be carried out case by case, and is usually based on expert judgements.

To evaluate the significance of the impact, the UK guideline (Highways Agency, 2010) suggests combining the magnitude of the impact and sensitivity of the receptors to form a significance matrix as shown in Table 2.1, with typical descriptors of the significance levels provided in Table 2.2.

Table 2.1. Matrix of the significance of the impact, reproduced based on Table 3 in Highways Agency (2010).

			Magnitude of impact			
		No change	**Negligible**	**Minor**	**Moderate**	**Major**
Sensitivity of receptor	**low**	Neutral	Neutral/Slight	Neutral/Slight	Slight	Slight/Moderate
	Moderate	Neutral	Neutral/Slight	Slight	Moderate	Moderate/Large
	high	Neutral	Slight	Slight/Moderate	Moderate/Large	Large/Very Large

Table 2.2. Typical descriptors of the significance levels, reproduced based on Table 4 in Highways Agency (2010).

Significance level	Typical descriptor
Very large Beneficial	The project would create an iconic new feature that would greatly enhance the view.
Large Beneficial	The project would lead to a major improvement in a view from a highly sensitive receptor.
Moderate Beneficial	The proposals would cause obvious improvement to a view from a moderately sensitive receptor, or perceptible improvement to a view from a more sensitive receptor.
Slight Beneficial	The project would cause limited improvement to a view from a receptor of medium sensitivity, or would cause greater improvement to a view from a receptor of low sensitivity.
Neutral	No perceptible change in the view.
Slight Adverse	The project would cause limited deterioration to a view from a receptor of medium sensitivity, or cause greater deterioration to a view from a receptor of low sensitivity.
Moderate Adverse	The project would cause obvious deterioration to a view from a moderately sensitive receptor, or perceptible damage to a view from a more sensitive receptor
Large Adverse	The project would cause major deterioration to a view from a highly sensitive receptor, and would constitute a major discordant element in the view.
Very Large Adverse	The project would cause the loss of views from a highly sensitive receptor, and would constitute a dominant discordant feature in the view.

A complete assessment will also include propose of mitigation measures. Mitigation should be considered early in the design stage, e.g., when choosing the location of road corridors, designing the alignment of road lines and features of roadway and roadside structures (Federal Highway Administration, 1988). Apart from mitigation measures applied by modifying the road project itself, screening the road project visually by solid barriers, earth mounds or vegetation is also widely used measure in practice. However, it should be noted that some visual screens themselves can cause visual intrusion, and the usually more visually pleasant vegetation screen would need a few years to become effective (Highways Agency, 2010).

2.2. Visual landscape and impact research

Once visual impact assessment was included in systematic and rational planning process, it was necessary to objectively measure even those normally unmeasurable effects to enable the objective comparison of alternatives. In the recent decades, improved technologies in geographic data collecting and processing have enabled more accurate, objective and efficient measurement and calculation in visual impact assessment and led to the development of several visibility-based assessment methods. Meanwhile, it is also realised that absolute quantification is impossible and it is the common nature of the assessment work of any environmental effects that subjective judgements should be included (Landscape Institute & IEMA, 2013). A lot of efforts have been made on perception-based visual impact studies, seeking to develop more reliable assessment methods of which the results reflect human perception and their subjective judgements. A review of these two types of studies is presented in the following sections.

2.2.1. Visibility-based visual impact studies

2.2.1.1. Introduction

Visibility analysis can simply mean the analysis of whether the object(s) can be seen or not. But this kind of analysis is not sufficient to describe potential visual impact. Information about visibility in visual impact studies may be extended to include the position and size (in millisteradian, square minute, etc.) of the visible object(s) in the views (Gigg, 1980), or even different degrees of visibility categorised as can be detected, recognized or induce impact, which, though, have to some extent extended beyond the objective description of the visibility (Shang & Bishop, 2000).

There are a variety of internal and external factors that will influence the visibility, including the size, shape, colour, texture, movement of the object and their contrast to the surroundings, and lighting and atmospheric conditions. In a study on visual thresholds, Shang & Bishop (2000) examined the effect of visual size, visual contrast (calculated as the difference between the average lightness of the object and the background pixels along the object border in the presented grey scale images divided by 256) in determining visual thresholds of objects of different shapes in different landscape settings, and found that contrast weighted visual size, measured in square min multiplied by contrast percentage, is a predictive and effective variable for visual thresholds. More details about colour contrast in landscape can be find in Bishop (1997) which showed that a colour difference formula based on CIELab, an opponent colour system indicating values of light and dark, red and green, and blue and yellow with L, a and b axes, may be applied to estimated perceived colour differences between the object and the background in a landscape setting. The effect of atmospheric scattering in the case of wind turbines was address by Bishop (2002) with concerns of the rotating blades and a reduction of about 20% in the visual threshold distance was found when light haze typical to the study area was applied. Besides, visibility also varies depending on individual viewers' visual acuity.

In visual impact assessment, visibility analysis can be used in initial stages to identify areas that need to be covered for study, viewpoints especially those of particular interest that need to be examined, and groups of people who may be affected by the proposed development (Landscape Institute & IEMA, 2013). It will also be useful in the consideration of design alternatives based on the visibility of different design options as well as in mitigation design and other detailed assessment of the development in further stages (Landscape Institute & IEMA, 2013). In some cases, the visibility analysis itself may make up an entire study. A very common application of this type of studies is to save views of valued and cherished elements (e.g., landmark constructions, parks) in urban development (Cote, 2006; Danese et al. 2009).

Computer programs capable to calculate visibility have been developed over the past decades, including VIEWIT (Travis et al, 1975), MAP (Tomlin, 1983), ArcGIS, Global Mapper, KeyTERRA-FIRMA, etc. And new applications based on these programs were found to produce assessment systems and prediction models of both visual impact and visual quality, though very little has evolved in algorithmic development (Bishop 2003). These visibility-based visual impact studies may be classified as showed in Table 2.3, and will be reviewed in this classification in the following sections.

Table 2.3. Different types of visibility analysis

Visibility Analysis					
Viewshed Analysis				**Visibility Indices**	
Single Viewshed Analysis	Multiple Viewshed Analysis	Cumulative Viewshed Analysis	Identifying Viewshed Analysis	Visual Magnitude Analysis	Other Indices

2.2.1.2. Viewshed-analysis-based visual impact studies

Viewshed analysis is an essential part of most visual impact studies. It examines whether a line of sight exists from a chosen object to each part of the surroundings in a given landscape setting, or from the surrounding areas to the object as views are reflective. The analysis is based on a digital elevation model (DEM) represented as a raster grid or triangular irregular networks. The basic algorithm can be described as (Bishop 2003):

> "The basic algorithm is based on lines radiating from the point being analyzed (called the target point in some GIS products) at a fixed angular increment (1° in MAP). Along each line the angle from vertical to the next nearest cell is calculated. This cell is visible. If the angle to the next cell is larger, then that cell is also visible. This goes on until the angle decreases—then the cell is not visible, it is hidden by the cell at the larger angle in front of it. Cells then are all hidden until an angle greater than the previous largest angle is found. That cell is then visible and the process continues" (page 678).

The calculation only reflects elevation's effect on visibility, though in most cases the radius of the area for analysis will be pre-limited according to the visual threshold of the object or the limit of human sight in the specific condition. Earth's curvature should be taken into account when the analysis covers a large area and this is achievable in many related computer programs.

The simplest viewshed analysis is single viewshed analysis where only one target point is set to represent the observed object (Figure 2.1-a). The output of the analysis, based on a raster DEM which is more prominent in viewshed studies (Bishop, 2003; Chamberlain & Meitner, 2013), is a binary grid where the cells from which the target point is visible (here "visible" simply means a line of sight exists) are assigned the value "1" and otherwise "0". By adjusting the elevation value of the target point according to the height of each part of the object, it can determine whether the entire object or only the top part of it or the part above a certain height is in charge for the visual impact analysis (Hadrian, et al., 1988). Lake et al. (1998) applied the analysis in an inverted manner, by taking the target point as the view point, in a property price study which concerned the effect of available views from each property.

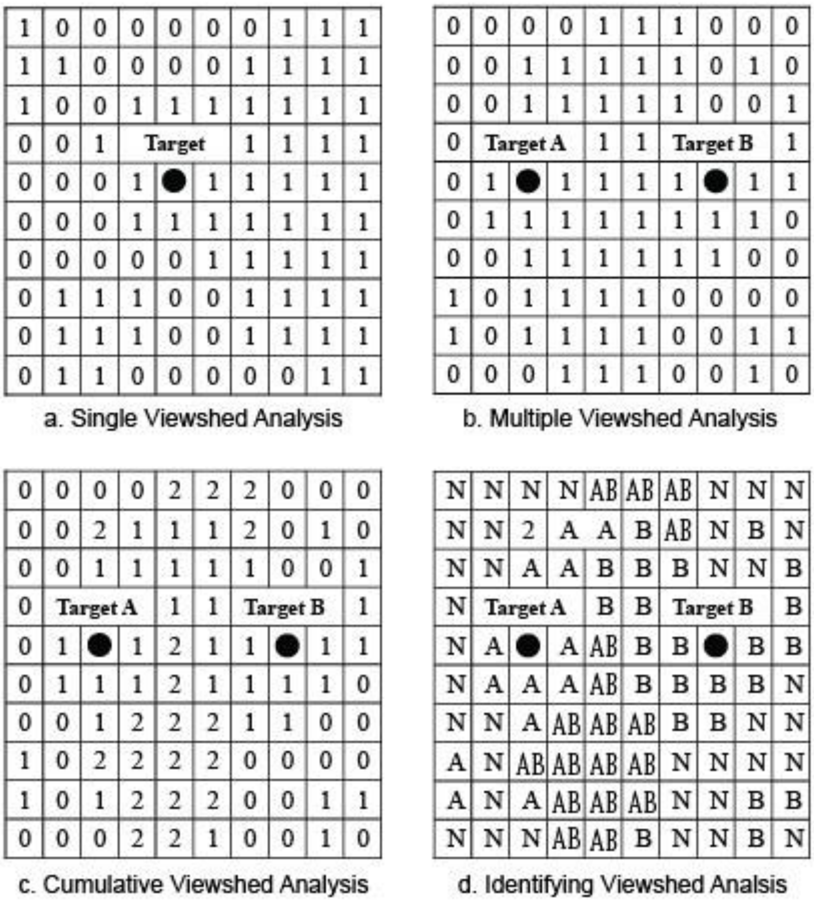

Figure 2.1. Viewsed analysis: a. single viewshed analysis; b. multipul viewshed analysis; c. cumulative viewshed analysis; d. identifying viewshed analysis

But in most cases in visual impact analysis, as well as in other applications of viewshed analysis, one point is not sufficient to represent an object of certain shape and size or a set of objects. Multiple viewshed analysis processing more than one target point was thus developed which also produce a binary grid but where "1" means at least one of the target points is visible from the cell and "0" means none of the target point is visible (Figure 2.1-b) (Danese et al., 2009). But still, multiple viewshed analysis only shows whether the object(s) can be seen or not (regardless of distance and effect of factors other than elevation).

To further explore how much of the object(s) can be seen or how often it/they can be seen, it is necessary to introduce cumulative viewshed analysis (Figure 2.1-c). In a cumulative viewshed analysis there is also more than one target point but the result of single viewshed analysis of each target point is added together to obtain a non-binary grid where the number in each cell indicates the number of target points visible from the cell (Danese et al., 2009). In developing methods to reduce the visual impact of greenhouse parks in rural areas, Rogge et al (2008) used 35 target points along the perimeter of the studied greenhouse with exact building heights above the landscape surface to represent the building and thus to calculate the percentage of the building visible from each observation cell by cumulative viewshed analysis. However, it neglected the fact that the building is a solid object and it is impossible to see every part of it from one view point however visible it is. Cumulative viewshed analysis can also be used to calculate the number of times an area can be seen from the chosen observation (target) points to indicate the relative importance of each area in a landscape when, for example, dealing with visual resource management along a scenic route (Iverson, 1985).

In some cases where the objects or different parts of the object represented by target points have different properties which will have different visual effect, it is desired that the specific target points visible from each observation cell are identified to calculate more accurately the visual impact received in different locations, and identifying viewshed analysis was developed to serve this purpose (Figure 2.1-d) (Danese et al., 2009). A very practical use illustrated in the ArcGIS online help resource (Esri, 2012) is quantifying visual quality of locations in a given landscape setting by assigning a value to each target point which represent for positive or negative visual resource like local parks, city dumps, transmission towers, etc.

2.2.1.3 Visibility-index-based visual impact studies

The visual index here means an indication system by which the degree of visibility of an object can be recorded or interpreted using objective measures, e.g., distance from the object, the shape of the object, size of the object in view and the number of potentially affect people. While it does not directly reflect human perception of visual impact, it is a more detailed and more human-based measure of visibility for the delineation of visual impact, compared with viewshed.

Among various visual indices, visual magnitude is one of the well-established and has been used and developed in many visual impact studies. Basically, visual magnitude is a measure of the relative size of the object in the field of view which depends on the size of the object and the distance to it from the observer. It can be measured in square degree or steradian of the solid angle of the sphere at the observation point as occupied by the object (Figure 2.2).

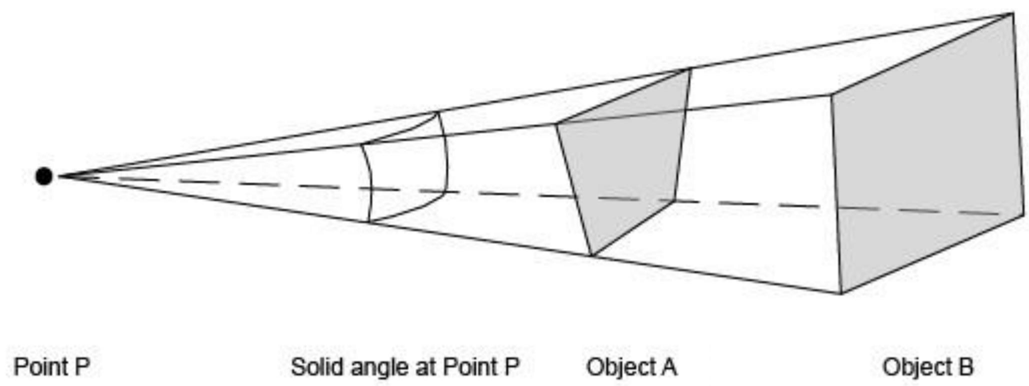

Figure 2.2. Object A and B have the same solid angle at Point P

The concept of visual magnitude was applied in the computer program VIEWIT initiated by the U.S. Forest Service for "computation of seen areas, slope, and aspect for land-use planning" (Travis et al. 1975). Analysis in this program is based on the input map of the study area divided into grid cells. It can calculate of each grid cell the distance to the observer point by distance weighting, the "aspect relative to the observer", described as "vertical tilting and horizontal rotation of the plane of the grid cell" (since the area of each grid cell is a fixed value, the absolute size of each cell as presented in the observers' views will depends on the tilting and rotation), and the times seen. The measure of visual magnitude was achieved by combining these three calculations. However, while remain an important indicator of visual impact, the times seen measure was not counted for visual magnitude in most other studies on this topic.

Iverson (1985) further explained the concept and theoretical basis of visual magnitude, “a measure of the slope, aspect, and distance of a land plane or object from the observer”, and the improvement and extension of its use that may be achieved. Examples were given as to be employed in clearcutting in regards of visual impact and in scenarios where new constructions were to be introduced into the concerned scenic views. To complete the physical measurement of visual impact, Iverson suggested that the measure of visual magnitude should be used combined with contrast rating and shape rating.

While estimation of visual magnitude is seldom available in contemporary software (Bishop 2003), the concept of visual magnitude is still applied in many visual impact related studies in recent years. Gret-Regamey et al (2007)’s study concerns the visual impact of recreation and tourism development and modified land use in mountainous regions. The visual magnitudes of land cover changes were estimated by an equation using the angle of visual magnitude, the area of the grid cell, and the distance between the viewer and the cell as variables in a 3D GIS model, and were used based on a willingness-to-pay survey to predict people’s preferences for the changes in views, which is important to the tourism economy. Chamberlain & Meitner (2013) proposed methods of visibility analysis for route-based applications by introducing the analysis of average-weighted visual magnitude, max visual magnitude and max visual magnitude causal viewpoint in addition to viewshed analysis from a large number of observation points, to enable the understanding of the potential visual impact of developments as visible by individuals moving through the landscape. Domingo-Santos et al (2011) employed the concept of visual magnitude as visual exposure expressed by the precise calculation of solid angle, rather than by combining measures of the effective factors, in a GIS-based visibility analysis tool which was developed to assist visual impact assessment of land use or cover changes. Chamberlain & Meitner (2009) developed and tested a prototype model to be applied in timber harvest design aiming to reduce the visual impact of the harvest while keep a certain level of timber availability. While the term “visual magnitude” was not used directly in their work, the index used in the fitness assessment of the generated harvest designs in the model process—the percentage of the visible harvested area in the forest cover as presented in the view, can be understood as a calculation of the visual magnitude of the visible harvested area divided by the visual magnitude of the given forest cover before the harvest in the view from a specified view point.

Apart from visual magnitude, there are some other visual indices developed and applied in visual impact studies. The contrast rating and shape rating mentioned in Iverson (1985) were considered as the other two indices needed to fully reflect the physical dimension of visual impact. Contrast rating is usually obtained based on the colour differences between the object and the background (Bishop 1997; Iverson 1985; Shang & Bishop 2000). However, the human perception of the contract can be rather subjective, though the contract itself is a result of differences in physical properties. So it may be questioned if the rating is objective enough to be an index as defined here. The concept of shape rating is supported by the psychological theory that irregular objects are harder to detect compared with those of regular form (Dember, 1960). Few studies have developed or applied shape rating in visual impact analysis. Its operability and objectivity remain uncertain.

An equation combining several indices to calculate the visibility of an object from a specific view point (specific visibility S"(r, ϕ)) was proposed by Groß (1991), taking into consideration the visual magnitude, the acuity of the human eye, and the color difference and atmospheric optics:

$$S''(r,\emptyset) = \frac{1}{\mathrm{dA}} \int_{\Omega} V(a) \cdot \Delta\mathrm{E}(r,\emptyset) \cdot \mathrm{d}\Omega \tag{2.1}$$

where r and ϕ are the object's distance and angle in a polar coordinate system; Ω is the solid angle taken up by the object and dΩ is the solid angle area covered on the retina; V is the visual acuity which is dependent on the visual angle α; and ΔE is the colour difference between the object and the background calculated based on the CIE colour system with atmospheric extinction. dA is the observer's area and is $1m^2$ here. All these factors are objective, as the author claimed in the classification of influencing factors that the method to be developed was "limited to objective criteria". However, it still reflects more or less subjective human perception. For example, the formula for ΔE "was chosen according to its correlation with perceived differences in color and contrast".

There are some more simple and straightforward indices which can also express the degree of visibility of an object and thus its visual impact. In addition to a visual magnitude measure, three other indices were used in Rodrigues et al (2010) to quantify the visual impact of large scale renewable-energy facilities: the Visually-Affected Area; the Visually-Affected Populated Area; and the Visually-Affected Travel Time. In Bishop (1996), a tower index, calculated as:

$$\text{Tower index} = \sum_i (1000/(\text{distance to visible tower}_i)) \qquad (2.2)$$

was defined to reflect both the number of visible transmission towers and their distance from an observation point.

2.2.2. Perception-based visual impact studies

2.2.2.1. Introduction

While the objective visibility analysis has been rapidly developed and proved to be significantly helpful, subjective judgement still remain an essential component in visual impact assessment. Visual impact is an interactive concept. It is produced by the object(s) in a landscape as changes in visual resource and received by the receptor(s) giving negative judgement. The impact is not solely a property of the physical appearance of landscape, in fact it is more of a matter of how the receptors perceive and respond to physical appearance. Even in some of the visual indices studies in the above sections, subjective judgement had been involved to some extent, though not necessary related to preference.

Each individual has his/her judgemental standards or criteria which vary from person to person. An object judged as visual intrusive by one person may not be annoying to others. However, overall, high agreement of judgement between different groups has been found (Anderson & Schroeder, 1983) which reveals that general criteria are shared among the variety of individuals. This is the premise of the idea that perception-based visual impact studies are valid and assessment work based on thus developed prediction models can be carried out.

A prediction model in visual impact or quality studies is to provide measures of the degree of the impact or quality, usually correlated with general human responses, by calculating input data of defined predictor variables based on mathematical relationships between these variables and the human preference. It enables the prediction of visual effect as a result of new development or management alterations if information of proposed changes in visual resource of the landscape is available, or enables the evaluation of visual quality of existing landscape without carrying out preference study for all of the sites or observation points in question.

This section is to review perception-based visual impact studies with prediction models developed. However, not all, or in fact, only a few studies to be reviewed are directly concerned with visual impact. Most of them addressed the issues of visual quality, that is, the quality of visual appearance of the overall landscape rather than the visual effect of moving away existing element(s) from and/or introducing new element(s) into the landscape. But after all, visual impact can basically be thought of as induced by changes in visual quality, and theories and methods in visual quality studies can also work in visual impact studies

2.2.2.2. Perception-based studies without using GIS

Attempts at systematic assessment of landscape scenic beauty, which is largely perceived visually, has been made since the 1960s (Smardon et al. 1986; Wu et al. 2006; Daniel & Boster 1976). Daniel and Boster (1976) divided the assessment methods of that day into three general approaches: (1) descriptive inventories; (2) surveys and questionnaires; and (3) evaluations of perceptual preference.

The inventory approach requires that a set of landscape features, components or elements thought to be related to scenic beauty be defined and an inventory of them made. The scenic beauty of the studied landscape can be revealed, based on users' interpretation, by the high subjective or relatively objective information recorded for each listed item (Daniel & Boster 1976). The inventory approach is a typical expert-based approach as discussed in Section 2.1.1, whereas surveys and questionnaires and evaluations of perceptual preference are two examples of the perception-based approach. Both of them obtain judgement of human observers to evaluate the scenic beauty rather than based on the expertise or intuition of those who carry out the assessment work or by analysing the intrinsic physical properties of the landscape (Daniel & Boster 1976). In general, the approach of surveys and questionnaires is performed as opinion surveys where a set of questions relevant to landscape scenic quality are presented in written or oral form to selected respondents to indicate their preferences, and thus to determine the desirability of various landscape management and planning alternatives (Daniel & Boster 1976). Evaluations of perceptual preference are similar in many aspects to surveys and questionnaires. The difference is they generally show graphic representations of the landscape to the respondents, or less often, the actual landscape being visited, instead of verbal questions (Daniel & Boster 1976). While surveys and questionnaires are more economical and in some aspects more efficient, Evaluations of perceptual preference are more direct and accurate, and can avoid distortion of information caused by wording, phrasing and misunderstanding, and thus was seen at that time as “offer distinct advantages over surveys” (Daniel & Boster 1976, Page 11). Judgments regarding the quality of specific landscape characteristics or components may be required in a perceptual preference evaluation, or most often, the scenic quality of the overall appearance of the landscape is directly evaluated (Daniel & Boster 1976). A number of judgment procedures had been developed and used, including forced-choice procedure, ranking procedure, and individual rating procedure, with both advantages and disadvantages over each other (Daniel & Boster 1976).

These assessment methods were mainly proposed, or more suitable, for the evaluation of scenic beauty, rather than for prediction, especially the perceptual preference approach where landscape needs to be presented for the assessment. However, inventories had actually been quite similar with prediction models in many ways, especially those with a numerical value assigned to each listed items and an index indicating scenic quality of the landscape made by summing up these values. An example can be found in Leopold (1969) where, to quantitatively compare some aesthetic factors among rivers, a uniqueness ratio of each listed site factor (e.g., river width, bed material, artificial controls) was calculated and the overall uniqueness ratio of each site, as a scenic quality index, obtained by summing up those of each listed site factor. Based on Leopold’s inventory scheme, if information of changes in listed site factors can be predicted, which is readily achievable by analysing the development proposal that induces the changes, then the overall uniqueness ratio of the site after the development can be predicted. However, the relationship between uniqueness and scenic quality, or any other concerned aspects of the landscape, is not clear. The validity of uniqueness ratio in Leopold's scheme was backed up by the philosophy that "landscape which is unique – that is, different from others or uncommon–has more significance to society than that which is common" (Leopold, 1969), which was only an assumption and remained untested. If appropriate indices are chosen and the index value measured for each item can be transformed to reflect their actual effectiveness to the degree of scenic beauty as perceived by human beings, then an inventory can pretty much work as a prediction model, and that is actually how a prediction model developed.

In Shafer et al. (1969), an early attempt to develop a prediction model was made by using edge length and covered area of landscape elements such as water and vegetation in three distant zones as predictor variables which were measured by counting the number of grid cells enclosing/covering each particular element in the "gridised" photographs which present the landscape to be assessed. Regression analysis was used to relate the variable measures with the landscape preference score of each photograph obtained by a preference survey which was quite similar to the evaluations of perceptual preference mentioned above, to find out the mathematical relationship between them based on which prediction equations were established. Application of models developed in this way was demonstrated in Shafer & Brush. (1977). It showed that the prediction of changes in scenic quality was achieved by comparing the preference scores of the landscape before and after the development or management alterations. While reference score of the existing landscape can be easily computed, the scores of the changed landscape were computed using variables measured in sketched photos, which can be seen as graphic simulation or photomontage used today. Development or management recommendation for the landscape was proposed to obtain an optimised score. However, in this approach, the landscape can only be assessment from one view point. An element suggested to be eliminated as a negative factor in the intermediate distance zone in one view may contribute to the scenic quality in another view where it appears in the immediate zone. Scenic scores of views from a group of viewpoints should be computed if it is to assess landscape that covers a large extent of area (Shafer & Brush, 1977). Anderson & Schroeder (1983) tested the feasibility of this approach in urban context and explored the contributions of each selected physical characteristics of the urban landscape to the overall scenic quality. Apart from objective physical characteristics obtained from photo measurements, subjective ratings of physical characteristics were also used for analysis. It found that overhead wires and poles, vehicles and parking lot detracted from the scenic quality most and suggested that vegetation screening is an effective mitigation method. Based on the correlation result, seven most predictive variables from both the objective and subjective physical characteristics were selected and two prediction models developed using regression analysis. The study showed that it was possible to assess urban scenic quality using the same research strategies and methods developed in wild natural context, but much remained to be learned due to the complexity of urban landscape. Studies in scenic quality prediction model can also be found in Schroeder & Daniel (1981), Louise (1977), and Buhyoff, & Leuschner (1978).

2.2.2.3. Perception-based studies using GIS

While the above reviewed studies dealt with visual landscape issues, few of them had taken advantage of the visibility studies which had been in rapid development in the landscape sphere during the same period. Prediction model thus developed suffered from a weakness when performing prediction, that is, it was hard to obtain input dada for prediction. Photographs presenting the changed landscape need to be simulated and one photograph can only present the view from one specific viewpoint. This kind of “prediction” models are more suitable for, or limited to, offering implications for landscape planning and management, but not efficient in carrying out prediction.

A significant progress in visual quality/impact studies is the integration of prediction models with the visibility analysis as well as some other useful GIS applications. One of the first examples can be found in Steinitz (1990). The prediction model in this study was developed using the conventional preference survey and regression analysis approach. The selection of potential predictive factors had drawn on the variables used in five alternative prediction models previously developed by other researchers, these variables, including objective measures and subjective ratings, were all derived or estimated from photographs. By combining the most powerful predictor variables (all measured by subjective rating on a scale from 0 to 4 in this study), this model achieved a much higher coefficient of determination than the five alternatives. But the key step distinguishing Steinitz work from the others is that the model was applied to map the distribution of visual quality via GIS. Using a viewshed analysis, it was possible to find out whether a sight of line exist between each of the landscape element representing the rated predictive factors and each of the grid cell as the view point, thus the content in the 360° view from each grid cell can be obtained and a visual quality score computed based on the prediction model. Development or landscape management alterations can be easily simulated by changing the input data in the GIS according to the proposals, which enables the prediction to be carried out efficiently. But it is not clear whether the author used multiple or cumulative viewshed analysis or just used one single point to represent each landscape element in determining the visibility of the elements which might cover more than one grid cell in the DEM model. Mapping by cumulative viewshed analysis can better reflect the views as being presented in photograph which was employed during the model developing, but it will make it hard to apply the model in the scenic quality mapping. Nor is it clear how the scenic score of the 360° view will be calculated if there are elements of the same category but with different rated scores in the view.

The limitation of Steinitz's (1990) work lies in that the variable values for prediction model computation cannot be obtained from or effectively transformed to map-based information. This was improved by Bishop and Hulse (1994) in which the predictor variables used in the prediction model were derived from mapped data in a GIS. The preference survey in this study was carried out and scenic quality scores for each view obtained by conventional procedure. The difference was that the views to be rated were presented to participants by 360° video panoramas rather than by slides or photographs which only show views within a restricted arc. The values of the variables, which reflected the amount of landscape elements including slope, water, vegetation, land use and corridor in each view, were not measured on the video screen or by subjective rating, instead, they were calculated, based on the raster grid map layers containing the element information, as the number of the grid cells representing each element visible from (within the viewshed of) each grid cell as view point, with the diminishing effect of distance considered. While the map-based information did not directly show what participants saw in the video panoramas during the preference survey, it was one of the objectives of the study to "demonstrate that predictive equations based on GIS-derived variables could predict with a high level of statistical validity the variations in site scenic beauty evaluation derived from 'public' evaluation of video panoramas". The study results showed that a high level of prediction of visual quality could be achieved using GIS-based mapped data as predictor variables. Thus it can be confident in a visual quality/impact assessment using this method that the score showed in each grid cell on the obtained quality/impact map will match the preference score of the landscape judged by people at that location in the field. And the high manipulability of GIS data, as well as the rapidly developing GIS technologies, will highly enhance the efficiency of the visual quality/impact prediction models which use mapped data.

A recent work of this type can be found in Schirpke et al. (2013) in which a GIS-based model for prediction of scenic beauty of mountain regions were developed. While more detailed and accurate analysis had been allowed by improved computational technologies and landscape elements were quantified and rasterised as landscape metrics using FRAGSTATS in this study, the principal methodology had remained the same.

There is another type of mapping by which the value showed in each grid cell of the outcome raster map does not indicate the quality of view as viewed at that location in the field, but the degree of visual effect of the targeted object(s) received at that location. Hadrian et al. (1988) developed a GIS-based model to predict the visual impact of transmission lines. The prediction model was not constructed in the form of a mathematical equation, rather, it was split into three components associated with the object, the observer and the environment. The contribution of the transmission structure's properties to the overall visual impact was processed by the object component of the model. Normalized ratings for the visual effect magnitude and radius of different types of structures were derived by preference, and were to be used as input data. The effect of the environmental settings around the structures to the perceived impact was considered by applying sensitivity weightings of object context based on the visual compatibility between the transmission structures and their surroundings. The values of these weightings were derived by quantifying the result of preference surveys, and in this study, the industrial setting was assigned a lowest weighting and the river the highest. Observer context sensitivities were also introduced to reflect the effect of observers' properties. While it could be the most complicated part in developing the model, land use zonings were simply used to represent different observer groups and sensitivity weightings assigned to each type of land use based on subjective rating. This type of models requires some quite subjective input and it may be risky to separately assess the effect of each component which is very interrelated and interactive to each other. However, once their validity is proved, automated mapping of the visual impact can be readily achieved and applied with a high confidence.

2.3. Noise impact of road traffic

2.3.1. An overview of the issue of environmental noise.

Environmental noise has been a worldwide environmental issue of growing concern for many years. World Health Organisation (1999) defines environmental noise as noise emitted from all sources, except noise at the industrial workplace. Environmental noise is mainly emitted by road, rail and air traffic, industries, construction and public work, and neighborhood activities (World Health Organisation, 1999).

Road traffic is the most dominant source of environmental noise in Europe. The 2007 data collected in EEA member countries shows more than 65 million people living inside urban areas and more than 30 million people living outside urban areas were exposed to road traffic noise above 55 dB L_{den}, which is the EU threshold for excess exposure, compared to more than 14 million people exposed to rail traffic noise and more than 4 million people exposed to air traffic noise above 55 dB L_{den}. Among those exposed to road traffic noise, nearly 30 million were exposed to levels above 65 dB L_{den}. Estimations based on the 2012 data set suggest that more than 125 million people in EEA member countries could actually be exposed to road traffic noise above 55 dB $L_{den,}$ among which more than 37 million experiencing high level exposures above 65 dB L_{den}. (European Environment Agency, 2014).

Among all the negative effects of road traffic noise the most prevalent effect is annoyance, which can be defined as the general unpleasant feelings caused by noise. About 20% of the people feel annoyed by road traffic noise when exposed to a level of 55 dB(A), some people begin to feel annoyance at a level as low as 40 dB(A). Apart from inducing annoyance, road traffic noise can have other serious impact on people's health and well-being, e.g., contributing to certain cardiovascular diseases, affecting cognitive functioning, disturbing sleep patterns, and even leading to irreversible loss of hearing (den Boer & Schroten, 2007).

Efforts are continuingly being made in response to noise pollutions. The first comprehensive step to develop a coordinated EU policy on noise was made in 1993, with the approval of the Fifth EC Environmental Action Programme by the European Commission, titled 'Towards Sustainability', which stated an objective that 'no person should be exposed to noise levels which endanger health and quality of life' (European Commission, 1993). In 1996, the Green Paper on Future Noise Policy was adopted, which emphasised a higher priority of noise as one of the major environmental problems in Europe, and identified improvement to be made in key areas (European Commission, 1996). In 2001, the Sixth EC Environmental Action Programme, titled Environment 2010: Our Future, Our Choice', reinforced the concept of a knowledge-based approach to policymaking and proposed the adoption and implementation of a directive on environmental noise which aimed to define a common approach for assessment and management of environmental noise in the EU (European Commission, 2001). Most recently, in the Seventh EC Environment Action Programme, 'Living well, within the limits of our planet', it was committed to significantly decrease noise pollution in the EU by 2020, moving closer to the World Health Organisation recommended levels which would require the implementation of an updated EU noise policy aligned with the latest scientific knowledge, measures to reduce noise at source, and improvements in city design (European Commission, 2013).

2.3.2. Traffic noise impact assessment

Potential noise impact of road projects can arise from construction of new roads, improvement of existing roads, operation and maintenance. There can be temporary impact, which is usually noise disruption due to construction, maintenance and/or advance works, and permanent impact, which is caused by noise from engine, exhaust and transmission systems of vehicles in the stream of traffic and noise from the interaction of vehicle tyres with the road surface (Highways Agency, 2011). This part of review focus on the permanent impact. The main factors that influence the noise level of free flow traffic are the traffic volume, speed and composition, the road gradient and surface characteristics, the distance from the noise source, the nature of the intervening ground surface, and the presence of obstructions (Highways Agency, 2011). The detailed procedures of road traffic noise impact assessment vary from state to state, and the level of effort may change according to the scoped significance of potential impact. Generally, the full procedure involves the identification of potential affected areas or receptors, the assessment of resulted changes in noise environment and the harmful effect, and evaluation of mitigation measures.

Identification of potential affected areas or receptors is usually desk based. In the UK, the affected receptors are identified by weather noise changes caused by the project within one km from the carriageway edge will be greater than the threshold levels. The threshold levels are defined as change in noise level of 1 dB $L_{A10,18h}$ in the short term (baseline assessment year) or 3 dB $L_{A10,18h}$ in the long term (future assessment year). Where sufficient traffic data is available, it is acceptable to use this to determine whether the threshold is exceeded. If it is not exceeded, the assessment will be ended at this point; if it is exceeded, detailed assessment will be required. Where it cannot be decided at this stage whether the threshold levels will be exceeded or not, a simple assessment will be required and then decide whether a detailed assessment is needed (Highways Agency, 2011). In the US, activity category for all land uses adjacent to project to be assessed needs to be defined, and representative locations for all activity categories selected to determine baseline and future noise levels in the following assessment steps (Federal Highway Administration, 2011).

The determination of baseline noise level can be done either by on-site measurement, or desk-based calculation, or a combination of both. On-site measurement might be preferred as it also addresses background noise which is not sourced from traffic and thus gives more accurate information of the noise climate. Time of the day, day of the week, week of the year, representativeness of the noise, and extenuating circumstances need to be considered for the measurement (Federal Highway Administration, 2011). Where it is clear that baseline noise in affected areas or at the receptors is predominantly due to road traffic, the baseline noise level can be calculated using noise models which will also be used to predict future noise levels.

Different noise models are used in difference countries or regions, requiring different input usually including traffic type, traffic flow, road and environmental data, and providing different output, e.g., A-weighted overall level or detailed spectral information (Steele, 2001). In the UK, the calculation of baseline and future noise levels is based on the noise model described in 'Calculation of Road Traffic Noise' (CRTN) published by Department of Transport and the Welsh Office (1988). The CRTN model assumes a line source consisting of two types of vehicles, light vehicles and heavy vehicles, with constant speed, the calculated noise index is $L_{A10,18h}$ covering the time period from 6 am to midnight. A common noise model was developed in EU and the calculation method is published in 'Common Noise Assessment Methods in Europe' (CNOSSOS-EU) (European Commission (2012a). The CNOSSOS-EU model uses noise indices L_{den} and L_{night}, which cover the full 24 hour period of the day with different weightings applied to the day, evening and night period of the day. Since EU Directive requires member states to produce noise maps based on common noise indices (European Commission, 2002b), method to convert the UK noise index to EU noise indices was developed (Abbott & Nelson, 2002). The converting method also provides a technique for calculating night time noise levels which is not available from the CRTN model (Highways Agency, 2011).

The effect of noise impact on population can be assessed using exposure-effect relationships, e.g., the relation between noise indices and annoyance and/or sleep disturbance. In the UK, the increases or decreases in the number of people annoyed by noise, comparing the baseline and future assessment years, need to be calculated. The calculation is based on curves, derived from results of empirical surveys, fitting between percentage of people highly annoyed by traffic noise and noise level in $L_{A10,\ 18h}$, and between change in percentage of people highly annoyed by traffic noise and change in noise level in $L_{A10,\ 18h}$ (Highways Agency, 2011).

Mitigation of traffic noise can be considered in three components: mitigation at source, mitigation at propagation path, and mitigation at receptor (Hong & Jeon, 2014). Measures of mitigation at source include absorptive road surface, traffic speed and volume control, and low noise vehicles etc.; measures of mitigation at propagation path include alteration of road alignments, noise barriers, earth mound etc.; measures of mitigation at receptor include installation of sound-proof windows (Federal Highway Administration, 2011, Highways Agency, 2011). Since the performance of noise barriers in mitigating the environmental impact of motorways is one of the issues addressed in this thesis, a detailed review of noise barriers is made in section 2.3.3.

2.3.3 Noise barriers

Noise barriers are constructed to be solid obstacles that intercept the line of sight between noise source and the receiver. The sound reduction effectiveness of barrier mainly depends on the frequency of the sound and path difference of the sound ray. Path difference is defined as difference between the direct ray and diffracted ray due to screening of the source line by the barrier. For a single point source and an infinitely long barrier, the path difference δ, as illustrated in Figure 2.3 (Cohn & McVoy 1982), can be calculated as:

$$\delta = A + B - C \tag{2.3}$$

The sound reduction of a barrier is closely related to the Fresnel number, N, defined as:

$$N = 2\,\delta / \lambda \tag{2.4}$$

where λ is the wavelength of sound in air. For $0.2 < N < 12.5$, Kurze & Anderson (1971) gave a simplified equation to calculate the insertion loss (IL) of an infinitely long barrier against a single point source:

$$\mathrm{IL} = 20\log\frac{(2\pi N)^{1/2}}{\tanh(2\pi N)^{1/2}} + 5 \tag{2.5}$$

For N > 12.5, a 24 dB upper limit of IL is shown in experimental data (Kang, 2007), however, the extreme value of δ can hardly be achieved in practice and a realistic limit of IL is about 15 dB(A) (Kotzen & English, 2009).

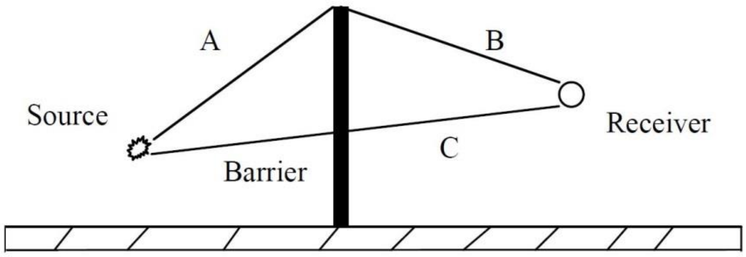

Figure 2.3. Noise barrier theory.

For the noise reduction by barriers to be achieved, it also needs to be ensured that the sound transmitted through the barrier (Path C in Figure 2.3) does not contribute to the overall level significantly at the receiver. This insulation provided by a barrier is dependent on many factors including surface mass, stiffness, loss factors, the angle of incident sound wave etc. Among these factors the most decisive one is surface mass and many calculation methods adopt it as the only descriptor of a barrier's sound insulation (Kotzen & English, 2009). A contribution of 0.5 dB(A) of the transmitted sound to the overall level at the receiver is commonly used as the allowed limit (Kotzen & English, 2009).

Higher attenuation provided by noise barriers without increasing the height of barrier can be achieved by refined design of barrier forms. Well-established solutions include cantilevered barriers, T-shape barriers, Y-shape barriers, multiple-edge barriers, tubular capped barriers, phase interference barriers, phase reversal barriers etc. Many of these refined designs are reported to offer 1- 3 dB(A) benefit of noise attenuation (Kang, 2007; Kotzen & English, 2009).

Noise barriers are mainly categorised into reflective and absorptive. In the case of reflective barrier sound can be reflected in a way similar to light and usually only the first and second reflections are considered in geometrical analysis. In the case of absorptive barrier noise penetrates the outside material through perforations, and absorbed by the internal porous material. Different materials have different absorption abilities which can be expressed by absorption coefficient ranging from 0.0 for totally reflective to 1.0 for totally absorptive. The coefficient is not constant for a given material as it is frequent dependent and also varies with the angle of incidence of the sound. Reflective barriers are appropriate where sensitive receptors are only on one side of the road, otherwise absorptive barriers are preferred (Joynt, 2005).

Barriers can be made from virtually any construction material or combination of materials. The most commonly used materials includes timber, metal, concrete, brick, plastic and those for transparent barriers e.g., reinforced glass, acrylic or polycarbonate sheet. Timber barrier is the most commonly used barriers in the UK, can be designed either reflective or absorptive. The popularity of timber barrier may be attributed to its low cost, easy maintenance, long lifespan, and good fit with rural landscape. There is a general limit of height of 3 m in the UK to avoid negative landscape impact of timber barriers. Metal barriers are more advantages for areas where wind load and weight can be an issue. The commonly used metals are aluminium and steel both of which can come as reflective or absorptive. The minimum service life of metal barriers can be 20-30 years long, however, they have relatively high requirements for maintenance. Concrete barriers can also be reflective or absorptive. Despite its good insulation and durability, concrete barriers consume large amount of energy to produce and its aesthetic quality is questionable. Similar to concrete barriers, brick barriers offer significant advantages in maintenance cost and lifespan, but cause high environmental impact to be produced and transported. Plastic barriers are not common in the UK. They require low maintenance but have relatively short lifespan. The environmental cost of the material production is also high. The advantage of plastic barriers is the unusual forms and colours they can take which lead to their use as architectural features. Different from barriers of other materials, transparent barriers allow access to vies, light to penetrate, and are generally neutral in landscape effect. They are usually preferred options for elevated positions, e.g., bridges or viaducts, for their lightweight appearance. However, the potential maintenance and environmental cost of transparent barriers are high (Highways Agency 1995a; Highways Agency 1995b; Joynt, 2005; Kotzen & English, 2009).

Achieving the noise attenuation goals at the best available cost is often the priority concern when developing barrier solutions (Kang, 2007). In the UK, Highways Agency also emphasised the landscape effect of noise barriers in their design manual (Highways Agency 1995a). The perceived effectiveness of noise barriers, however, is also influenced by many other factors. e.g., before-barrier sound levels (May & Osman 1980), engagement in the barrier design (Hall 1980, Joynt 2005), social and economic effects, e.g., changes in property value and risk of crime (Perfater, 1979). Particularly, the aural-visual interaction in environmental perception plays an important role on perceived barrier performance. A more detailed review on this topic is made in Section 2.4.

2.4. Aural-visual interaction in environmental perception

Research in environmental psychology has shown the multisensory nature of human perception (Cassidy, 1997). The integration and interaction of physical environmental properties, including colour, light, tactile, temperature, humidity, sound, odour etc., can modulate human reactions to certain sensory stimuli as well as the overall human experience in the environment (Maffei, 2012). Among the sensory interactions, aural-visual interaction plays a very important role in human environmental perception. Early in the 1960s, Southworth (1969) conducted an exploratory study and revealed that acoustic and visual experiences of the environment are closely related to each other. More attention has been paid to this issue in the following decades and the concept of aural-visual interaction has been applied in many studies aiming to gain deeper understanding on environmental perception and develop human-centred methodologies for assessments of soundscape and landscape. While some studies investigated either the effect of visual stimuli on perception of sound environment or the effect of audio stimuli on perception of visual environment, some others have focused on their interactive effects on perception of the overall environment. A review of some selected studies was made in the following sections.

2.4.1. Effect of visual settings on sound perception

Many studies have investigated the effect of visual landscape on sound perception. Viollon et al. (2002) conducted an experiment in an artificial audio-visual environment where participants rated the quality of eight urban sound environment presented by playing back audio recordings via loudspeakers associated with five visual settings presented by projected colour slides. The results showed that more urban visual setting generally led to more negative sound ratings, i.e., less pleasant and relaxing, where the sound environment did not include human sound. This effect was absent where the recordings contained human sounds, which were footsteps and voices in this study. Somewhat contradicting results were found in Anderson et al. 1984. The study tested the perceived loudness of pure tone played by headphones to participants at different sites ranging from a woodland to an urban street. The results showed that perceived loudness of sound tended to increase as the amount of visible vegetation increased. Similar results were found in Mulligan et al. (1987) where listening tests with changing visual settings were conducted both on sites and in a laboratory. The phenomenon was explained by that people expect lower levels of sound in vegetated areas and this expectation leads to higher sensitivity to sound. More visual effects like this on sound perception are possible, as visual information can play a very important role in shaping people's expectation of a place and research has shown that expectation can affect sound perception in several different ways (Bruce & Davies, 2014).

Studies on the effect of visual screening on sound perception have also revealed the effect of expectation. Aylor and Marks (1976) studied the perceived loudness of noise transmitted through barriers of different solidity in "sight + sound" and "sound only" conditions. Barriers used in their experiment included an acoustic tile barrier, a row of hemlock trees, a slat fence barrier, as well as a without-barrier scenario, offering different levels of noise reduction and visual shielding of noise source. The results showed lower perceived loudness when the sight of the noise source was partially obscured, which can be attributed to the psychological benefit of reducing annoyance by visual shielding; but when the sight of noise source was completely obscured, loudness was perceived higher than when noise source was entirely or partially visible, given the same level of noise exposure at the listeners. This was explained by that 'when a sound source is occluded visually, one expects its loudness to be diminished. Therefore, sounds coming from behind barriers appear surprisingly loud and hence is overestimated relative to sounds coming from open space' (Aylor & Marks, 1976, p.400). Similar results were found in Watts et al. (1999) where the effect of visual screening of vegetation on traffic noise perception was investigated both on site and in laboratory. It was shown that perceived noisiness was higher where the level of visual screening of vegetation was higher.

In the laboratory experiment of Watts et al. (1999), the effect of visual characteristics of noise barriers on sound perception was also investigated. Two types of barriers, a willow barrier and a metal barrier of the same dimension, were tested. The noise source was invisible from behind the two barriers and participants reported much higher attractiveness of the willow barrier but similar noisiness as behind the metal one, indicating that aesthetics of noise barriers had little effect on perception of noise level behind barriers. However, some studies suggested otherwise. Joynt & Kang (2010) conducted a more dedicated and detailed study on the effect of barrier aesthetics. The study compared perceived effectiveness of four motorway noise barriers, including concrete, timber, metal, transparent acrylic barriers, and a deciduous hedgerow, in a laboratory experiment carried out in a virtual reality setting. The results showed a strong negative correlation between aesthetic preference and the perceived noise attenuation of the barriers. The study also investigated the effect of preconception of barrier effectiveness on the perceived noise attenuation and found positive correlation between them. Also using virtual reality to present experimental scenarios, Maffei et al. (2013) studied the effect of visual characteristics of barriers, concerning the aesthetics of the barriers and the visibility of the noise source through the barriers, on the perceived loudness and annoyance of railway noise. The results showed that perceived loudness was lower for transparent barriers than for opaque barriers, and remained largely the same for barriers of different aesthetics which agreed with the results in Watts et al. (1999). Noise annoyance was, however, perceived lower for barriers with higher aesthetics, as well as for transparent barriers. The effect of visual characteristics of barriers on noise perception increased as noise level increased in this study

2.4.2. Effect of sound on visual landscape and impact perception

Landscape studies involving multisensory environmental perception have shown that sound plays an important role in visual landscape perception. Carles et al. (1999) studied the interaction of image and sound in the perception of general landscape quality. The study conducted an laboratory experiment where 36 sound and image combinations were presented to participants via loudspeakers and projected slides, and rated in terms of pleasure. The study found that natural sounds increased the perceived pleasantness of both urban and natural images, while man-made sounds degraded the appreciation of natural landscapes. Also, congruent sound and image combinations generally received higher pleasantness ratings. Anderson et al. (1983) carried out three experiments, presenting visual and audio stimuli on site, via photographs and tape recordings, or described in a questionnaire, to study the effect of sound on preferences for landscapes. Results similar to Carles et al. (1999) were found for natural sites where natural sounds were shown to have enhancing effect on the aesthetic evaluation whereas mechanical sounds had detracting effects, however, in urban areas the effect of sounds were relatively neutral. In regards to the specific effect of traffic noise, Mace et al. (1999) examined the influences of 40 dB(A) and 80 dB(A) helicopter noise on the assessment of a simulated Grand Canyon vista in a laboratory experiment, and found that helicopter noise had negative influences on visitor experience in national parks including decreasing the perceived scenic beauty of the landscape. In a more recent study, Benfield et al. (2010) conducted a laboratory experiment where participants rated 25 landscape scenes presented by projected slides with presence of different sound stimuli played back by loudspeakers. The results showed that aircraft and road traffic noise decreased ratings in scenic evaluation of natural landscape especially for scenes of high scenic beauty. Using similar landscape evaluation procedure and aesthetic indicators, Weinzimmer et al. (2014) investigated the effect of noises of propeller planes, motorcycles, and snowmobiles in national parks. The results indicated that all the three motorised noises detracted from the evaluation of landscape quality and the motorcycle noise had the most detrimental impact. Contrasting to these cases, however, Anderson et al. (1983) observed that road traffic noise turned to have an enhancing effect on the aesthetic evaluation of urban streets.

The effect of traffic noise on visual landscape perception is of particular importance for VIA of motorway projects, as the visually intrusive motorway traffic induces high level noise as well. However, little effect has been made to investigate the effect of noise on traffic visual impact perception. In an evaluation of visual impact of rural road and traffic in the Lake District, Huddart (1978) used composite cine films both with and without sound to show controlled combinations of road projects and background sites for subjective assessment, and concluded that traffic noise had no significant effect on the assessment. However, it should be noted that traffic volume on the rural roads in that study were much lower than that of motorways today, and scenes with generally far distances to traffic were used due to the restriction in video simulation using composite cine films. In a study that specifically focused on the visual impact of moving traffic, Gigg (1980) also compared the subjective ratings given to filmed video scenes of moving traffic with and without sound, and found that traffic noise had a dominant effect on the visual assessment. In this study, while traffic volume was still relatively low, viewpoints close to the traffic (about 5m-45m) were selected. The contradictory results of the two studies might be ascribed to the very different stimuli used.

2.4.3. Interactive effects on overall environmental perception

Pheasant et al. (2008) examined the role and importance of audio-visual interaction in constructing tranquil environment where multisensory stimulation provides reflection and relaxation and enables the recovery of sense of well-being. In this study, a laboratory experiment was carried out where videos recorded on-site representing 11 contrasting environments were shown to the participants on a Plasma TV screen in audio-only, visual-only and audio-visual conditions. The tranquillity of each video scene was rated. The results showed that perceived tranquillity is influenced by complex interactions between audio and visual stimulations. Regression equations were developed to calculate the degree of tranquillity using percentage of natural feature in captured view and sound level indicators such as L_{Aeq} and L_{Amax} as predictors. Hong & Jeon (2013) investigated the effects of sound and visual components on perceived overall quality of urban environment. Nine audio stimuli for the audio-only condition, 16 photomontages for the visual-only condition, and the combined stimuli for the audio-visual condition, were evaluated in a laboratory experiment in this study. The results showed that natural sound and visual components can enhance soundscape and landscape qualities respectively, however, water sound can decrease the overall environmental quality when the level of traffic noise is high. It was also found that acoustic comfort plays a more important role than visual factors on the overall environmental quality when the level of traffic noise is high. Nilsson et al. (2012) explored the relationship between soundscape, visual landscape and the overall quality of the environment by means of a soundwalk study. The results showed that agreement among participants was greater for evaluation on the overall environmental quality than on sound or visual quality, which suggests that assessing the overall environmental quality is easier and more natural than assessing environmental qualities of each individual sensorial modality.

Following this argument, Hong & Jeon (2014) studied the overall preference for noise barriers considering both acoustical and visual performances. A laboratory experiment was carried out, with participants evaluating the performance of nine tested barriers in audio-only, visual-only and audio-visual conditions. The results show that vegetated barrier was the most preferable one, followed by concrete and wood barriers, translucent acrylic and aluminium barriers were the least preferred, despite the lower perceived loudness found for transparent and nonsolid barriers in Aylor & Marks (1976), Maffei et al. (2013) and Watts et al. (1999). Preconception of barriers' noise reduction effectiveness was the most affecting factor in determining the overall preference for the barriers when the noise level was relatively low, while aesthetic preference for barriers came to be the most determinant one when noise level was relatively high. One limitation of Hong & Jeon (2014) is the use of static images to present noise barriers for road traffic in their experiment. It failed to present moving traffic which should be visible in some barrier scenarios, while moving traffic has been shown to be influential on perceptions of both sound (Fastl, 2004) and visual (Gigg, 1980; Huddart, 1978) environmental qualities.

2.5. Summary

It can be summarised that approaches of motorway project VIA in current practice have not kept abreast of recent academic research and technological progress related to visual landscape and impact assessment. More efficient and reliable methods should be developed to response to the need of a VIA system for motorway projects that is updated with the theoretical and technological advances. There is also a lack of emphasis on perception-based visual landscape and impact research focusing on topics related to road projects in current literature, despite some early studies in the 1970s. Meanwhile, the aural-visual interaction found in human environmental perception indicates potential advantages of addressing issues of perceived visual and noise impacts of motorways in a combined approach. However, systematic investigations are still needed to understand how the identified factors which are influential on visual and/or noise impacts contribute to their integrated impact, and to explore possible assessment methods for the integrated impact.

Chapter 3 Perceived visual impact of motorways without moving traffic: the influential factors and impact prediction

Following reviews on visual impact assessment and research in Chapter 2, this chapter investigated on visual impact of motorways without consideration of potential impact from moving traffic. Effects of characteristics of road project and character of existing landscape on perceived visual impact of motorways were examined, and a GIS-based prediction model was developed. This chapter starts with a review on related practice and research to set up the context and identify research questions of this part of work (Section 3.1), followed by a detailed description of the research methods employed in this chapter (Section 3.2). The results of the investigation are then presented and findings discussed, including analysis of the effects of road project and existing landscape on perceived visual impact and development of a GIS-based prediction model for the impact (Section 3.3). Finally, conclusions of the work and findings of the chapter are made (Section 3.4).

3.1. Background

Visual impact is one of the major environmental impacts of motorway projects that need to be assessed and considered for decision making (Federal Highway Administration, 1988; Highways Agency, 2010). In current practice, the assessment of visual impact of motorway projects largely draws on approaches proposed by relevant government agencies (e.g., Bureau of Land Management, 1984; Federal Highway Administration, 1988; Highways Agency, 2010; Roads and Traffic Authority, 2009; U.S. Forest Service, 1974 & 1995). By these approaches the assessment is carried out with respect to certain assumption or design criteria which are relevant to visual landscape quality, and the obtaining of judgement for steps of these approaches is very often expert-based (Daniel, 2001). Expert-based assessment is efficient (Lothian, 1999), but is criticised for the inadequate level of reliability and precision, as the assessment is typically made by a single person and only gives very rough classifications of the impact level (Daniel, 2001).

On the other hand, a considerable amount of research studies on visual landscape assessment have drawn on perception-based approach to obtain more precise and reliable judgement (e.g., Anderson & Schroeder, 1983; Bishop & Miller, 2007; Buhyoff, & Leuschner, 1978; Louise, 1977; Schroeder & Daniel, 1981; Shafer, 1969). This approach, usually by the mean of a preference survey, derives visual quality of the landscape or visual impact on it as perceived by a sample of actual or potential viewers on site or via surrogate media (Daniel, 2001). Perception-based approach is relatively time-consuming and expensive, but the results have a capability of being used for prediction (Lothian, 1999), if the sample viewers are representative for a wider or targeted population. While some studies found differences between viewer groups, e.g., by cultural background (Zube & Pitt, 1981); by landscape expertise and knowledge (Hunziker et al., 2008; Tveit 2009), many show substantial agreement between diverse groups in visual landscape assessment (e.g., Anderson & Schroeder, 1983; Daniel & Boster, 1976; Kearney et al., 2008; Ode et al., 2009; Wherrett, 2000; Zube, 1974).

Attempts to study the visual impact of road projects and the possible predictive factors using perception-based approach has been made in the 1970s. Based on visual judgement made by respondents on site, Hopkinson & Watson (1974) found that the increases of the visibility of the road and the number of dwellings in the view detracted from the visual quality of the view while the amount of visible sky enhanced it. Using colour-slides, prints and cine films, Huddart (1978) obtained visual pleasantness ratings from local residents and visitors to study the visual impact of roads in the Lake District, UK, and concluded that the ratings decreased as road construction became more visible and the decrease rate was probably affected by the character of the background landscape.

However, this type of research on visual impact of road projects is very limited in literature. Moreover, the existing studies have a limitation that they only investigated view-based predictive factors, and their results could only be applied for the assessment of circumscribe views rather than the whole affected areas

(Bishop & Hulse, 1994). To achieve area-wide assessment, some visual landscape studies integrated the prediction models derived from the preference surveys into a geographic information system (GIS) by using map-based measures as predictive factors (e.g., Bishop & Hulse, 1994; Grêt-Regamey et al., 2007; Schirpke et al., 2013). With the increased availability and manipulability of geographic data, the results of these studies can be applied to assess visual quality or visual effect of landscape changes from viewpoints covering the whole area in interest with efficiency and reliability.

Early examples of using GIS for road project visual assessment can be found in Federal Highway Administration (1988). Landscape features visible from the road were mapped and classified to indicate the quality of views from the road. The impact of roads on views to the road, which is the issue addressed in this paper, was assessed by mapping the viewshed of the road and weighting the viewer sensitivity inferred from land use. In recent research, Garré et al. (2009) calculated three morphological metrics of the visible landscape from random viewpoints using GIS, and compared the results from the on-road viewpoints with those off-road, to investigate the visual access to the landscape offered by roads. Chamberlain & Meitner (2013) analysed route-based visual magnitude of DTM cells for views from a tourist highway, to demonstrate a more advanced GIS application for planning. However, no attempt seems to have been made to predict human-perceived visual impact of road projects in GIS. It is still difficult to achieve reliable assessment for the whole affected area instead of a limited number of selected key views along the long corridor of a large scale road project like a motorway project.

Therefore, the aim of this chapter is to investigate how factors of project development and existing landscape contribute to the perceived visual impact of motorways, and consequently to develop a GIS-based model to predict the impact. In this chapter, factors of project development of interest include the appearance of roadways, noise barriers, and tree screen, as they are the main motorway features that are potentially predictive for the visual impact assessment at a large scale. The potential impact of moving traffic is not investigated in this chapter. Factors of existing landscape considered are map-based measures of land covers and landform, as visual landscape is mainly defined by land cover and landform (Daniel, 2001). It is also aimed to use predictors that are readily derivable from the general planning data for the prediction model. With human preference for computer-visualised scenes of different motorway and landscape scenarios obtained via an online survey, the specific steps and objectives of this chapter are: (1) investigate the effect of the appearance of roadways, noise barriers, and tree screen on the perceived visual impact; (2) explore the relationship between map-based measures of the existing land covers and landform and the perceived visual impact; (3) predict the perceived visual impact using the derived model in GIS.

3.2. Methods

This study used computer-based visualisation for the preference survey, and visual impact was calculated as reduction in mean visual pleasantness ratings given to the same view without and with motorways. Tree screen, timber and transparent noise barriers were simulated in addition to the original motorway to study the effect of the characteristics of the motorway project on the perceived visual impact. Different landscape scenarios varying in land cover of buildings and trees in three distance zones were created to study the effect of the existing landscape. In total 120 images captured from 10 viewpoints were rendered and used for the preference survey which was carried out online. Based on the result of the preference survey, a regression model was developed and applied to a grid of viewpoints in GIS to map the predicted visual impact.

3.2.1. Visualisation

3.2.1.1. The advantage and validity of computer-based visualisation

Computer-based visualisation is more advantageous than photographs, which have been commonly used as a surrogate of the actual environment for visual landscape preference surveys (Palmer & Hoffman, 2001), in terms of scenario creation and variable control (Bishop & Miller, 2007; Ode et al., 2009), as well as links between 2D and 3D data (Ode et al., 2009) which is of particular importance for GIS-based analysis. The validity and realism of computer-based visualisation for visual landscape assessment has been examined by research studies (e.g., Appleton & Lovett, 2003; Bishop & Rohrmann, 2003; Lange, 2001; Oh 1994). The results of these studies indicated that although computer-based visualisation could not be used with full confidence to represent the actual landscape for visual perception or assessment, generally reliable judgments could be obtained and its use was supported. They also showed that increasing the level of simulated details could enhance the degree of reality, and some specific landscape features, e.g., foreground vegetation and ground surface (Appleton & Lovett, 2003), were more important than others and would require more realistic presentation. Sophisticated use of visualisation can provide powerful tools for communicating with different interest groups and obtaining public landscape preferences (Lange & Hehl-Lange, 2005; Lange et al, 2008; Wissen et al 2008; Smith et al 2012).

3.2.1.2. Base site modelling

A site along a segment of the UK M1 motorway between Junction 34 and 35, covering an area of 2500 m × 2500 m, was chosen as the base site for computer visualisation (Figure 3.1). It was not intended to study the visual impact of the specific motorway on the specific site, rather, it was only to get a typical motorway project that can be seen in the actual world. The selection is based on the ideas that the site should be a typical UK rural or semi-rural area where motorway corridors are usually located, slightly varying in land cover and landform, and it should be an open area so the existing road would have been built without too much earth work, which ensures that the modelling of the without-road baseline scenarios can be made without too much transformation of the land. The road on the selected site is a dual 3-lane motorway with asphalt surface. The dimensions of cross-section components for rural motorway mainline provided by Highways Agency (2005) was used for modelling. Detailed information can be found in Figure 3.2.

With terrain data of the site obtained from Ordnance Survey, the motorway was modelled in AutoCAD Civil 3D, and then imported into Autodesk 3ds Max Design to add further road structures, vehicles, land cover, and to apply materials and daylight for rendering. modelled land cover features include trees and buildings, of which the geo-data was obtained from Ordnance Survey's MasterMap. Most of the trees were modelled 12m in height and 8m in diameter, a few shorter trees were set 6m in height and 4m in diameter. A random 50%-150% variation in scale was applied to all the trees. Most of the buildings on the site are 2-story semi-detached houses and the height was set as 8m. The heights of other buildings were estimated on site. All the buildings were site-typically textured using images captured from

Google Street View. For each camera view (see Section 3.2.1.2), the land surface behind the road was draped with satellite imagery to make the scene more realistic; the land surface between the viewpoint and the road was textured with a bitmap of grassland since the draped image blurs when getting close to the camera. The weather and daylight condition was set as sunny June midday in the UK and was kept the same for all the renderings.

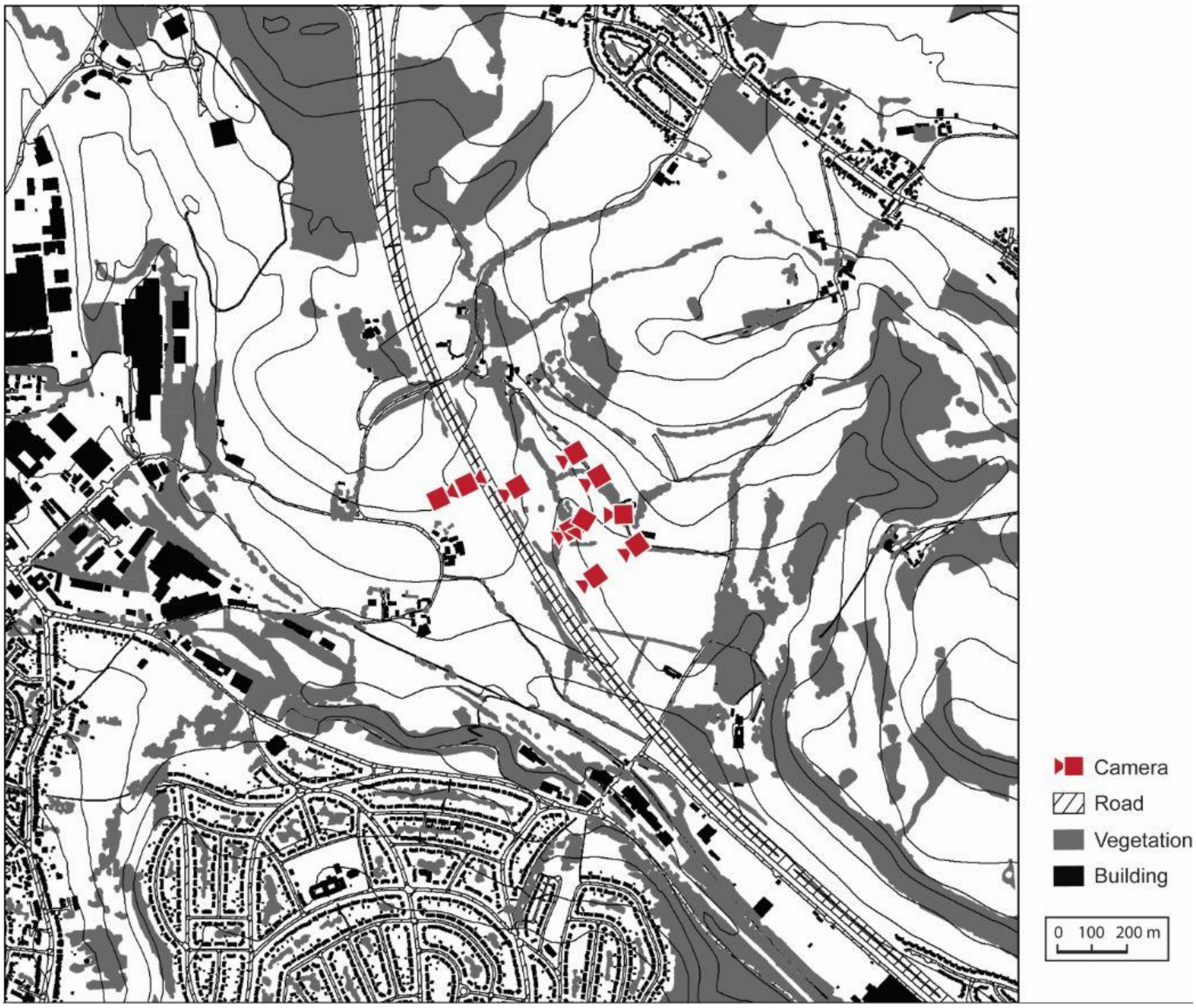

Figure 3.1. The base site and the location and direction of the cameras (reproduced based on Ordnance Survey MasterMap).

3.2.1.3. Viewpoints and cameras

Ten viewpoints, covering distances to road (horizontal distance to road central line) from 53m to 286m, were chosen to start scene creation. Only viewpoints accessible on site were considered so field assessment of their suitability was allowed. The chosen criteria were to have various land covers and landforms at the starting point.

The distance to road was limited within 300m as on-site observation suggested that the visibility of the motorway from approximately this distance has declined to a low level that it only forms a relatively small element at ground level in the view. It was aimed to study visual impact in the most affected area, so short distances within 300m were thought to be suitable. However, it should be kept in mind that possible visual impact can reach much further distances (Federal Highway Administration, 1988; Highways Agency, 1993) and should still be considered in practice.

The camera for each viewpoint was set 1.6 m above the ground and with a horizontal viewing angle ranging from 60° to 90° to the motorway. Figure 3.1 shows the location and direction of the ten cameras. To ensure that the motorway was vertically in the middle of each view, the target of each camera was set at the same height as the targeted road surface. So the vertical viewing angles of the viewpoints varied depending on their relative elevations to the road surface. Horizontal field of view of 72°, which is wider than that of a standard lens, was chosen for this study to convey the breadth of visual information required for road project which extends transversely in the view (Landscape Institute, 2011). To avoid distortion of distance perception, the vertical field of view was kept at 27°, which is close to that of a standard lens. The resulted aspect of the captured images was 3:1. Photographs taken at accessible viewpoints on-site were used to compare and calibrate the base site simulation.

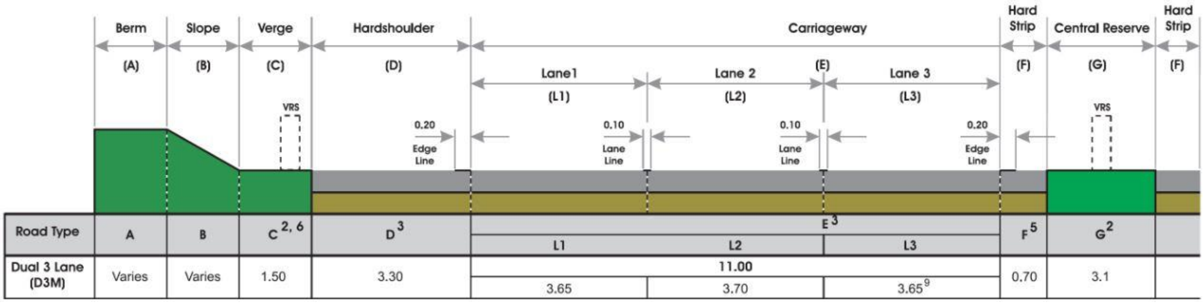

Figure 3.2. Dimensions of cross-section components for the simulated motorway (reproduced based on the Figure 4-1a in Highways Agency (2005)).

3.2.1.4. Visual feature design

Variations in visual features from each viewpoint were designed to create different but controlled motorway and landscape scenarios for the purpose of this chapter. For the motorway scenarios, tree screen and two types of noise barriers: timber barrier and transparent barrier, were introduced in addition to the original roadway. The height of the tree screen was set 9m with a little variation; the heights of the two barriers were both 5m. Apart from the original dual 3-lane scenario, a dual 2-lane scenario was also considered. However, the two scenarios looked almost identical at ground level with the viewing angles nearly perpendicular to the road. So the dual 2-lane scenario was abandoned. To create the baseline scenarios, the modelled motorway was deleted and the land was draped with a photoshopped satellite image in which the existing motorway was masked by grassland.

Different landscape scenarios for each viewpoint were created based on the original settings of the base site by adding and/or removing buildings and/or trees, which are the two typical types of land cover apart from grassland in this area. Since research has shown that the same landscape elements at different distances from the viewpoint will have different effect on visual judgment (Shafer, 1969; Steinitz, 1979), three distance zones were defined: 0-300m (foreground); 300-900m (midground); and greater than 900m (background), and buildings and trees were added and/or removed in each of the distances zones to ensure that there were changes in land cover at each distance from the viewpoint. Scattered trees between the motorway and the viewpoints were added to or removed from some of the scenes to create counterpart scenes for the comparison of the effect of their presence, as research has shown that landscape elements between the viewer and the project object has a strong influence on visual assessment (Hadrian et al., 1988). No modification in landform was made and the original landform which varied slightly from the ten viewpoints was used to represent changes in landform for investigation, for the reasons that landform along a typical motorway corridor usually changes less dramatically than land cover and any modification in landform will make data preparation for GIS analysis very complicated.

3.2.1.5. Output images

The resolution of the rendering output images was 1200 × 400 pixels. Overall, 120 images, including 88 images with road and 32 images for the corresponding baseline scenes, were rendered. Figure 3.3 shows a set of 24 images used in one of the questionnaires (see Section 2.3 for questionnaire design).

Figure 3.3. A set of 24 images used in one of the questionnaires (Enlarged image content is provided in Figures 10.1, 10.2 10.3 and 10.4 in Appendix 6).

3.2.2. Scene content measurement

The scene content shown in each image was dummy-coded or measured, and 24 variables were derived for study (Table 3.1). For each landscape scenario at each viewpoint, visible buildings and trees in each distance zone were measured by cell count in GIS based on baseline landscape without motorway. To achieve this, a 5m × 5m raster digital terrain model (DTM) of the site was built in ArcGIS 10.1 with terrain data obtained from Ordnance Survey. For each landscape scenario, another raster of the same cell size recording the height of buildings and trees was superimposed onto the DTM to generate a digital surface model (DSM). With the DSMs, viewshed analysis was performed in ArcGIS to calculate visible cells from each viewpoint of which the attributes were set consistent to the corresponding camera in Autodesk 3ds Max Design. Numbers of cells representing buildings and trees in the three distance zones were then counted within the viewshed by overlaying the viewshed onto corresponding land cover raster. Average slope and standard deviation of the slopes of the visible DTM cells from each viewpoint were also calculated in ArcGIS.

Table 3.1. Dummy-coded and measured variables

	Variable	All the 120 images				88 with-road images			
		Mean	**Min**	**Max**	**S.D.**	**Mean**	**Min**	**Max**	**S.D.**
Motorway Characteristics	Original road	0.26	0 (no)	1 (yes)	-	-	-	-	-
	Road with timber barrier	0.18	0 (no)	1 (yes)	-	0.25	0 (no)	1 (yes)	-
	Road with transparent barrier	0.18	0 (no)	1 (yes)	-	0.25	0 (no)	1 (yes)	-
	Road with tree screen	0.11	0 (no)	1 (yes)	-	0.15	0 (no)	1 (yes)	-
	Distance to road	-	-	-	-	173	53	286	73
Existing Landscape Character	Scattered trees between road and viewpoint	0.34	0 (no)	1 (yes)	-	0.32	0 (no)	1 (yes)	-
	Amount of buildings in the viewshed (AB)	773	0	1744	561.83	791	0	1744	560
	Amount of buildings in the viewshed in foreground (ABF)	7	0	27	10.94	7	0	27	11
	Amount of buildings in the viewshed in midground (ABM)	170	0	552	172.49	169	0	552	170
	Amount of buildings in the viewshed in background (ABB)	696	0	1504	460.42	615	0	1504	462
	Amount of trees in the viewshed (AT)	1054	42	2256	615.99	1047	42	2256	613
	Amount of trees in the viewshed in foreground (ATF)	37	0	243	57.03	34	0	243	52
	Amount of trees in the viewshed in midground (ATM)	351	10	1200	286.85	341	10	1200	276
	Amount of trees in the viewshed in background (ATB)	665	5	1313	430.15	671	5	1313	432
	Percentage of buildings in the viewshed (PB)	18	0	40	10.01	18	0	40	9.64
	Percentage of buildings in the viewshed in foreground (PBF)	1	0	7	1.82	1	0	7	1.79
	Percentage of buildings in the viewshed in midground (PBM)	18	0	58	16.47	18	0	58	16.17
	Percentage of buildings in the viewshed in background (PBB)	37	0	90	15.17	37	0	90	13.88
	Percentage of trees in the viewshed (PT)	25	4	61	12.22	24	4	61	11.45
	Percentage of trees in the viewshed in foreground (PTF)	7	0	84	14.96	6	0	84	12.74
	Percentage of trees in the viewshed in midground (PTM)	30	5	67	18.33	29	5	67	18.24
	Percentage of trees in the viewshed in background (PTB)	44	10	100	15.60	43	10	100	14.33
	Average slop of visible land (SLPavg)	5.0 °	4.1 °	8.2 °	0.91	4.9 °	4.1 °	8.2 °	0.81
	Standard deviation of the slops of visible land (SLPstdv)	2.74	1.78	3.44	0.44	2.72	1.78	3.44	0.44

3.2.3. Online preference survey

The preference survey was carried out online. Since assessing 120 images would take too long for an online survey and leads to a high drop-out rate, it was decided that each participant only needed to assess 24 images out of the 120 which would take no more than 5 minutes in total. However, simply dividing the 120 images into

5 groups of 24 images to be assessed by 5 different groups of participants will induce biased responses, since not only different people have different judging criteria, but also people's judgement of each image can be influenced by the presentation of the other images in the same group (Gescheider, 1997). To minimise the potential bias, 100 questionnaires were designed and the 120 images were distributed across them such that each questionnaire contained a unique combination of 24 images and each image was shown in a unique set of 20 questionnaires (see Appendix 1). Thus, all the 120 images were treated equally. To minimise the sequential effect on judgement, the 120 images were ranked in a random order before distributed to the 100 questionnaires, and within each questionnaire, the 24 images were further randomised. Each questionnaire should be answered by the same number of participants.

The online survey consisted of five parts: introduction, participant and device information collection, image assessment, daily commute information collection, and a word of thanks. Participants were only informed that the study was about visual landscape assessment, the exact purpose of studying the visual impact of motorways was not mentioned, and questions about living area, car ownership and daily commute were asked only after the image assessment.

In the image assessment part, which was laid out with one image per page, participants were asked to rate the visual pleasantness of each image using visual analogue scale, that is, by moving the slider on a bar which was set 0 to 100 (the value was not shown) and only had "low pleasantness" and "high pleasantness" labelled at the two ends (Figure 3.4). Visual analogue scale was favoured over the more commonly used Likert scale as research has shown possible difference in results from using these two scales (Cowley & Youngblood, 2009) and visual analogue scale gives continuous measures which are more suitable for the statistical analysis that would be used for this study. A comparison between visual analogue scale and paired comparison as rating approaches was also made in a pilot study (Appendix 2), which shows highly congruent results between the two approaches. Given these supporting results and considering the large number of images to be rated, visual analogue scale was chosen for this study. However, it should still be noted that paired comparison is generally seen as a more reliable rating approach

(Lavrakas, 2008), additional biases introduced by response range effect (Poulton, 1977) may occur with the visual analogue scale used in this study which can reduce the reliability of the results. The term "pleasantness" was used since Landscape Institute and Institute of Environmental Management and Assessment (2013, p158) defined visual amenity of the landscape as "the overall pleasantness of the views people enjoy of their surroundings". The use of "pleasantness" was also found in some other studies involving subjective visual evaluations (e.g., Day, 1967; Ruddell et al., 1989). Participants were informed at the beginning of the image assessment part that visual pleasantness in this study could be understood as visual landscape quality or scenic quality of the scenes, and there were no clear criteria for the rating, and they could draw upon whatever value judgements they deemed necessary.

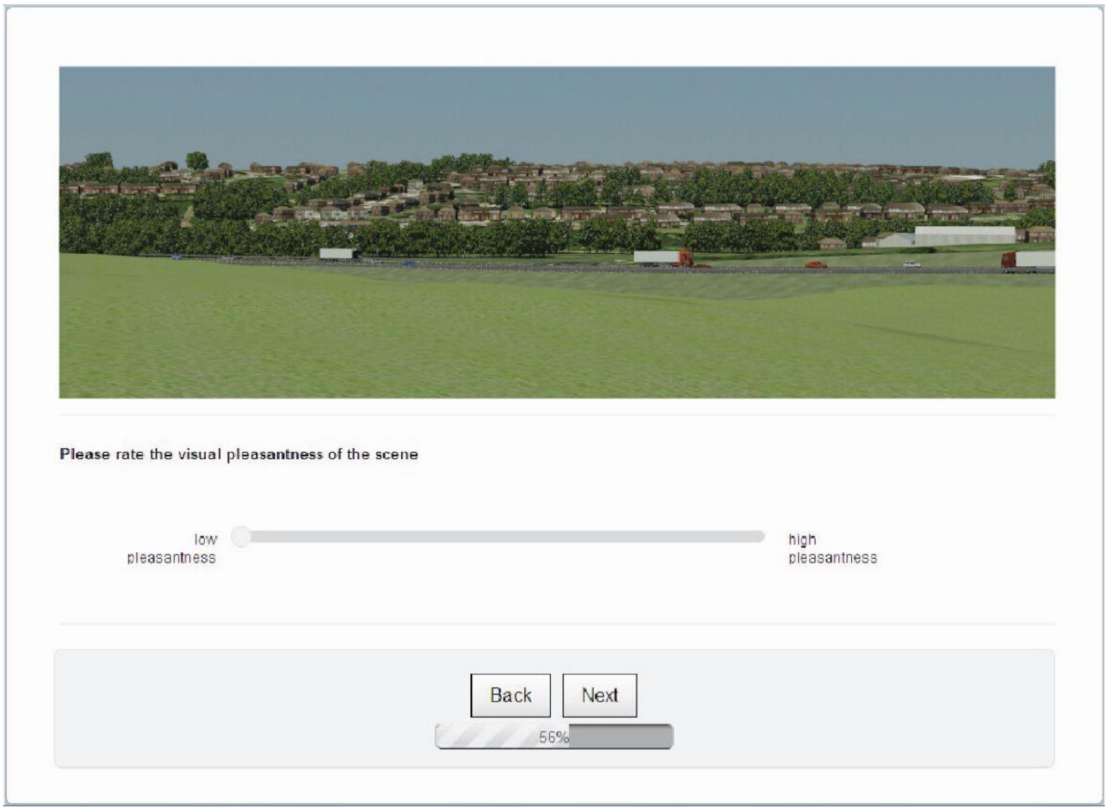

Figure 3.4. The online survey interface

The survey was broadcasted via university email lists, Facebook, QQ groups, and receivers were encouraged to forward the survey invitation to others. While there were 100 different questionnaires, only one unique URL was used for the survey, and participants were randomly directed to one of the questionnaires upon starting the image assessment part. To balance the number of responses received for each questionnaire, the survey was monitored and questionnaires receiving more responses than others were deactivated. The survey was online for one week and received 253 completed responses and 74 partial responses (dropout rate: 22.6%). 200 of the 253 completed responses, two for each questionnaire, which means each of the 120 images received 40 judgements, were used for analysis.

3.2.4. Data analysis and visual impact prediction

Forced-entry regression analysis was used to test the effect of participant groups on image ratings. The *t*-test was applied to analyse reductions in visual pleasantness of scenes when the motorway was introduced, as well as to compare visual pleasantness and impact ratings in scenarios with and without scattered trees between the motorway and the viewpoint. Correlation analysis was used to study the relationship between visual impact and measures of land cover and landform. To predict the perceived visual impact, a regression model was chosen from four tested models, and applied on a grid of viewpoints to map the predicted impact in GIS. To verify the prediction, predicted visual impacts at three typical viewpoints were compared to empirical results collected in a supplementary online survey (N = 58) using photos taken on-site and their edited copies as visual stimulus. The supplementary survey used the same template as the main survey as shown in Figure 3.4.

3.3. Results and discussion

3.3.1. Analysis of responses

Figure 3.5 shows the distribution of demographic, transport and device groups of the 200 participants whose responses were used for analysis. Among the 200 participants, 83 were male and 117 were female. The majority of them were young people in the age groups of 18-24 (62%) and 25-34 (26.5%), implying that most of the participants were university students. Approximately half of the participants (52.5%) chose UK as their home country, while 11.5% from China which made up the second largest group. The rest of the participants were from 30 other countries across the world. 88.5% of the 200 participants were living in the UK when answering the survey. In terms of living areas, 52.5% of the participants were living in urban area and 39% in suburban area, only 8.5% in rural area. In terms of transport, 29% of the 200 participants had one or more motor vehicles, but only

10.5% drove for their daily commute. Most of the participants (65.5%) chose walk as the form of their daily commute. Most of the rest used public transport. The devices that participants used to answer the survey were mainly personal computers (88.5%), followed by tablets (5.5%) and smart phones (5%). Various sizes of screens were used, with the majority of them were 10”-15” (27%), 15”-23” (32.5%), and 23”-30” (10%).

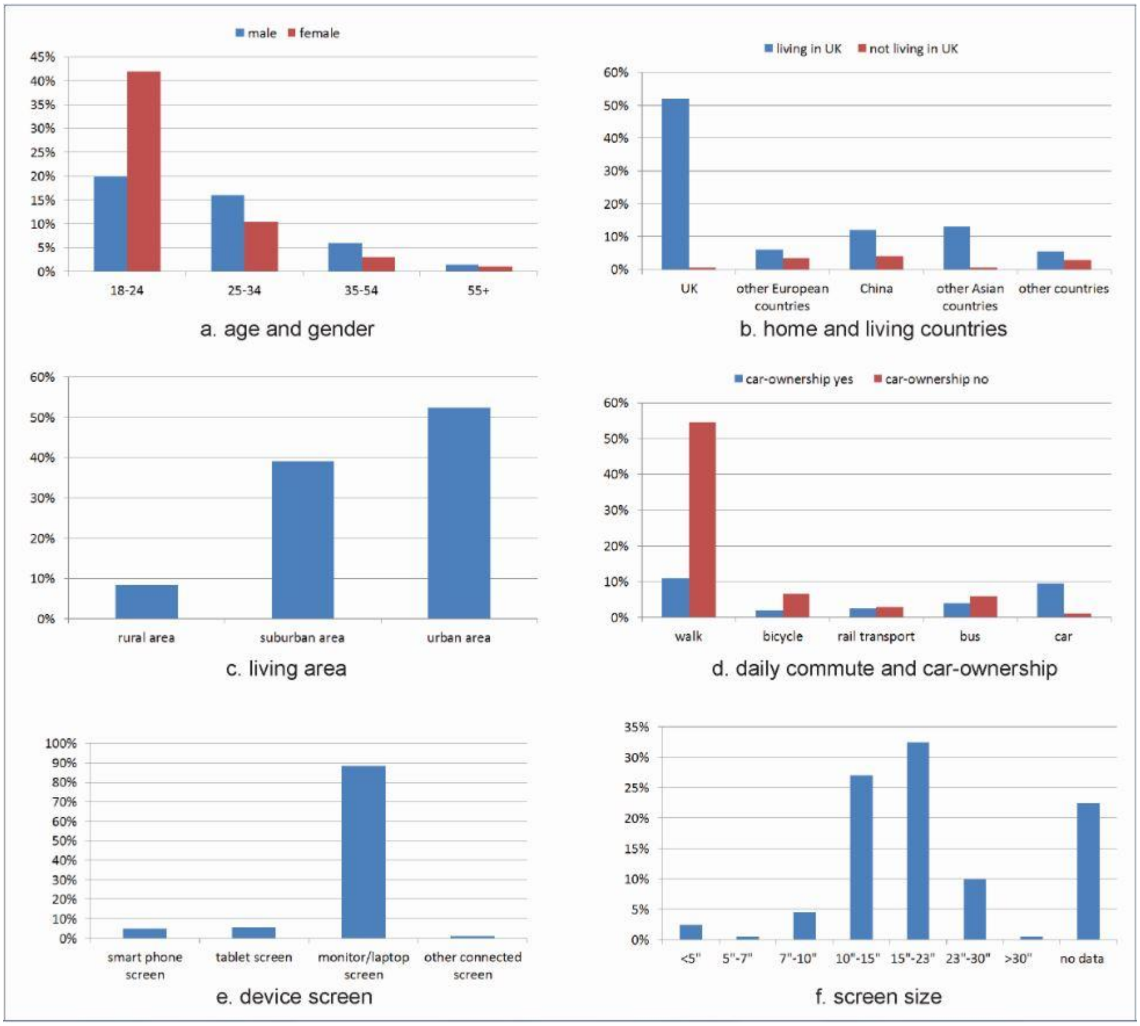

Figure 3.5. Distribution of demographic, transport and device groups of the 200 participants.

The respondent sample skewed to be more representative of the UK university students. However, given the large amount of research that has shown the minor effect of participant groups for landscape assessment (e.g., Anderson & Schroeder, 1983; Daniel & Boster, 1976; Kearney et al., 2008; Ode et al., 2009; Wherrett, 2000;

Zube, 1974), there is still confidence to generalise the result to give useful information. The effect of participant groups in this particular study was also tested.

Using the 4800 visual pleasantness ratings (200 participants $\times$ 24 ratings/participant) with the participant variables (dummy-coded) and image variables (Table 3.1 for all the 120 images) attached to each rating, a forced-entry regression analysis, which assesses the unique contribution of each independent variable that is not shared by other independent variables, was applied to test the effect of participant groups on the visual pleasantness rating. Full correlation of the participant variables with the visual pleasantness ratings was also applied to offer additional information for interpretation since it is possible for an independent variable to appear unimportant in a forced-entry regression when it actually has high correlation with the dependent variable. Table 3.2 shows the regression result, only significant predictors are listed. Since the prediction level of the regression model is low (adj R^2= 0.287), this part of discussion remains tentative.

It is shown by the coefficients and Partial R^2s that the ratings were largely dependent upon the characteristics of the motorway. The coefficients and Partial R^2s of the existing landscape variables are small, but given that the value ranges of these continuous landscape variables are much larger than those dummy-coded participant variables, they still accounted for a larger variation in the ratings. So it might be concluded that participant groups had limited effect on ratings, differences in ratings given to scenes of different motorway and landscape scenarios were mainly decided by the scene content itself. So the effect of participant groups will not be addressed further in the following discussion. It is noticeable however that participants whose home country is China generally gave much higher ratings (12.8 higher than those from the UK), which might be explained by that the greener UK-based scenes were more appreciated by the Chinese participants. The differences resulted from screen size were also relatively large (variation in ratings up to 8.1). While screen size did not show significant effect on ratings in Wherrett (2000), the larger size-difference of devices today especially when comparing smartphones and PCs might require more attention to the possible effect of screen size for such studies. One unexpected result is that those who commute by car gave more negative ratings to the scenes of which the majority have motorway content (3.0 lower than walkers and 9.8 lower than cyclists).

Table 3.2. Result of the regression against the 4800 visual pleasantness ratings (adj $R^2 = 0.287$, only significant predictors shown).

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Partial R^2
	B	Std. Error	Beta			
(Constant)	72.090	13.302		5.419	.000	
Original road	-15.490	.745	-.309	-20.802	.000	.084
Road with timber barrier	-21.026	.846	-.368	-24.855	.000	.115
Road with transparent barrier	-17.077	.857	-.293	-19.929	.000	.077
Scattered trees between road and viewer	2.955	1.422	.063	2.078	.038	.001
Amount of buildings in the viewshed in midground (ABM)	-.019	.009	-.144	-2.041	.041	.001
Percentage of trees in the viewshed in foreground (PTF)	-.293	.118	-.197	-2.489	.013	.001
Percentage of trees in the viewshed in midground (PTM)	-.533	.138	-.440	-3.861	.000	.003
Percentage of buildings in the viewshed (PB)	-.706	.265	-.318	-2.664	.008	.002
Percentage of trees in the viewshed (PT)	1.085	.471	.597	2.304	.021	.001
Age 18-24	-6.855	1.976	-.150	-3.470	.001	.003
Age 25-34	-4.330	1.993	-.086	-2.173	.030	.001
Home country UK	3.159	1.181	.071	2.675	.008	.002
Home country China	15.917	1.285	.230	12.383	.000	.031
Home country other Asian country	3.568	1.243	.062	2.871	.004	.002
Living in UK	5.290	1.030	.076	5.135	.000	.005
Screen size <10”	2.674	1.207	.032	2.216	.027	.001
Screen size 15”-23”	-5.431	.823	-.115	-6.596	.000	.009
Screen size >23”	2.300	1.076	.032	2.137	.033	.001
Living in urban area	2.523	.622	.057	4.056	.000	.003
Living in rural area	4.374	1.094	.055	3.998	.000	.003
Daily commute bike	6.893	1.068	.087	6.451	.000	.009
Daily commute railway	5.859	1.371	.058	4.274	.000	.004
Daily commute car	-2.956	1.183	-.041	-2.499	.012	.001

Dependent Variable: Visual Pleasantness

3.3.2. The effect of the motorway project

The *t*-test was used to analyse the visual impact induced by the motorway in four different motorway scenarios. Table 3.3 shows the result for each scenario. Since visual impact in this study was measured as reduction in mean visual pleasantness ratings given to the same view without and with motorways, possible visual impact values would range from -100 to 100, where a negative value means the introduction of the motorway enhances the visual quality of the view, 0 means no change in visual quality of the view, and a positive value means detracts from the visual quality of the view.

It shows that the introductions of the original motorway, motorway with timber noise barrier, and motorway with transparent noise barrier all lead to a significant reduction in the visual quality of the scenes. The effects of them were all very large and that with timber noise barrier came the largest. On average, the original motorway caused visual impact of 16.2; the installation of timber noise barrier increased the visual impact to as high as 20.9, whereas the installation of transparent noise barrier made no noticeable increase. The different detrimental effects can be explained by the higher detactability of the opaque timber barrier and the usually negative visual effect of noise barriers (Bendtsen, 1994). However, this chapter did not address the visual impact of moving traffic, and when traffic is introduced, opaque barriers may have a mitigation effect in some cases by blocking undesirable views to the traffic (Kotzen & English, 2009).

When the motorway was screened by trees, the difference in visual pleasantness ratings with and without motorways is not significant, which implys that tree screen had a strong mitigation effect and could reduce visual impact considerably or even entirely. However, this does not mean that the issuse of visual impact of motorways can be addressd simply by applying tree screening. Regardless of the cost or any other limitations, new plantings will have little effect within a few years and may need more than 15 years to become fully established (Highways Agency, 2010).

Table 3.3. Visual impact induced by motorways in different project scenarios.

Motorway scenario	**Mean visual pleasantness without road**	**Mean visual pleasantness with road**	**Mean visual impact**	***t***	**df**	***p***	**Effect size***
Original road	57.4	41.2	16.2	14.595	29	< 0.001	0.880
With timber barrier	55.1	34.2	20.9	18.574	21	< 0.001	0.943
With transparent barrier	55.4	38.5	16.9	13.783	21	< 0.001	0.900
With tree screen	55.1	55.9	-0.8	-0.476	12	0.643	-

*effect size calculated as $r^2 = t^2/(t^2 + df)$

Corresponding to Table 3.3, Figure 3.6 shows the visual impact of motorways of different scenarios scattered over distance to road. Overall, visual impact decreased as distance increased except in the with-tree-screen scenario. The correlations indicate that the relationship was stronger in the with-barrier scenarios. Approximately at all the distances, noise barriers tended to increase visual impact, especially the more visible timber barrier, while tree screen had a mitigation effect and made the impact considerably lower.

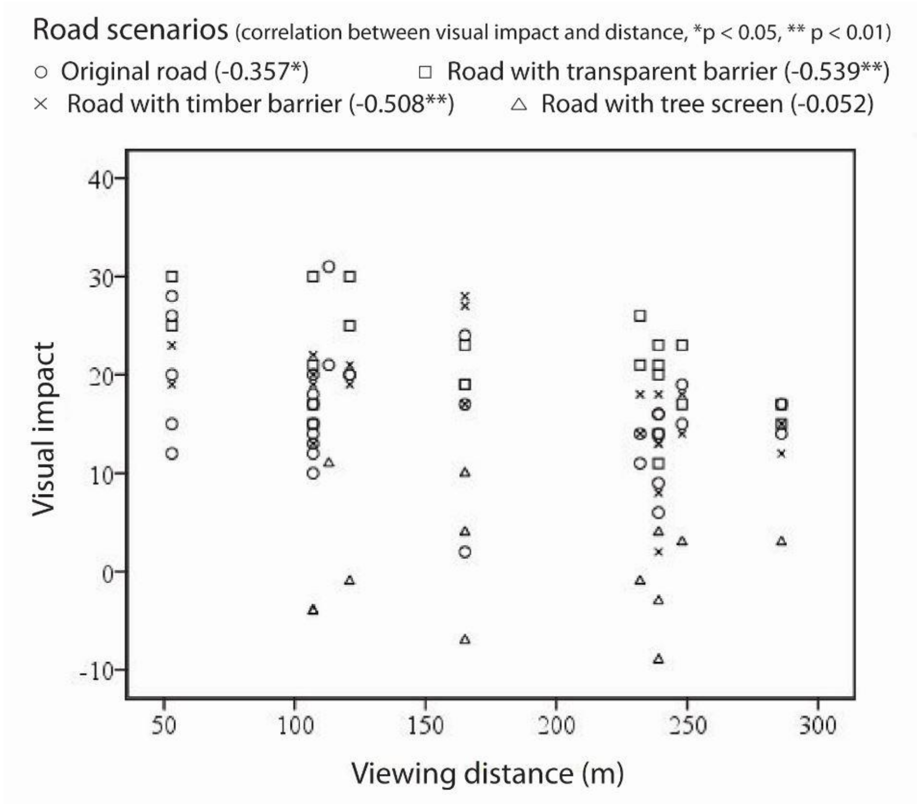

Figure 3.6. Visual impact of motorways at different distances.

3.3.3. The effect of the existing landscape

Correlation between visual pleasantness of the baseline scenes and the measures of trees and buildings in the viewshed of the scenes, as well as between visual impact of the motorway and the measures of trees and buildings, are shown in Table 3.4. Correlations of visual pleasantness and visual impact with the slope measures of the visible land were also examined.

The result shows that there were significant negative correlations of the visual pleasantness of the baseline scenes with the presence of buildings in the view, and significant positive correlations with the presence of trees in the view. It indicates that the appearance of buildings detracts from the visual quality while trees enhance it, which is generally consistent with findings in other visual landscape studies that assessed various scenes using various presenting media (e.g., Anderson & Schroeder, 1983; Bishop & Hulse, 1994; Shafer, 1969; Steinitz, 1990). A significant positive correlation was also found between the visual pleasantness and the average slope of the visible land. However, since only a limited variation of slope was tested in this study, and the average slope was also found highly correlated with most of the significant land cover variables, the relationship between the average slope and the visual pleasantness remains questionable in this study.

Table 3.4. Correlations between ratings and landscape measures in the viewshed.

	AB	**ABF**	**ABM**	**ABB**	**AT**	**ATF**	**ATM**	**ATB**	**SLPavg**
Visual pleasantness	-0.472**	-0.388*	-0.562**	-0.356*	0.355	0.677**	0.575**	-0.013	0.638**
Visual impact	-0.326**	0.116	-0.311**	-0.284**	-0.083	0.196	0.120	-0.218*	0.177
	PB	**PBF**	**PBM**	**PBB**	**PT**	**PTF**	**PTM**	**PTB**	**SLPstdv**
Visual pleasantness	-0.504**	-0.278	-0.391*	-0.402*	0.608**	0.619**	0.392*	0.480**	0.308
Visual impact	-0.220*	0.103	0.038	-0.164	0.154	0.236*	0.300**	0.183	-0.077

*$p < 0.05$; ** $p < 0.01$

Similar but less strong correlations were found between the visual impact of the motorway in the scenes and the measures of trees and buildings in the viewshed. Generally the visual impact was significantly negatively correlated with the amount of buildings in the viewshed, but with the percentage of buildings in the viewshed, only the overall measure in the whole viewshed was significantly correlated at a relatively low level. Correlations with measures of trees were less clear. As for the amount of trees in the viewshed, only those in the background had a significant correlation with the visual impact and the correlation was negative. Stronger and positive correlations were found of the visual impact with percentage of trees in the viewshed in foreground and percentage of trees in the viewshed in midground. It indicates that visual impact of motorway tends to be lower where there are more buildings and/or less trees in the view, which further suggests that sites that are originally less visually attractive are less sensitive to the visual intrusion of motorways and tend to have a lower visual impact caused by them. However, since visual impact is not a direct measure but obtained by comparing baseline and post-construction scenes, the relationship of it with the land cover measures is not straightforward and thus less strong. No significant correlation between visual impact and slope measures was found.

To analyse the specific effect of the scattered trees between the motorway and the viewpoint, *t*-test was used to compare the visual impacts of 28 scenes with scattered trees and their corresponding scenes without scattered trees, as well as the visual pleasantness of the two groups of scenes in their without-motorway baseline scenarios. It shows that the presence of scattered trees between the motorway and the viewpoint reduced the visual impact by 1.9 on average, the reduction was significant and the effect size was medium (t = 2.414, df = 27, p = 0.023, r^2 = 0.178). The baseline sites were also more visually pleasant when there were scattered trees, with a mean visual pleasantness rating 5.6 higher than that without scattered trees (t = -5.158, df = 12, p < 0.000, r^2 = 0.689). The higher visual pleasantness of sites with scattered trees in the baseline scenario is consistent with the finding of the enhancing effect of trees within short distance in this chapter. However, the lower visual impact occurring on sites with scattered trees where the original visual quality is higher is contradict to the higher sensitivity of these sites found in this chapter. This might be explained by the visual absorption effect of the landscape elements (in this case the scattered trees) between the object and viewers (Hadrian et al., 1988).

3.3.4. Prediction of the visual impact using GIS

3.3.4.1. The prediction model

Using motorway characteristics variables and existing landscape character variables in Table 3.1 for 88 with-road images as independent variables, and visual impact as dependent variable, linear regression analysis was applied to develop models for predicting visual impact. Scenes with tree screen were excluded for analysis as the road-visibility based prediction would not be suitable for scenarios where the motorway is screened by trees. The obtained regression models using different combinations of variables are shown in Table 3.5. From Model 1 to Model 4, the prediction power decreases as the number of predictors used decrease. To be used in practice, an ideal model should use only a small number of predictors while have a high prediction power, so Model 3 was chosen to predict visual impact in this chapter for its good balance between number of predictors and prediction power.

Table 3.5. Tested regression models

Model	Number of predictors	R^2	Adj R^2	Std. Error of the Estimate	Note
Model 1	24	0.781	0.676	3.452	All independent variables entered, high multicollinearity.
Model 2	13	0.709	0.647	3.602	Only independent variables with partial R^2 > 0.02 entered, three variables have tolerance value < 0.1.
Model 3	11	0.690	0.636	3.659	Only independent variables with partial R^2 > 0.02 entered, two of the three variables with tolerance value < 0.1 removed.
Model 4	6	0.622	0.588	3.892	Stepwise entry.

Table 3.6 shows the details of Model 3. *Presence of timber barrier, Presence of transparent barrier, Amount of buildings in the viewshed in midground, Amount of trees in the viewshed in midground, Amount of buildings in the viewshed in background, Amount of trees in the viewshed in background, Percentage of buildings in the viewshed in foreground, Percentage of buildings in the viewshed in midground, Percentage of trees in the viewshed in background, Percentage of trees in the viewshed, and Distance to road,* were identified as predictors of visual impact and a relatively good level of prediction (adj R^2 = 0.636) was achieved. Higher prediction levels were achieved by regression models in some similar studies, 0.902 in Bishop et al. (2004); 0.83 in Grêt-Regamey et al. (2007); and 0.69 in Schirpke et al. (2013). However, given that much smaller numbers of scenarios (16 scenarios in Bishop et al. 2004, 12 scenarios in Grêt-Regamey et al. 2007, and 24 scenarios in Schirpke et al. 2013) were assessed in those studies, which means much smaller variations needed to be explained and thus high prediction levels were more achievable, the 0.636 prediction level found in this study is thought to be acceptable. The input data needed for the model in this study is also more readily available and

does not require complex data transformations that are not common in the general planning practice.

Table 3.6. Regression model chosen for visual impact prediction (adj $R^2 = 0.636$).

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Partial R^2
	B	Std. Error	Beta			
(Constant)	19.678	3.486		5.645	.000	
Presence of timber barrier	6.948	1.065	.525	6.524	.000	.403
Presence of transparent barrier	2.777	1.061	.210	2.617	.011	.098
Amount of buildings in the viewshed in midground	-.019	.004	-.535	-4.418	.000	.236
Amount of trees in the viewshed in midground	.016	.003	.688	4.477	.000	.241
Amount of buildings in the viewshed in background	.0005	.002	.036	.202	.841	.001
Amount of trees in the viewshed in background	.003	.002	.222	1.350	.182	.028
Percentage of buildings in the viewshed in foreground	-1.166	.423	-.363	-2.755	.008	.108
Percentage of buildings in the viewshed in midground	.157	.064	.432	2.472	.016	.088
Percentage of trees in the viewshed in background	.116	.056	.279	2.077	.042	.064
Percentage of trees in the viewshed	-.243	.089	-.460	-2.732	.008	.106
Distance to road	-.057	.011	-.706	-5.258	.000	.305

Dependent Variable: Visual impact

The predictors used in the model show a good level of consistency with the results in Section 3.2 and 3.3 regarding the effects of the motorway project and the existing landscape. The presence of both the two types of barriers are included for prediction, with the *presence of timber barrier* having a larger coefficient as it increased the visual impact much higher. *Distance to road* was also selected as a predictor as visual impact has a clear decrease by distance as was found in Section 3.2. *Amount of buildings in the viewshed in midground* and *Percentage of buildings in the viewshed in foreground* have negative coefficients and contributes to the predicted visual impact more rapidly than *Amount of buildings in the viewshed in* *background and Percentage of buildings in the viewshed in midground* which have positive coefficients. So overall, using this model, the presence of buildings in the view is more likely to lead to a lower visual impact as is indicated in Section 3.3. *Amount of trees in the viewshed in midground, Amount of trees in the viewshed in background* and *Percentage of trees in the viewshed in background* all have positive coefficients, while *Percentage of trees in the viewshed* has a negative coefficient with a medium-sized partial R^2, indicating similar contributions of the presence of trees in the view as was found in Section 3.3 that it generally increases visual impact but in less consistent ways than that of buildings.

3.3.4.2. The visual impact maps

To predict visual impact for the whole affected area, the prediction model was applied to a grid of viewpoints covering the affected area in GIS. Figure 3.7 shows the procedure. To define the affected area, a line of target points were assigned on the road central line with 5m intervals to represent the road (540 points in total) (Figure 3.7-a), and viewshed analysis with a 300m limit was performed for each target point. The obtained 540 viewsheds were then merged together to create the viewshed of the road line, i.e., the affected area (Figure 3.7-b). For road without barrier, the absolute height of the road surface (0m above ground) was assigned to each target point for viewshed analysis, while for road with barrier, a 5m offset was applied. A 25m × 25m grid of viewpoints was then created within the affected area excluding areas covered by trees (Figure 3.7-c). The 25 m × 25 m resolution used here was for the purpose of computational efficiency, and was thought to be sufficient for outcomes of large scale mappings demonstrated in this study. Landscape content visible from each viewpoint was still measured in 5m x 5m resolution in the same way as described in Section 2.2 (Figure 3.7-d). The difference was that the horizontal field of view of each viewpoint was set 180° and towards the road, and the vertical field of view 180° covering -90° to 90°, since viewers on actual site can get wider views as they move their eyes, heads and bodies (Smardon et al., 1986). However, the use of wider field of view, particularly the wider horizontal field of view, meant the amounts of trees and buildings in the viewsheds from these viewpoints would probably reach very high values outside the range of the input variables used for developing the prediction model. To avoid over extrapolation, amounts of trees and buildings in viewshed were transformed by multiplying 72°/180°. With the values of required predictors calculated for each viewpoint, the regression model was applied to calculate value of visual impact received at each viewpoint (Figure 3.7-e).

Figure 3.7-f shows the map of visual impact of motorway with timber barrier on the original base site, and Figure 3.7-g shows the map of visual impact of motorway without barrier (the original road) on the original base site. Visual impact induced by the original motorway ranges from -5 to 50 with an average of 19.7 (see Section 3.2. for the definition of the scale). Since the M1 was opened around the 1960s and plantings along it have been well established, the motorway is not highly visible and only affects a relatively small area of 520000m^2 within the 300m limit. The installation of timber noise barrier, which is 5m in height, not only increases the maximum impact to 62 and average impact to 24.6, but also considerably extends the affected area to 758750m^2. Since this chapter did not address the effect of traffic, absolute height of the road surface was used for viewshed analysis in scenarios without noise barrier. However, Highways Agency (1993) suggest that 4m above road surface should be added to take account the height of traffic, which will largely increase the extent of the potential visual impact of motorways without barrier. It can be seen in the two maps that a large area beyond the 300m limit is affected in both the scenarios with and without noise barriers. While visual impact value is not calculated for this area in this study, consideration should still be given to this area in an assessment. Highways Agency (1993) suggests a cut-off line at a distance of 1000m from the road for the UK context.

3.3.4.3. Verification and application

Photos taken at Viewpoint 0215, 0901, and 1181, along with their photoshopped copies of baseline scenes where the road was removed, were used in the supplementary survey to verify the predicted visual impact (Figure 3.7-h). The three viewpoints were chosen as they were accessible on site and offer some variations on the impact map. In both the predicted and perceived results, visual impact at Viewpoints 0215 and 1181 are relatively close to each other while that at Viewpoint 0901 is much lower, showing a certain level of consistency. However, the agreement at Viewpoint 1181 is weak. There is also some inconsistency in the scales of predicted and perceived impacts. The predicted impact seems to use a larger range of levels and thus tends to give impact higher in values than the perceived one (comparing the predicted mean impact to the mean impact in Table 3.3 will also reveal this tendency). Nevertheless, this should not be much a problem in interpreting the predicted results. Special attention might need to be given to the extreme levels, e.g., those below 0 or higher than 40 or 50, as there are potential risks of extrapolation of input predictors, although they only count for a very small part of the affected area. In general, there is confidence to say that the derived visual impact maps can show the extent of the impact with largely reliable "human-perceived" impact levels.

With affected area and impact level shown, the visual impact maps would be helpful for comparing alternative road plans and mitigation measures in visual impact assessment, or for trade-off analysis against other environmental impacts in GIS. The maps can also be used to find visually desirable locations for new developments, scenic stops or recreational paths in areas adjacent to existing motorways. The maps shown here only consider the effects of the characteristics of the motorway project and character of the existing landscape. To take into consideration the effect of viewer sensitivity, simple attempts can be made by overlapping the visual impact map onto a land use map where subjective weightings for viewer sensitivity are assigned for each land use category (Hadrian et al., 1988), or by measuring viewer exposure with a good approximation of affected viewer number and viewer locations (Federal Highway Administration, 1988). Further studies are required to investigate the more detailed effect of viewer sensitivity, which includes susceptibility of the viewers to changes in views and the value attached to particular views (Landscape Institute and Institute of Environmental Management and Assessment, 2013).

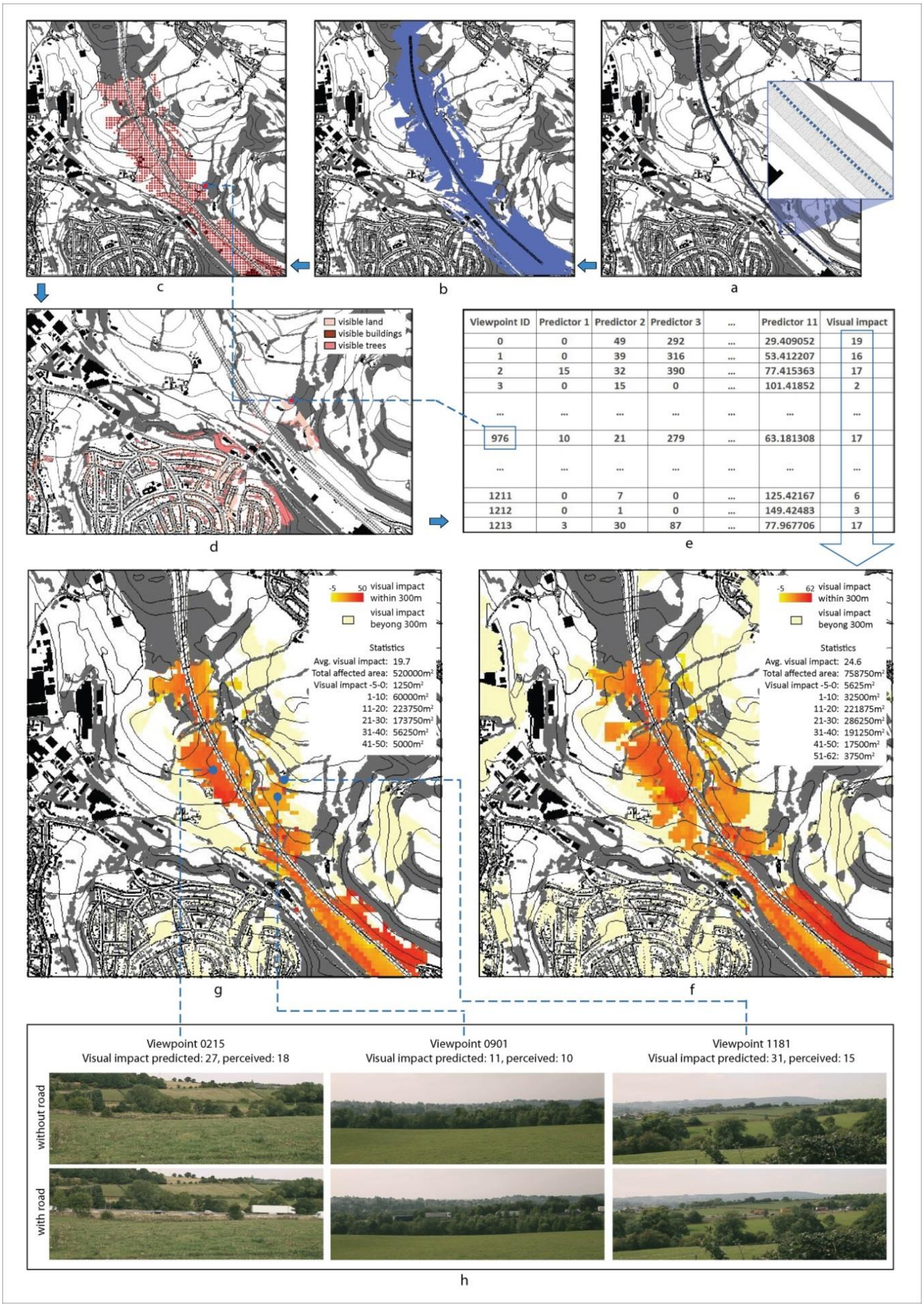

Figure 3.7. Procedure of visual impact mapping: a. target points representing the road; b. affected area with the 300m limit; c. 25m × 25m grid of viewpoints; d. measuring view content for each viewpoint; e. calculating visual impact received at each view

3.4. Conclusions

This chapter aimed to investigate the effects of the characteristics of the motorway project and the character of the existing landscape on the perceived visual impact of motorways, and to develop a GIS-based model to predict the perceived impact. A preference survey using computer-visualised scenes was carried out online to obtain perception-based judgements on the visual effect of motorways. Based on the survey result, a visual impact prediction model using map-based input variables was developed and the predicted impact was mapped in GIS.

It was found from the survey result that the introduction of a motorway significantly detracted from the visual quality of the views. Installation of noise barriers, especially the opaque timber barriers, further increased the resulted visual impact, while tree screening considerably reduced the impact. For the effect of the existing landscape, it indicated that visual impact tended to be lower on sites that were less visually attractive with more buildings in the views, and scattered trees between the motorway and the viewpoint offered a visual absorption effect which slightly reduced the visual impact.

Presence of timber barrier, *Presence of transparent barrier*, *Amount of buildings in the viewshed in midground*, *Amount of trees in the viewshed in midground, Amount of buildings in the viewshed in background*, *Amount of trees in the viewshed in background, Percentage of buildings in the viewshed in foreground, Percentage of buildings in the viewshed in midground*, *Percentage of trees in the viewshed in background, Percentage of trees in the viewshed, and Distance to road* were identified as predictors for the visual impact prediction model which was applied to a grid of viewpoints in GIS to generate maps of visual impact of motorways in different scenarios. Distribution of areas affected by visual impact of different levels was shown on the generated maps. Further work is needed to include the effects of moving traffic and viewer sensitivity.

The proposed GIS-based prediction model can assess the visual impact of motorways for the whole affected areas automatically using judgement obtained from preference surveys, offering results that are more reliable than those from the conventional expert-based approaches. With the proposed model, perceived visual impact of alternative motorway plans with changing future land cover scenarios can be easily calculated and mapped to assist decision making in the planning process.

Chapter 4 Perceived visual impact of motorway traffic: the influential factors and the effect of traffic noise

Following Chapter 3 which is devoted to perceived visual impact of motorways without consideration of the potential impact of moving traffic, this chapter focuses on perceived visual impact of motorway traffic, investigating the effects of traffic condition, distance to road and background landscape on the impact, and the contribution of traffic noise to the impact. Firstly, reviews on visual impact and multisensory perception research are made to set up the context and identify research questions of this chapter (Section 4.1), followed by a detailed description of the research methods used in this chapter (Section 4.2). Results in the designed with- and without-sound conditions are analysed separately and the effect of noise examined by comparing the two conditions (Section 4.3). Findings and their implications for visual impact assessment of motorways are then discussed (Section 4.4). Finally, conclusions of the chapter are made (Section 4.5).

4.1. Background

Efforts to study visual impact of moving traffic were made early in the 1970s. By using composite cine films to show controlled combinations of road projects and background sites for subjective assessment, Huddart (1978) explored the relationship between characters of roads and traffic and the quality of the view affected by them in the Lake District in the UK. It appeared that moving traffic only had considerable impact in the most picturesque views. However, the potential effect of distance to the road was noticed but not studied. Hopkinson & Watson (1974) developed prediction equations to predict visual quality of scenes where roads and traffic presented based on visual judgments made on sites. The equations indicate that higher traffic flow and percentage of heavy good vehicles detracted from the visual quality. The effect of existing landscape was also addressed but it only showed its contribution to the overall visual quality but not to the magnitude of the impact induced by the traffic. A more detailed study was found in Gigg (1980), where hourly traffic flow, percentage of heavy good vehicles and distance to traffic were found contributing to the negative visual impact based on subjective ratings given to filmed and selected video scenes. However, this study focused on the effect of moving traffic alone regardless of the landscape. Despite the limitations and the fact that these studies were based on lower-classed roads with a traffic volume much lower than that of motorways today, these studies have shown that, in addition to the fixed road structure, moving traffic on it can create considerable visual impact in certain landscapes.

However, empirical research on the visual impact of moving traffic is very limited in literature, more attention has been given to the design of road structure approached using design and art concept or theoretical assumption of aesthetic (Blair et al., 1979; Blumentrath & Tveit, 2014; Jones et al., 2006). Also, in recent decades, there is a lack of academic research on visual impact assessment (VIA) specifically for road projects. Principles and procedures of road project VIA have not been updated for a very long time (Churchward et al. 2013).

The VIA of road project has also largely ignored the possible effect of traffic noise on the perceived visual impact. Research has found that sound influenced judgments on visual quality of scenes where there was a significant dynamic element (Hetherington et al., 1993). More specifically, traffic noise decreased ratings in natural landscape assessment especially for scenes of high scenic beauty (Benfield et al., 2010). Similar detracting effect of traffic noise was also found on aesthetic evaluations in residential areas although it turned to be enhancing on downtown streets (Anderson et al., 1983). Given these findings, however, VIA practice today and in the past shows little concern for the effect of traffic noise but assesses road projects as insulated from the project-induced noise (Churchward et al. 2013).

Visual impact ratings with and without sound have been compared in some of the 1970s' research, but the results were very contradictory. Huddart (1978) concluded that traffic noise had no significant effect on the assessment. However, it should be noted that traffic volume on the rural roads in that study were much lower than that of motorways today, and scenes with generally far distances to traffic were used due to the restriction in video simulation using composite cine films. Gigg (1980) found that traffic noise had a dominant effect on the visual assessment. In that study, while traffic volume was still relatively low, viewpoints close to the traffic (about 5m-45m) were selected. The contradictory results of the two studies might be ascribed to the very different stimuli used. A possible hypothesis could be that traffic noise has significant effect on the perceived visual impact of moving traffic but only from short viewing distances. However, it is hard to draw any further conclusions regarding the changes of this effect with different traffic conditions in different background landscapes.

Therefore, the aim of this study is to first have a systematic investigation on the perceived visual impact of motorway traffic in different traffic and landscape conditions, and then explore the effect of traffic noise on the perceived visual impact. Using computer visualisation, four traffic conditions, varied in traffic flow and composition, from three viewing distances, were simulated according to UK motorway traffic statistics; two background landscapes, natural and semi-rural residential landscapes, which are typical along the motorway corridors, were modelled based on a real site, as well as a baseline scenario without motorway and traffic for each landscape. Traffic noise was recorded on site where the visualisation was based on and edited to match the simulated scenarios. Subjective responses to the visual effect of motorway traffic in the simulated scenes in both with- and without-sound conditions were obtained in a laboratory experiment. The effect of traffic noise was explored by comparing results from the two sound conditions

4.2. Method

4.2.1. Visual stimuli

Choosing and modelling of the base site are described in Section 3.2.1.2. Based on the 3D model of the base site, the natural landscape scenario was simulated by removing all the buildings and replacing the original draped satellite image with a satellite image of grassland captured near the base site; the semi-rural residential landscape scenario was simulated by adding more buildings at some suitable positions where there are spacious open areas but not too close to the motorway. Trees were added and/or removed for both scenarios to avoid or mask conflict feature combinations after the alterations. To create the baseline scenarios, the modelled motorway was deleted and the land was draped with an altered satellite image in which the existing motorway was masked by grassland. For each scenario, the land in the foreground was textured with a bitmap of grassland since the draped satellite image blurs when getting close to the camera.

Three viewing distances were assigned for each landscape scenarios. According to the Federal Highway Administration, views of three distances were defined for road project VIA (Federal Highway Administration, 1981): foreground views (0 to 400-800m), middle ground views (400-800m to 4.8-8km), and background views (4.8-8km to infinite). Roads and traffic in foreground views are most potential to induce visual impact (Jones et al. 2006), while those in background views are unlikely to have an effect (Federal Highway Administration, 1981; Highways Agency, 1993). Field observation on the study site suggests that even from a distance of about 300m, the visibility of the road and traffic has declined to a level that they only form a small element in the view. So distances (from road central line to the viewpoint) of 100m, 200m and 300m, which covered the most affected area, were used for the three distance levels. Each viewpoint was set 1.6m above the ground and with a view angle perpendicular to the road. The finished visualisations of the two landscapes as well as their baseline scenarios over the three distances are shown in Figure 4.1.

Four traffic conditions, varied with two levels of both traffic flow and percentage of heave good vehicle (HGV), which were shown to be predictive for the visual impact in Hopkinson & Watson (1974) and Gigg (1980), were designed for moving traffic simulation. The exact values of traffic flows and percentages of HGV were determined based on the annual traffic count of UK motorways. The annual average daily flow (AADF) of M1 is 106612 in 2012; the average and maximum AADFs of UK motorways in 2012 are 71293 and 207482 (Department for Transport, 2014). While the max AADF of UK motorways was too extreme, a value in the middle of it and the M1 AADF was thought to be suitable for the high traffic flow condition, that is 157000. 78500, which is half of the 15700 and lies between the average UK motorway AADF and the M1 AADF was chosen for the low traffic flow condition. As all the simulated traffics were for daytime condition, the AADFs were further transformed to 12-hour (07:00-19:00) weekday flows according to the AADF calculation method (Highway Agency, 2004). So finally, the low traffic flow was

5464/h and the high traffic flow was 10928/h. 10% and 20% were chosen for the low and high percentages of HGVs, given that the values of M1, average and max of UK motorways are 10%, 10% and 30% (Department for Transport, 2014). A summary of the four traffic conditions can be found in Table 4.1.

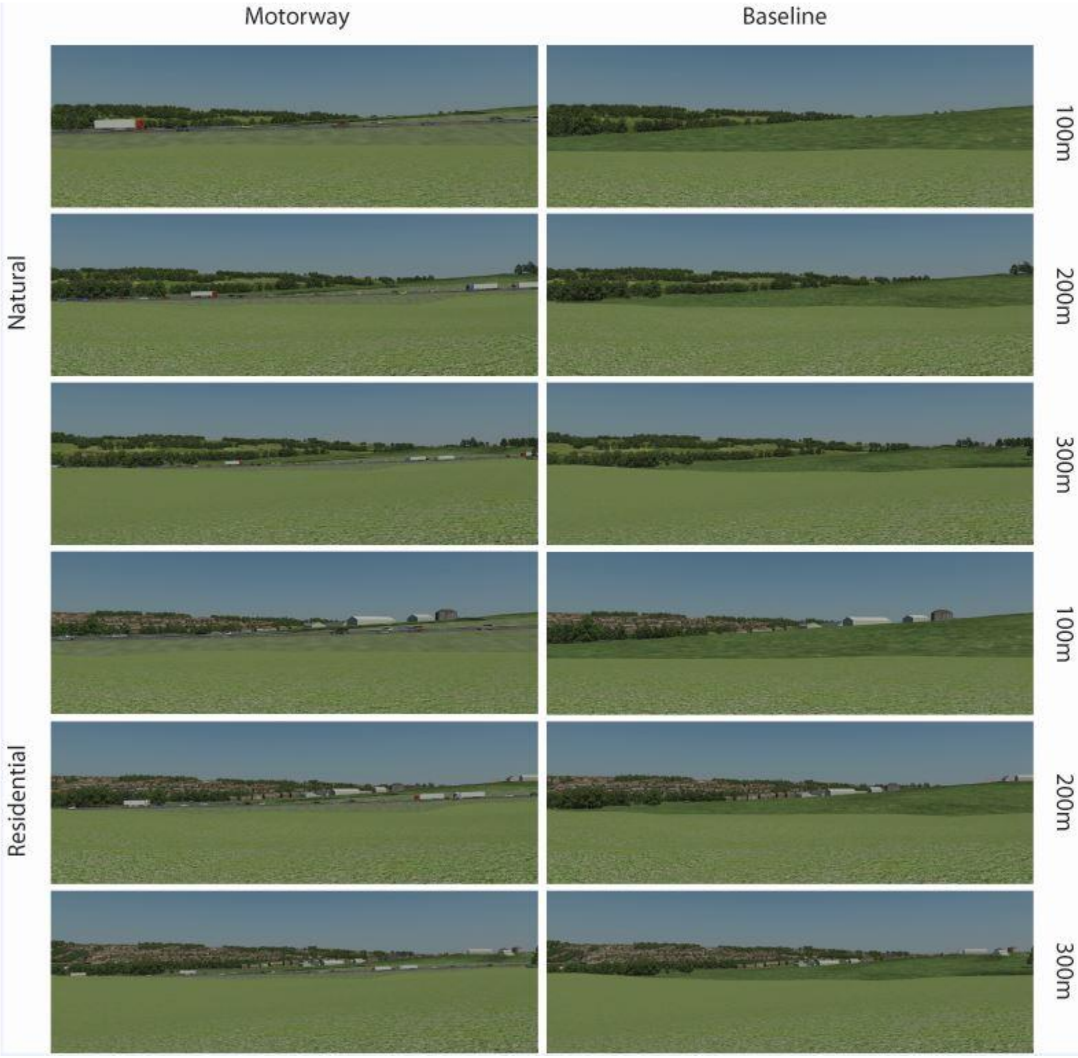

Figure 4.1. Computer visualisation of the two landscapes over the three distances (Enlarged image content is provided in Figures 10.5 and 10.6 in Appendix 6).

Changes in vehicle speed were not considered in this study because introducing various speeds would make the experiment design over complicated, and it was assumed that traffic flow is fairly consistent on motorways and vehicles move at a speed around the speed limits. So 110km/h was assigned to cars and 90km/h assigned to HGVs according to the UK motorway speed limits (GOV.UK, 2014). Vehicles for the four traffic conditions were added into the 3D model in Autodesk

3ds Max Design for animation rendering. Colour and other detailed attributes of individual vehicles were excluded as they were beyond the scope of this study.

The resolution of the rendering output was 1800 × 600 pixels, which was much wider than most of the standard frame sizes but was thought to be suitable and preferred for road project which extends transversely in the view (Landscape Institute, 2011). To avoid distortion of distance perception, the camera and rendering in 3ds Max were set in such a way that the vertical field of the widened view remained the same as the vertical field that a 3 × 2 image captured by a 35mm format camera fitted with a 50mm lens would have from the same distance.

Each scene of moving traffic lasted 25 seconds, which was thought to be long enough for making judgment yet not too long to avoid boredom. The frame rate was set at 30 fps to ensure smooth movement of the vehicles. The scenes of baseline scenarios were still images and each was 8 seconds in length which is a proper exposure time for visual landscape assessment using images (Daniel & Boster, 1976). In total, 24 scenes of moving traffic covering four traffic conditions, three viewing distances, two landscapes, plus 6 scenes of corresponding baseline scenarios, were compiled for the experiment.

Table 4.1. The four traffic conditions and their sound pressure levels (dBA) at the three distances.

	Hourly traffic flow	**No. of vehicle in 25s***	**Percentage of HGV**	**No. of HGV in 25s***	**PCU** in 25s***	**SPL 100m**	**SPL 200m**	**SPL 300m**
Traffic condition 1	5464	38	10%	4	46	69.6	65.0	62.7
Traffic condition 2	5464	38	20%	8	54	70.9	66.3	63.9
Traffic condition 3	10928	76	10%	8	92	72.6	68.0	65.7
Traffic condition 4	10928	76	20%	15	106	73.9	69.3	66.9

*25s is the length of each scene with traffic.

** PCU: passenger car unit, car = 1; HGV = 3.

4.2.2. Audio stimuli

Audio recordings of the M1 traffic noise was made on site using a digital recorder Sound Devices 722 and a pair of DPA 4060 Miniature Omnidirectional Microphones, worn by an operator facing perpendicularly to the road from distances of about 230 m and 350 m, each for 10 minutes long. Recordings from shorter distances were not available due to limited accessibility. Estimated based on the simultaneous video recording, the traffic flow during recording was about 6300/h with a 14% HGV rate at speeds around 80-110km/h, and was generally consistent. The recording was made on 24th October 2013. The weather was dry and the wind speed was very low at about 2.2 m/s. The temperature during the recording hour was about 12 ℃.

A 25-second audio recording sample was extracted from the full 230 m audio recording for reproduction. To calibrate the recording sample, the playback system (see Section 2.4) was first calibrated by playing back a calibrator signal recording (94 dB/1 kHz) and adjusting the setting-ups according to the sound pressure level (SPL) read on a sound level meter (SOLO Black 01dB) placed at the participant head position. The recording sample was then played back using the system with the same setting-ups. The received SPL of the recording sample was 70.4 dB(A).

In order to produce the traffic noise of the simulated moving traffic that would be received at the viewpoints of the three distances, SPLs for the three receiver positions in each of the four traffic conditions were predicted using the noise prediction software CadnaA. In Cadna A, 3D models for the two landscape scenarios were built using the same terrain and land cover data as used for the 3D modelling in 3ds Max. The absorption coefficient of the ground, which was grassland in this study, was set as 0.5. The UK CRTN model was used to calculate the noise levels (Department of Transport, 1988) and the obtained $L_{A10,18h}$ levels were further converted to $L_{Aeq,18h}$ levels (Abbott & Nelson, 2002)). The results showed that change of land cover in the background of the two landscape scenarios did not make the predicted SPLs any different. The SPLs for each traffic conditions are shown in Table 4.1. The original recording sample was then edited using Adobe Audition CS6, either by increasing or by decreasing the level, to produce traffic noise files of the needed SPLs.

For baseline scenarios where there would be no traffic, bird song was thought to be suitable for the soundtrack to be added, as it was the main background sound at the base site and was also contained in the extracted traffic noise recording sample. So audio recording of bird sound was obtained in a quiet park in Sheffield and an 8-

second sample was extracted and attached to each of the baseline images. The played-back SPL of the bird song sample was 47.8 dB(A).

In total, 12 sound files of moving traffic for the four traffic conditions at three viewing distances, and 1 sound file of bird song for all the baseline scenarios, were produced for the experiment.

4.2.3. Combining visual and audio stimuli

Two copies of the 30 visualised scenes were made, one for the without-sound condition; and the other were matched up and combined with the sound files for the with-sound condition; The total 60 video clips were put together in a random order to create a single long video, with the scene number (Scene 1 to Scene 60) appearing for 4 seconds before each scene and an 8-second blank interval for the participants to do the rating after each scene. The overall length of the video was 35 minutes.

To reduce possible order effects, which can occur in a repeated measures design and affect participants' judgement due to practice, boredom and/or fatigue, another video was made with scenes showed in an inverse order, and the two videos were equally but randomly assigned to the participant sessions. Ideally, the order effects should be addressed with a counterbalanced measures design, however, this would be impractical since the experiment in this study contained 60 conditions, which were too many even for a Latin Squares. The two videos with inversed random orders used in this study was a compromise. As a consequence, the likely limitations, apart from confounds induced by participants' gained familiarity, boredom and fatigue in the later stage of each experiment session, might include lower or higher ratings to certain scenes depending on the relative content of previous scenes, and the size of this effect might be dependent on the degree of contrast or similarity to previous scenes.

Correlation between ratings given to the two videos were tested after the experiment and a significantly high correlation was found (Pearson's $r = 0.953$, $p < 0.001$), which suggests that the inter-group agreement was high and bias in judgment caused by order effect was low. However, there was still an uneliminated possibility that the two inversed orders used in this study happened to have similar order effects and thus the effects would not be revealed by comparing the two orders.

4.2.4. The experiment and procedure

To decide the sample size needed for the $4 \times 3 \times 2$ within-subject design in this study, a power analysis was conducted using G*Power 3.1 (Faul et al. 2007). With an effect size f = 0.25, an $\alpha = 0.05$, and a power = 0.95. The result suggested that a sample of 12 participants was needed. For this study, thirty participants (14 male and 16 female), aged 18-47 (Avg. = 24.2, S.D. = 6.2), with normal hearing and normal or adjusted to normal vision, were recruited via email invitation in the university and other online social media. Each participant received five pounds cash as compensation for their time.

The experiment was carried out in a 3.5m × 3.5m × 2.3m anechoic chamber equipped with a playback system which consisted of a Dell Studio 1535 laptop, a RME BabyFace USB Audio Interface, a pair of Genelec 8030B loudspeakers which are self-powered, and a Genelec 7060B subwoofer. Loudspeakers and subwoofer were preferred as it reproduces sound contribution of traffic noise at low frequencies better than headphones (Maffei et al. 2013b). Crosstalk effect, which occurs when audio signal delivered to the ipsilateral ear is heard by the contralateral ear when playing binaural audio with loudspeakers, was not addressed in this study, since the level of received noise, rather than the accuracy of 3D reproduction of the recorded soundfield, was the main parameter concerned in investigating the effect of traffic noise on perceived visual impact in this study. The video was projected via a Hitachi ED-X33 LCD projector onto a 203cm × 152cm Duronic floor stand projector screen about 2.2 meters away from where the participants were seated (Figure 4.2).

During the experiment, participants were asked to rate the visual pleasantness of each scene using visual analogue scale, that is, by marking a "×" on a bar which was 100mm long on the printed questionnaire and had only "low pleasantness" and "high pleasantness" labelled at the two ends. Before start, participants were reminded that visual pleasantness in this study could be understood as visual landscape quality or scenic quality of the scenes, and there were no clear criteria for the rating, and they could draw upon whatever value judgements they deemed necessary. However, the purpose of this study was not mentioned. At the end of each participant session, a short interview was carried out asking about participants' rating criteria. It was also attempted to ask the participants to rank the importance of the factors he/she mentioned but some found it very difficult. Participants were also asked to give comments on the experiment, e.g. the quality of the visualisation and sound playback, the length of the experiment, and the rating instrument used.

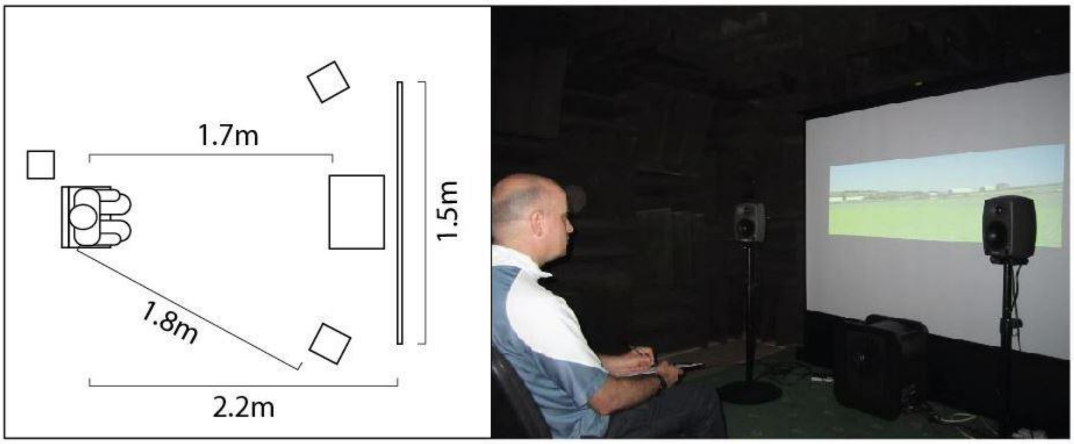

Figure 4.2. The layout of the anechoic chamber.

4.2.5. Data analysis

Visual pleasantness score was measured on questionnaires as the length from the low-pleasantness end of the visual analogue scale bar to the marked "×" on the bar in millimetre. For example, if the length is 60mm, then the visual pleasantness score is 60. So possible visual pleasantness scores would range from 0 to 100. The perceived visual impact of traffic in each scene with traffic was calculated by subtracting visual pleasantness score of the scene from visual pleasantness score of the corresponding baseline scene. Possible visual impact values would thus range from -100 to 100, where a negative value means the traffic enhances the visual pleasantness whereas a positive value means the traffic decreases the visual pleasantness, the larger the absolute value the higher the degree of impact. To study the effect of traffic noise on the perceived visual impact, the index "noise effect" was proposed and was calculated by subtracting visual impacts in scenes without sound from visual impacts in corresponding scene with sound. Noise effect with a positive value means it increases the perceived visual impact, and the larger the value the larger the increase.

The significances of visual impact in each scenario was tested using t-test. A 4 × 3 × 2 × 2 within subjects ANOVA was run to analyse the effects of traffic condition, viewing distance, landscape type and sound condition on the visual impact. All the statistical analysis was carried out using IBM SPSS Statistics 21.

4.3. Results

4.3.1 An overall analysis of the results

The t-test was applied to test if there were significant changes in visual pleasantness when motorway traffic was introduced as compared with the baseline scenes. In total, 48 t-tests were run and the results show that changes in visual pleasantness were highly significant in all the traffic-landscape-distance-sound scenarios (t = 4.339 to 19.559, $df = 29$, $p < .001$), which means the introduction of traffic induced significant visual impact in all the scenarios. Table 4.2 shows visual pleasantness of the baseline scene and visual impact of traffic averaged across the 30 participants for each scenario. All the visual impact values are positive, ranging from 14.9 to 46.6 with an average value of 30.9 in the without-sound condition, and from 29.1 to 58.2 with an average value of 42.5 in the with-sound condition. Given that the average visual pleasantness of the baseline scenes is 73.6 and 77.4 in the without- and with-sound condition respectively, the visual impact values indicate substantial deteriorations in perceived visual quality of the views caused by motorway traffic in both sound conditions.

A 4 × 3 × 2 × 2 within subject ANOVA was carried out for an overall analysis of the effects of traffic condition, viewing distance, landscape type and sound condition on the perceived visual impact of motorway traffic. The result shows that all the four factors had significant effect (Greenhouse-Geisser correction was applied where assumption of sphericity was violated), traffic condition: $F = 50.193$, $df = 2.175, 63.082$, $p < .001$, $\eta 2p = .634$; viewing distance: $F = 32.919$, $df = 1.426, 41.359$, $p < .001$, $\eta 2p = .532$; landscape type: $F = 24.763$, $df = 1, 29$, $p < .001$, $\eta 2p = .461$; sound condition: $F = 44.496$, $df = 1, 29$, $p < .001$, $\eta 2p = .605$, but none of their interactions was significant. The values of partial eta squared indicate that the effect of sound condition was even stronger than the effects of viewing distance and landscape type. Marginal mean comparisons show that differences between traffic condition 1 and 2, and between traffic condition 2 and 3 were highly significant ($p = .001$ and $p < .001$ respectively). The difference between traffic condition 3 and 4 was also significant but at a lower level ($p = .019$). As for the viewing distance, difference was significant between 100 m and 200 m ($p < .001$) but not between 200 m and 300 m.

The results indicate that all the studied factors played an important role in perceived visual impact of motorways. More detailed analysis is presented in Section 4.3.2 and Section 4.3.3.

Table 4.2. Visual pleasantness of the baseline scene and visual impact of traffic in each scenario.

			Natural				Residential				Mean			
			100m	**200m**	**300m**	**mean**	**100m**	**200m**	**300m**	**mean**	**100m**	**200m**	**300m**	**mean**
Without sound	**Baseline visual pleasantness**		80.7	83.8	84.3	82.9	64.4	63.0	65.3	64.2	72.6	73.4	74.8	73.6
	Visual impact	**Traffic condition 1**	34.0	27.8	24.6	28.8	31.4	16.9	14.9	21.1	32.7	22.4	19.8	24.9
		Traffic condition 2	41.7	30.4	29.3	33.8	30.1	22.7	20.0	24.3	35.9	26.6	24.7	29.0
		Traffic condition 3	46.6	38.9	31.4	39	33.5	26.7	22.6	27.6	40.1	32.8	27.0	33.3
		Traffic condition 4	46.3	40.1	35.3	40.6	41.0	30.2	24.6	31.9	43.7	35.2	30.0	36.3
		mean	42.2	34.3	30.2	35.5	34.0	24.2	20.5	26.2	38.1	29.2	25.3	30.9
With sound	**Baseline visual pleasantness**		81.0	84.7	90.0	85.2	68.7	70.4	70.0	69.7	74.9	77.5	79.9	77.4
	Visual impact	**Traffic condition 1**	44.8	36.4	40.0	40.4	38.2	32.1	29.1	33.1	41.5	34.3	34.5	36.8
		Traffic condition 2	50.7	43.4	40.8	45.0	41.2	34.0	29.7	35.0	45.9	38.7	35.3	40.0
		Traffic condition 3	56.8	45.9	47.3	50.0	47.7	38.6	36.6	41.0	52.3	42.3	41.9	45.5
		Traffic condition 4	58.2	50.0	49.5	52.6	52.3	39.4	38.0	43.2	55.3	44.7	43.8	47.9
		mean	52.6	43.9	44.4	47.0	44.9	36.0	33.4	38.1	48.7	40.0	38.9	42.5

4.3.2. Effects of traffic condition, viewing distance and landscape type

Corresponding to Table 4.2, Figure 4.3 compares visual impact for traffic condition, viewing distance and landscape type in the two sound conditions. While the results in the with-sound condition might be of more interest, since in real situations visual impact of motorways almost always occurs in the presence of traffic noise, the results in the without-sound condition can provide a useful comparison for understanding how effects of the examined factors might change when presence of noise is considered, which would help better interpretation and utilisation of findings from many of the visual impact studies that have been conducted without consideration of present noise.

In the without-sound condition, Figure 4.3-a shows that visual impact increased from traffic condition 1 to 4 and decreased by distance. The rates of decrease by distance kept largely the same across the four traffic conditions, and were faster between 100 m and 200 m than between 200 m and 300 m. Figure 4.3-b shows that visual impact in natural landscape was higher than that in residential landscape, and again the rates of decrease by distance were largely the same in the two landscapes. A similar trend is shown in figure 4.3-c where visual impact in natural landscape remained consistently higher than that in residential landscape across the four traffic conditions. The similar patterns of lines within each sub-figure indicate that the effect of each of the three factors on visual impact was largely independent from the others two.

In the with-sound condition, overall, visual impact increased from traffic condition 1 to 4, decreased by distance, and was higher in natural landscape than in residential landscape. However, although the ANOVA shows no significant interaction between any of the three factors in association with sound condition, patterns of lines within each sub-figure with sound are not as similar to each other as in the case without sound, and decrease by distance became smaller and less clear between 200 m and 300 m. Figure 4.3-d shows that visual impact decreased by distance between 100 m and 200 m at similar rates as those in the without-sound condition for the four traffic conditions, but remained largely unchanged from 200 m to 300 m except for traffic condition 2 where visual impact kept dropping. A noticeable difference in decrease by distance is also shown between the two landscape types in Figure 4.3-e. The two lines drop parallel from 100 m to 200 m, however, while visual impact in the residential landscape kept decreasing at a less rapid rate that in the natural landscape increased and became slightly higher at 300 m than at 200 m. The minor decrease and no decrease in the with-sound condition can explain the overall insignificant difference between distances of 200 m and 300 m in the ANOVA result. No clear possible interaction is shown between traffic condition and landscape type in Figure 4.3-f.

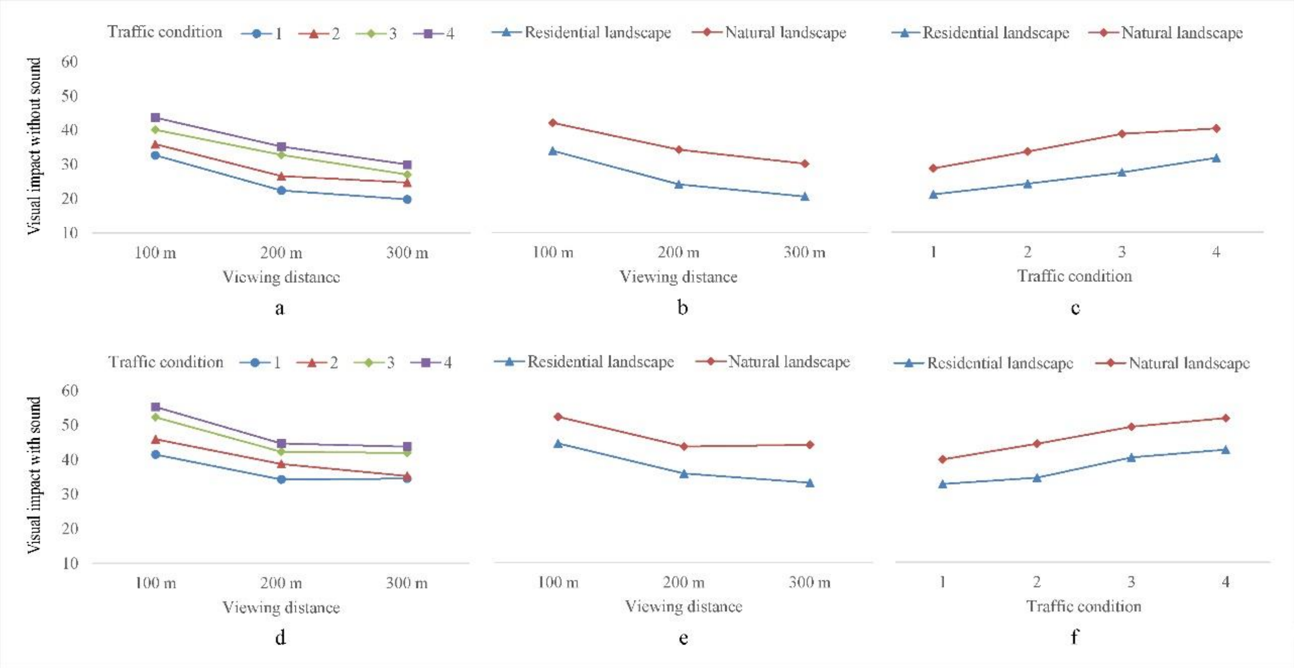

Figure 4.3. Comparisons of visual impact for traffic condition, viewing distance and landscape type in the two sound conditions.

4.3.3. Effect of traffic noise

The ANOVA in Section 4.3.1 shows a significant difference between the two sound conditions. Figure 4.4 illustrates the difference. Generally, traffic noise increased the perceived visual impact in all the traffic-landscape-distance scenarios and the increases were relatively constant across the scenarios with an average of 11.6. The relatively constant increases reflect the insignificant interactions between sound condition and the other factors reported by ANOVA.

Specifically, Figure 4.4-a compares the effect of traffic noise over the four traffic conditions. Increases in visual impact by traffic noise remained largely the same in the four traffic conditions, despite the different noise levels associated with them. Similar noise effect was found in Figure 4.4-b where increases in visual impact by traffic noise were nearly identical in the two landscapes. Figure 4.4-c, however, shows potential changes in noise effect with viewing distance, where increases in visual impact by traffic noise was slightly higher at the distance of 300 m. This has also been mentioned in the analysis of the effect of viewing distance. Overall, it can be concluded that the effect of traffic noise on visual impact was not affected very much by traffic condition, landscape type, or viewing distance, but there is a potential interaction with viewing distance.

To test the possible dependence of noise effect on SPL at receiver position, Pearson's correlation analysis was carried out for each of the two landscapes respectively. However, the results were not significant either.

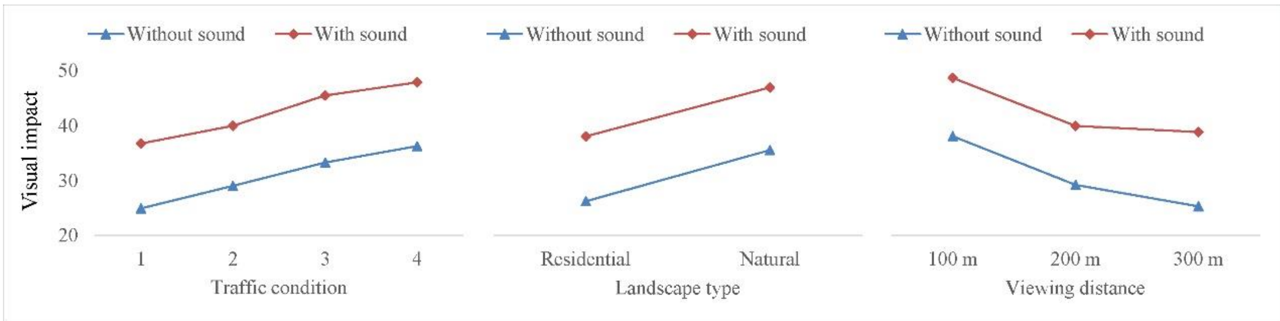

Figure 4.4. Differences in visual impact between the two sound conditions.

4.4. Discussion

4.4.1. Implications for visual impact assessment

The results of this study show that motorway traffic induced significant visual impact, and the higher the traffic volume, the higher the impact. In Huddart (1978), passenger car unit (PCU), as the index of traffic volume, was used as an independent variable to predict the visual impact of roads and traffic, whereas in Hopkinson & Watson (1974) and Gigg (1980), traffic flow and percentage of HGV were used to reflect not only changes in traffic volume, but also changes in traffic composition, which is analogous to the prediction of traffic noise. In this study, comparisons of the marginal mean of visual impact of each traffic condition indicate that in both sound conditions, traffic composition made significant difference on visual impact when traffic volume was low, but no significant difference when traffic flow was high. Figure 4.5 shows the increase of visual impact by traffic volume which is measured in PCU (car = 1, HGV = 3). In both sound conditions, visual impact increased rapidly when PCU increased by only 8 from 46 to 54 but with the number of HGVs doubled. The increase of visual impact was much slower from PCU 54 to 92 where the number of HGVs remained the same. From PCU 92 to 106, visual impact increased at a rate more similar to that from PCU 54 to 92 despite the doubled number of HGVs. It suggested that simply calculating or measuring PCU for visual impact assessment may be sufficient for projects where traffic volume is high enough, but may not be a proper method when traffic volume is low since the extra effect of HGVs would be eliminated.

It had been expected that the pattern of the increase of visual impact by traffic condition would be different in the two landscapes, given different sensitivities to visual intrusion of different landscapes. In Huddart (1978), equations using PCU as the predictor were developed for different landscapes and larger slopes of the linear regression equations were found for the more visually pleasant sites. However, the result in this study shows that whether with sound or not, the pattern of increase by traffic condition did not change significantly with landscapes, although with the same traffic, visual impact did tend to be higher in the natural landscape. The finding of this study indicates that it is possible to simplify the VIA of motorway projects as the effect of landscape seems to be rather independent from the effect of traffic condition. However, studies covering a wider range of landscape types are still needed.

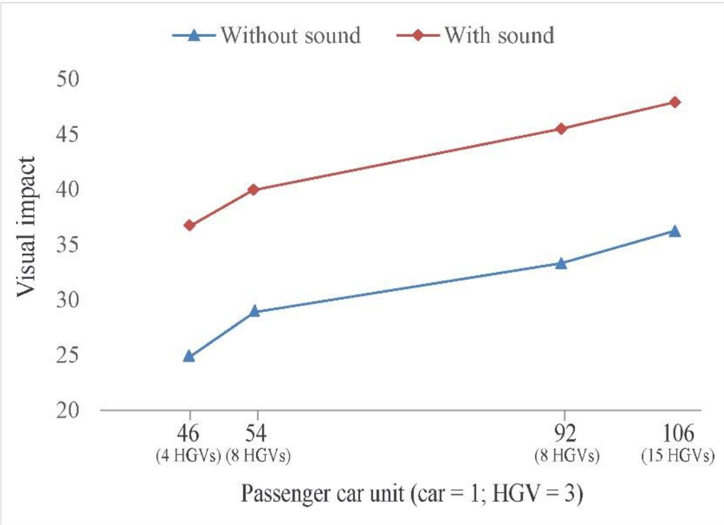

Figure 4.5. Increase of visual impact by traffic volume measured in PCU (car = 1, HGV = 3).

Independent effect on visual impact was also found of viewing distance. However, the effects were different in the two sound conditions. Marginal mean comparisons show that the decrease of visual impacts from 200m to 300m was significant without sound but insignificant with sound. In the with-sound condition, the decrease from 200 to 300m was very small. Specifically, visual impact at 300m was even slightly higher than at 200m in the natural landscape. This might be explained by that traffic noise and traffic visibility decline at different rates by distance, in this case the decline of traffic noise was less rapid and thus the intensification effect of it became more obvious at further distances. Also, the negative effect of traffic noise would be stronger in the more vegetated landscape (Anderson et al., 1984; Mulligan et al., 1987). However, on the other hand, no significant effect of distance or landscape was reported on noise effect in this study, nor was significant interaction effect between distance and landscape on visual impact in the with-sound condition. Further studies are needed to better understand the complex decrease of visual impact by distance when noise is present. The possible effect of noise would require a different approach for studying the visual impact of motorway project. Conventional visual impact research only focuses on the effect of visual stimuli when studying visual perception related to visibility or distance issues (Shang & Bishop, 2000; Bishop, 2002; Bruce Hull IV & Bishop, 1988). In the case of motorways where noise impact is severe, the effect of noise should be addressed and visual threshold for visual impact at a larger distance might need to be considered.

While traffic noise was found to have an overriding effect on visual assessment in Gigg (1980) but did not significantly affect the ratings in Huddart (1978), the result in this study suggests something in between. It shows that traffic noise had a considerable effect which however was constant and did not show clear dependence with noise level, traffic condition, landscape type, or viewing distance, although there was a possible increase in the effect by distance. So traffic noise significantly increased the perceived visual impact, but the variation in visual impact with sound was still largely determined by visual stimuli. One possible reason for this constant effect might be the high but small-ranged level of noise applied in this study (62.7 - 73.9 dBA). In this study, the contrast between with and without sound was sharp, but noise levels in the with-sound situation might not have varied widely enough to significantly diversify participants' response. At a lack of more improved knowledge from further studies, findings in this study suggests that the effect of traffic noise can be counted on in VIA of motorway projects by adding on a constant level of additional impact to the visual impact which is evaluated based on visual factors. This may not offer more useful information than when noise effect is ignored for comparing alternative plans within the issue of visual impact, but it will give more accurate weight on visual impact when balancing it with other environmental impacts of motorways, and also enable more cooperative and efficient measures for mitigations of visual and noise impacts.

4.4.2. Possible effects of vehicle speed and colour on perceived visual impact

Some participants mentioned the effect of vehicle speed on their judgment and gave lower visual pleasantness rating when the speed was “higher”. While speed was fixed in this study, the movement of vehicle did look faster from shorter distances, which is also the case in Gigg (1980) using filmed scenes of real traffic. It implies that higher visual impact of traffic being expected from a shorter distance may not only be because the traffic forms a larger element in the view but also because it appears to be faster than traffic passing the viewers at the same speed from longer distances. It also reveals the potential effect of speed which was not addressed in this study and would require further investigation.

Colour has also shown an effect in this study. Some participants mentioned that the colour contrast between the white lorry cargos and the greenery background detracted from the visual pleasantness. This inclination is consistent with findings or emphasis in research that addressed the effect of colour in landscape perception (Bishop, 1997; Garcia et al, 2003; Groß, 1991). While these findings can be useful in minimising visual impact of new constructions in sensitive areas, they are hardly applicable to moving traffic of which the colour cannot be defined in the proposal of development. However, awareness should be raised that traffic consisting of brighter-coloured vehicle is likely to have higher visual impact.

4.5. Conclusions

This study aimed to have a systematic investigation on the perceived visual impact of motorway traffic in different but controlled traffic and landscape conditions, and examine the effect of traffic noise on the perceived visual impact by comparing with- to without-sound conditions. Using computer visualisation, four traffic conditions, two types of landscape, three viewing distances were simulated, and a sample of motorway traffic noise recoding was edited and added for the with-sound condition. Subjective responses to the simulated scenes of motorway traffic both with and without sound were gathered in a laboratory experiment.

The results of this study show that motorway traffic induced significant visual impact, and the higher the traffic volume, the higher the impact. Specifically, when traffic flow was low, the composition of the traffic could change the impact dramatically; while when traffic flow was high, the composition made no significant changes, implicating that different concerns on traffic composition might be needed for VIA of motorway projects with different traffic volumes.

Consistently higher visual impact was found in the natural landscape than in the residential landscape, indicating a significant effect of landscape types. However, this effect seemed to be largely independent from the effect of traffic condition, which suggested that it might be possible to simplify VIA of motorway projects.

The effect of viewing distance was also significant and largely independent, and there was a rapid-to-gentle decrease of visual impact by distance. However, the decrease was less rapid and the decrease pattern less clear at further distance in the with-sound condition. Further studies are needed to address this issue and different approaches in deciding visual threshold might be required for VIA of motorway projects where loud traffic noise is present.

Comparing visual impact with sound to without sound, this study shows significant effect of traffic noise on the perceived visual impact of traffic. Generally, the effect of noise was consistent and increased visual impact by a relatively constant level despite the changing noise levels, traffic conditions, landscape types, and viewing distances. There was a possible effect of distance on noise effect but would require further studies to draw more confident conclusions. At this stage, findings in this study suggest to add on a constant level of additional impact to visual impact evaluated based on visual factors to count on the effect of traffic noise in the VIA of motorway projects.

Chapter 5 Integrated impact of visual intrusion and noise of motorways: the influential factors and the predictability

Having developed a better understanding of visual impact of motorways in Chapter 3 and 4, together with the already well-developed knowledge on noise impact of road traffic, this chapter investigated the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of visual intrusion and noise of motorways, and explored how indicative noise exposure is to the perceived impact. Firstly, a brief overview of the issues of visual and noise impacts from motorways and a review on multisensory environmental perception research are made to set up the context and identify research questions of this chapter (Section 5.1), followed by details of the experimental design and methods used in this chapter (Section 5.2). Analysis of the investigation results and exploration of the predictability of integrated impact by noise exposure are then presented (Section 5.3). Finally, conclusions of this chapter and the findings are made (Section 5.4).

5.1. Background

Motorways are often seen as intrusive to both landscape and soundscape. Potential visual impact of motorways can be induced as deterioration in visual landscape quality caused by the presence of the massive roadway structure, as well as by the large volume of traffic moving on the roadway (Federal Highway Administration, 1988; Highways Agency, 2000). Chapter 3 and 4 have shown that existing landscape, distance to road, traffic flow and composition can all have strong influence on the level of the perceived impact. Permanent noise impact of motorways is caused by moving vehicles and the interaction of their tyres with the road surface, and can have severe harmful effects on human health and quality of life (Highways Agency, 2011). While measured noise exposure can be helpful indices of the noise climate, the level of the perceived impact is however also influenced by many non-acoustical factors (Ruotolo et al., 2013).

Recently, research in environmental psychology has stressed the multisensory nature of human perception (Cassidy, 1997). Multisensory approach, especially addressing the aural-visual interaction, has been applied in many studies aiming to gain deeper understanding on environmental perception and develop human-centred methodologies for assessments of soundscape and landscape. While some studies investigated either the effect of visual stimuli on perception of sound environment (e.g., Anderson et al., 1984; Mulligan et al., 1987; Viollon et al., 2002), or the effect of audio stimuli on perception of visual environment (e.g., Anderson et al. 1983; Benfield et al., 2010; Hetherington et al., 1993), many have focused on their interactive effects on perception of the overall environment (e.g., Carles et al, 1999; Hong & Jeon, 2013; Pheasant et al., 2008). Nilsson et al. (2012) argued that assessing the overall environmental quality might be easier and more natural than assessing environmental quality of each sensorial modality separately. This might be particularly applicable for the assessments of visual and noise impacts of motorways, which means assessing the integrated impact of visual intrusion and noise on the overall environmental quality, as visual and noise impacts of motorways are very often coexistent and share some common influential factors. It would also be very helpful if strong relationships exist between the integrated impact and some well-developed visual and/or noise impact indicators.

While a large amount of research has been conducted to investigate how possible influential factors affect the perceived visual or noise impacts of road projects, little effect has be made for the integrated impact of visual intrusion and noise. The aim of this chapter is therefore to investigate the possible effects of some factors, which have been shown influential on both perceived visual and noise impacts, on the perceived integrated impact of visual intrusion and noise of motorways. Specifically, this chapter has two objectives: (1) investigate the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of noise and visual intrusion of motorways; (2) explore how indicative noise exposure is to the perceived impact.

5.2. Method

5.2.1. Experimental design

Six traffic conditions, consisting of three levels of noise emission × two levels of heavy good vehicle (HGV) percentage in traffic composition, were designed for this study. Two of the three emission levels were the same as the highest and lowest emission levels used in the first laboratory experiment (Chapter 4), which were 87.6 dB(A) L_{10} and 83.3 dB(A) L_{10}, as they were representative to traffic conditions of motorways like the M1. Since results of the previous experiment (Chapter 4) implied that the variation of thus derived noise levels at receiver positions might not have been large enough to make adequate difference, a third emission level, 79.0 dB(A) L_{10}, was designed for this study with the same interval between the three levels. The two HGV percentage levels were 10% and 20%, which were the same as those used in the previous experiment (Chapter 4). Each of the three emission levels was kept constant for the two HGV percentage scenarios by changing the overall traffic flow, so the visual effect of traffic composition on the perceived impact can be tested.

Three distances to road, 100 m, 200 m and 300 m, were chosen for this study. The upper limit of 300 m was thought to be suitable for both visual and noise impacts. For visual impact, roads and traffic in foreground views (defined as within 0 to 400-800 m) are most potential to induce visual impact (Federal Highway Administration, 1988), and field observation on the base site suggests that even from a distance of about 300 m, the visibility of the road and traffic has declined to a level that they only form a small element in the view. For the noise impact, the UK Noise Insulation Regulation has a within-300-m criterion for residential buildings to be eligible for grants for noise insulation (Department of the Environment, 1988), so 300 m would be a reasonable cut-off line for study, although like visual impact, the potential noise impact can reach further beyond. Distances shorter than 100 m were not covered in this study, since receiver positions too close to the edge of carriageways are less common in cases of motorways.

Two types of background landscape, natural and residential landscapes, which are typical along motorway corridors in the UK, were designed for this study. A summary of the experimental scenarios are shown in Figure 5.1.

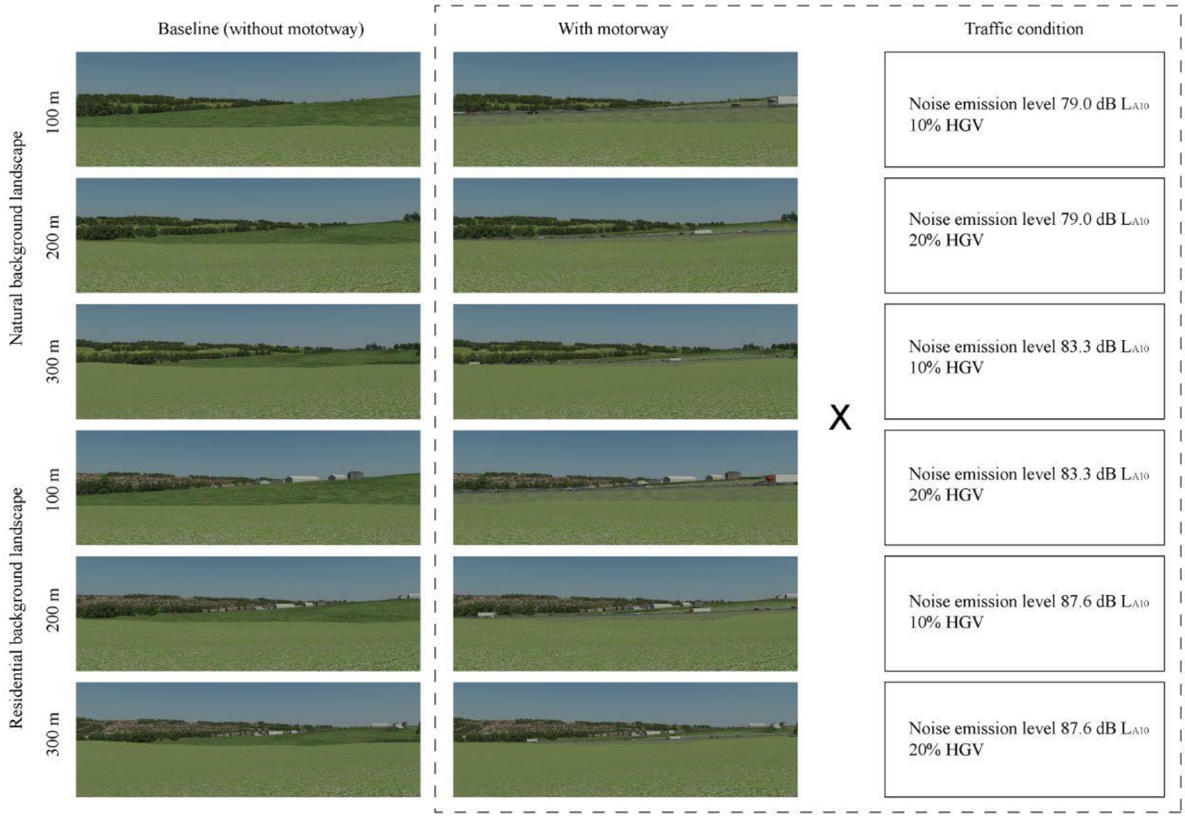

Figure 5.1. Summary of the experimental scenarios (Enlarged image content is provided in Figures 10.5 and 10.6 in Appendix 6).

5.2.2. Preparation of visual stimuli

Choosing and modelling of the base site are described in Section 3.2.1.2. Based on the 3D model of the base site, the natural and residential landscape scenario was created by changing the amounts of trees and buildings. Animations of moving vehicles were made for the six traffic conditions. The exact numbers of cars and HGVs for each traffic condition in 20 seconds, which was the length of each video scene that would be rendered, were calculated in CadnaA using the UK CRTN model (Department of Transport, 1988), and are shown in Table 5.1. To create the baseline scenarios, the modelled motorway was deleted and the land was draped with images of grassland. Three viewpoints, 100 m, 200 m and 300 m away respectively from the near edge of the motorway, were assigned in the models for the three distance scenarios. Cameras to capture views from the three viewpoints were set 1.6 m above the ground facing perpendicular to the motorway, with a horizontal field of view of 72°, which is wider than that of a standard lens, to present the breadth of visual information required for road projects which extend transversely in the view (Landscape Institute, 2011). To avoid distortion of distance perception, the vertical field of view was kept at 27°, which is close to that of a standard lens. The resulted aspect of the captured views was 3:1.

The captured views were rendered into video scenes with the animations of moving traffic. The resolution of the rendering was 1800 × 600 pixels at a frame rate of 30 fps. Each video scene was 20 seconds long. The scenes of baseline scenarios, where there was no moving traffic, were still images and each lasted 10 seconds. In total, 36 video scenes and 6 image scenes were produced, and were merged in a random order to create a single long video, with the scene number (Scene 1 to Scene 42) appearing for 3 seconds before each scene and a 3-second blank interval after each scene. Another long video was made with scenes in reversed order. The two videos would be equally but randomly assigned to the participant sessions to eliminate the possible effect of scene order.

5.2.3. Preparation of audio stimuli

Acquisition of audio recordings of motorway traffic is described in Section 4.2.2. A 20-second sample was extracted from each of the full 230 m and 350 m audio recordings for audio reproduction. The recording sample was calibrated with the signal of a 01dB Cal01 Calibrator (94 dB/1 kHz) using a Neumann KU 100 dummy head and the playback system (see Section 2.4) that would be used for the experiment. The obtained sound equivalent level of the 20-second sample from 230 m was 70.4 dB(A), and that from 350 m was 63.1 dB(A).

The required noise level at the receiver position in each scenario was calculated in CadnaA. In CadnaA, 3D models of the landscapes were built using the same input data as used for the 3D modelling in 3ds Max. The absorption coefficient of the ground, which was grassland in this study, was set as 0.5. The UK CRTN model was used to calculate the noise levels with input of the designed traffic conditions. The obtained $L_{A10,18h}$ levels were further converted to $L_{Aeq,18h}$ levels (Abbott & Nelson, 2002). Calculated levels for each scenario are shown in Table 5.1.

To produce audio files for received traffic noise in each scenario, the recording samples from 230 m and 350 m were edited in Adobe Audition CS6, either by increasing or by decreasing the overall levels. Audio files for scenarios marked with

"*" in Table 5.1 were produced using the recording sample from 230 m, while the others from 350 m. The spectral shapes of these two recording samples did not differ substantially from each other (Figure 5.2), so possible effect of spectral changes by distances was not considered in this study. Also, within the original 10 minutes recording from each of the two distances, the spectral shape did not change dramatically over time (Figure 5.3), despite some changes in traffic composition during the time, which suggests that changes in spectral character caused by changes in traffic composition were not remarkable in these traffic conditions from these distances. So the same audio files were used for the two HGV percentage scenarios to better serve the purpose of testing the visual effect of traffic composition while controlling the audio stimuli.

Table 5.1. Detailed information of the traffic conditions and noise levels (dB $L_{Aeq,\ 18h}$) at receiver positions

Noise emission level (dB L_{A10})	HGV %	Traffic condition: Average speed	Traffic condition: hourly flow	No. of cars in 20 s	No. of HGVs in 20 s	Noise level at receiver position: 100m	200m	300m
79.0	10	100km/h	2046	10	1	65.4	60.8	58.4
79.0	20	100km/h	1533	7	2	65.4	60.8	58.4
83.3	10	100km/h	5464	27	3	69.6*	65.1	62.7
83.3	20	100km/h	4131	18	5	69.6*	65.1	62.7
87.6	10	100km/h	14500	79	8	73.9*	69.3*	66.9*
87.6	20	100km/h	10928	49	12	73.9*	69.3*	66.9*

* produced using the recording sample from 230 m, otherwise from 350 m

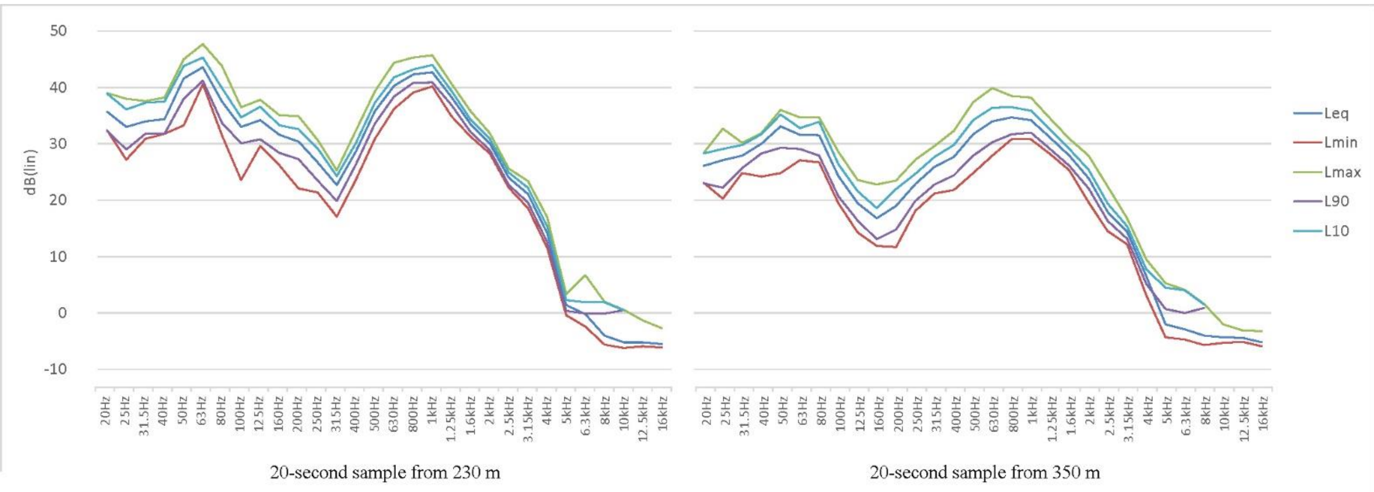

Figure 5.2. Spectral shapes of the 20-second recording samples from 230 m and 350 m.

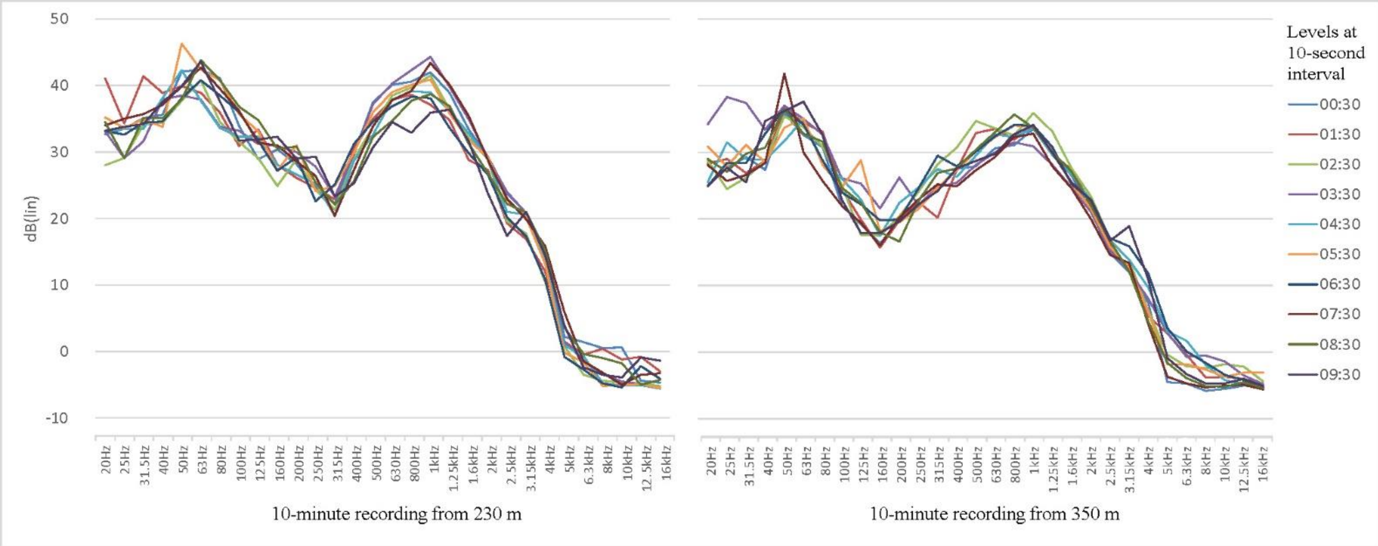

Figure 5.3. Spectral shapes of the 10-minute recordings from 230 m and 350 m changing over time.

For baseline scenarios without motorway, bird song was used as audio stimulus, since it was the main background sound at the recording site. Audio recording of bird sound was obtained in a quiet suburban park and an 8-second sample was extracted for use. The played-back level of the extracted sample was 47.8 dB(A).

5.2.4. The experiment and procedure

Thirty participants (15 male and 15 female), aged 18-27 (Avg. = 21.1, S.D. = 2.1), with normal hearing and normal or adjusted to normal vision, were recruited via email invitation within the university. Each participant session took about 20 minutes and the participant received a small amount of cash as compensation for his/her time.

The experiment was carried out in a 3.5m × 3.5m × 2.3m anechoic chamber. The videos were played by an ASUS X550C laptop and projected via a Hitachi ED-X33 LCD projector onto a 203 cm × 152 cm screen 2.2 m away from where the participants were seated. Sound was presented to participants via a pair of Beyerdynamic DT 770 Pro headphones.

During the experiment, participants were asked to rate the overall pleasantness of each scene using visual analogue scale, that is, by marking a "×" on a bar which was 100mm long on the printed questionnaire and had only "low pleasantness" and "high pleasantness" labelled at the two ends. Before start, participants were told that the term overall pleasantness in this study concerned mainly visual pleasantness and sound pleasantness, but the purpose of this study was not mentioned.

5.2.5. Analysis of the results

Overall pleasantness of each scene was measured on questionnaires as the length from the low-pleasantness end of the visual analogue scale bar to the marked "×" on the bar in millimetre. For example, if the length is 70 mm, then the overall pleasantness score is 70. So possible overall pleasantness scores would range from 0 to 100. The perceived integrated impact in each scene with motorway was calculated by subtracting the overall pleasantness score of the scene from overall pleasantness score of the corresponding baseline scene without motorway. Possible integrated impact would thus range from -100 to 100, where a negative value means the motorway enhances the overall pleasantness whereas a positive value means the motorway decreases the overall pleasantness, the larger the absolute value the higher the level of impact.

Within-subject ANOVA was run to analyse the effects of tested factors on the integrated impact; regression analysis was carried out to explore the indicativeness of noise exposure to the impact. All statistical analysis was carried out using IBM SPSS Statistics 21.

5.3. Results and discussion

5.3.1. The effects of traffic condition, distance to road and background landscape

A $3 \times 2 \times 3 \times 2$ within subject ANOVA was carried to analyse the effects of noise emission level, percentage of HGV, distance to road and background landscape on the perceived integrated impact of visual intrusion and noise of motorways. Table 5.2 shows the result. All the factors had significant effect on the perceived impact except percentage of HGV. The values of partial eta squared indicate that noise emission level was the most influential factor, followed by distance to road and then by background landscape. Marginal mean comparisons show that there were highly significant differences between each of the three noise emission levels and between distances of 100 m and 200 m ($p < .001$). Less significant difference was found between distances of 200 m and 300 m ($p = .031$). Significant interaction effects were found between noise emission level and Percentage of HGV, between noise emission level and distance to road, and between background landscape and distance to road, all with a medium effect size.

Table 5.2. Results of the ANOVA on the effects of noise emission level, percentage of HGV, distance to road and background landscape on the perceived integrated impact (only significant ineraction effects are shown).

Factor	f	df	*p*	η^2_p
Noise emission level*	120.886	1.557, 45.141	.000	.807
Percentage of HGV	1.280	1, 29	.267	.042
Distance to road	58.926	2, 58	.000	.670
Background landscape	16.325	1, 29	.000	.360
Noise emission level × Percentage of HGV	3.974	2, 58	.024	.121
Noise emission level × Distance to road	5.143	4, 116	.001	.151
Background landscape × Distance to road*	4.416	1.649, 47.810	.016	.132

*assumption of sphericity was violated and Greenhouse-Geisser correction was applied.

Although noise emission level and distance to road being the two most influential factors does not necessarily mean that noise impact was more dominant, since these two factors can also be decisive on visual impact, it does imply that noise level at receiver position can be a potential indicator for the integrated impact. The significant effect of background landscape, as well as the significant interactions with background landscape and percentage of HGV, suggests that some weightings by visual factors might be needed.

Figure 5.4 plots the mean differences and the interactions. It can be seen in Figure 5.4-a that there is a steady increase in integrated impact by noise emission level. Percentage of HGV does change the increase rate, but the change is not remarkable, despite the interaction being reported as significant. Figure 5.4-b shows that integrated impact decreases by distance to road in a rapid-to-gentle pattern, which resembles the decrease in noise levels at receiver positions by distance. The pattern is most obvious with the highest noise emission level. Similar decreasing patterns are also found in visual impact in Chapter 4 in the with-sound condition while less clear in the without-sound condition. These findings indicate the importance of noise level in deciding the perceived integrated impact. Figure 5.4-c shows that integrated impact is consistently higher in natural landscape than in residential landscape, which is of the same trend found with visual impact in Chapter 4, and can also be related to the higher sensitivity to noise in more vegetated settings (Anderson et al. 1984; Mulligan et al. 1987). Another difference between the two background landscapes is the patterns of decrease of integrated impact by distance. The decreasing rate is relatively constant in residential landscape while changes dramatically in natural landscape.

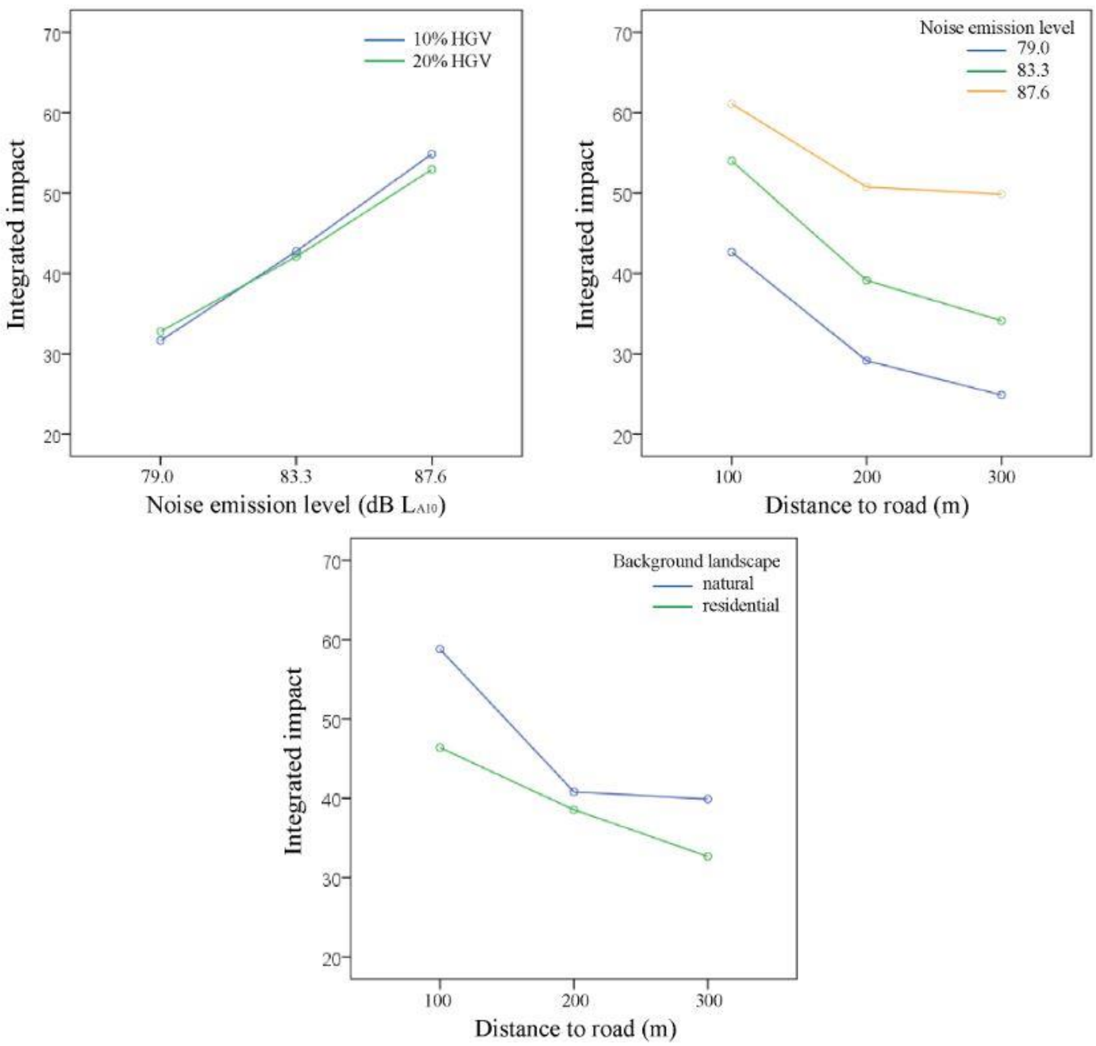

Figure 5.4. Perceived integrated impact of visual intrusion and noise of motorways: a. noise emission level vs percentage of HGV; b. distance to road vs noise emission level; c. distance to road vs background landscape

5.3.2. Noise exposure measures as indices for the perceived integrated impact.

Regression analysis, using noise emission level, distance to road, noise level at receiver position, background landscape (dummy coded) and percentage of HGV as independent variables and perceived integrated impact as dependent variable, was carried out to explore how indicative noise exposure is to the perceived impact. Table 5.3 listed the tested models. It can be seen that noise level at receiver position is the most powerful predictor. This is congruent with the result in Section 5.3.1 that noise emission level and distance to road was the two most influential factors. Adding background landscape as a second predictor can slightly increase the prediction power of the model, which reflects the significant landscape effect found in Section 5.3.1. Adding other predictors cannot improve the model further due to collinearity or ineffectiveness of the factor.

Table 5.3. Tested regression models

Model	Predictors	R^2	Adjusted R^2	Std. Error of the Estimate	Note
Model 1	Noise level at receiver position	.229	.229	20.635	Only one independent variable included in analysis
Model 2	Noise level at receiver position, background landscape	.253	.252	20.319	All independent variables included in analysis, stepwise entry
Model 3	Noise level at receiver position, background landscape, noise emission level, percentage of HGV, Distance to road	.255	.252	20.319	All independent variables included in analysis, forced entry

Table 5.4 shows the details of Model 2. In the model, every one dB(A) increase in noise level at receiver position will lead to 2.490 increase in perceive integrated impact on the scale used in this study, and being in residential landscape decreases the impact by 7.298 as compared to being in natural landscape. However, it should be noted that the prediction power of the model is very low, with an adjusted R^2 only equal to 0.252, which means noise level at receiver position and background landscape together can only explain 25.2% of the variation in perceived integrated

impact, the majority of the variation was decided by factors that were not tested in this study. Similar low predictiveness is also found of noise exposure for noise annoyance in literature. By reviewing 39 social surveys Job (1988) concluded that only typically less than 20% of the variation in noise annoyance could be explained by noise exposure, while factors such as attitude to the noise source and sensitivity to noise could account for larger variation in noise annoyance. This might also be applied in the case of the integrated impact of visual intrusion and noise, that attitude to the intrusion source and individual sensitivity to the intrusions can play a more important role in deciding the level of perceived impact.

Although factors such as ecological validity, variable control and experimenter effect may alter the cause-effect relationships found in laboratory experiments from those exist in real life situations (McLeod, 2012), the results of the experiment in this study indicate that the prediction power of objective exposure measures for integrated impact is low, which suggests that while such prediction models can conveniently allow an preliminary understanding of the climate of the integrated impact, it may not be sufficient to guide evidence-based decision makings regarding noise and visual impacts of motorways. Character of the affected population should also be studied for the assessment.

Table 5.4. Regression coefficients of Model 2 (adj R^2= 0.252).

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**Sig.**	**Partial R^2**
	B	**Std. Error**	**Beta**			
(Constant)	-117.323	9.050		-12.964	.000	
Noise level at receiver position (dB(A))	2.490	.137	.479	18.187	.000	.485
Background landscape (dummy coded as: natural = 0; residential = 1)	-7.298	1.237	-.155	-5.902	.000	-.177

Dependent variable: perceived integrated impact

5.4. Conclusions

This study aimed to investigate the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of visual intrusion and noise of motorways, and to explore how indicative noise exposure is to the perceived impact. A laboratory experiment, using computer-visualised scenes with edited audio recordings to present six traffic conditions consisting of three levels of noise emission and two levels of percentage of HGV, three distances to road and two types of background landscape, was carried out and human responses to the scenes were obtained.

The results show that traffic condition was the most influential factor. Specifically, it was the traffic volume as expressed by noise emission level that strongly influenced the perceived integrated impact while traffic composition did not make noticeable differences. Distance to road was the second most influential factor, followed by background landscape. Generally, perceived integrated impact increased steadily by noise emission level, decreased in a rapid-to-gentle pattern by distance to road, and was consistently higher in natural landscape than in residential landscape.

The regression model using noise level at receiver position and type of background landscape as predictors can predict about a quarter of the variation in the perceived integrated impact, which is similar to the relationship between noise exposure and noise annoyance found in social surveys. A larger part of the variation might be explained by factors such as attitude to the intrusion source and individual sensitivity to the intrusions.

Chapter 6 Mitigating the integrated impact of motorways using noise barriers: the combined acoustical and visual performance in varied scenarios

Following the investigation on the integrated visual and noise impact of motorways in Chapter 5, this chapter investigated the mitigation effect of noise barriers on the integrated impact in varied scenarios, taking into considerations the effects of the barriers on reducing noise and visual intrusions of moving traffic, but also potentially inducing visual impact themselves. Firstly, a review of previous multisensory research on noise barriers is presented to set up the context and identify research questions of this chapter (Section 6.1). Then details of the experimental design and methods used in this chapter are provided (Section 6.2). Results of the investigation are analysed in terms of perceived barrier performance in different experimental scenarios and its relationship with peoples' aesthetic preference and preconception of barrier effectiveness (Section 6.2), followed by a discussion of the findings in response to the research questions (Section 6.3). Finally, conclusions of this chapter are made (Section 6.4).

6.1. Background

The growing concern about noise pollution has increased the use of noise barriers along major transport infrastructures (Kotzen & English, 2009). Noise barriers come in various sizes, forms, placements and materials and can reduce noise up to about 15 dB(A) realistically in practice (Kotzen & English, 2009). Evaluation of noise barriers requires however more than the measurement of noise reduction. Studies on perceived effectiveness of noise barrier have shown influences of factors other than acoustical performance, e.g., before-barrier sound levels (May & Osman 1980), engagement in the barrier design (Hall 1980, Joynt 2005), social and economic effects, e.g., changes in property value and risk of crime (Perfater, 1979).

Among the influential factors, visual factor is a major one and many studies have investigated the effect of it. Aylor and Marks (1976) studied the perceived loudness of noise transmitted through barriers of different solidity in “sight + sound” and “sound only” conditions. The results showed lower perceived loudness when the sight of the noise source was partially obscured; but higher perceived loudness when the sight of noise source was completely obscured. Similar results were found in Watts et al. (1999) where the effect of vegetation on traffic noise perception was investigated both on site and in laboratory. It was shown that perceived noisiness was higher where the level on visual screening of the sound source by vegetation was higher. In their laboratory experiment, a willow barrier and a metal barrier of the same dimension were also included in the assessment. While participants rated the willow barrier more attractive than the metal one, similar perceived noisiness behind the two barriers was reported. Joynt & Kang (2010) conducted a more dedicated and detailed study on the effect of barrier aesthetics. The study compared perceived effectiveness of four motorway noise barriers and a deciduous hedgerow in a laboratory experiment. The results showed a strong negative correlation between aesthetic preference and the perceived noise attenuation of the barriers. The study also investigated the effect of preconception of barrier effectiveness on the perceived noise attenuation and found positive correlation between them. Lower perceived loudness behind the opaque barriers was found in this study which was contradictory to that in Watts et al. (1999) and Aylor & Marks (1976). Maffei et al. (2013a) studied the effect of barrier aesthetics and noise source visibility through barriers on the perceived loudness and annoyance of railway noise. The results were more in line with Watts et al. (1999) and Aylor & Marks (1976), that perceived loudness was lower for transparent barriers than for opaque barriers, and remained largely the same for barriers of different aesthetics. Noise annoyance was perceived lower for transparent barriers as well, and for barriers with higher aesthetics. The effect of visual characteristics increased as noise level increased.

The above studies show that perceived effectiveness of noise barriers are influenced by noise source visibility and barriers aesthetics in complex ways, requiring the use of aural-visual interaction approaches for the assessment of barriers. While some studies investigated either the effect of visual stimuli on sound environment perception (e.g., Anderson et al., 1984; Mulligan et al., 1987; Viollon et al., 2002), or audio stimuli on visual environment perception (e.g., Anderson et al. 1983; Benfield et al., 2010; Hetherington et al., 1993), many have focused on their interactive effects on the perception of the overall quality of the environment (e.g., Carles et al, 1999; Hong & Jeon, 2013; Pheasant et al., 2008). Nilsson et al. (2012) argued that assessing the overall environmental quality is easier and more natural than assessing environmental qualities of each individual sensorial modality, which is particularly applicable for the case of noise barriers, as design and installation of noise barriers is also a landscape issue: while they are aimed to be acoustically beneficial, they are often visually intrusive and can restrict sight of desired views (Arenas, 2008, Bendtsen, 1994, Kotzen & English, 2009).

Following this argument, Hong & Jeon (2014) studied the overall preference for noise barriers considering both acoustical and visual performances. Their results show that vegetated barrier was the most preferable one, followed by concrete and wood barriers, translucent acrylic and aluminium barriers were the least preferred, despite the lower perceived loudness found for transparent and nonsolid barriers in Aylor & Marks (1976), Maffei et al. (2013a) and Watts et al. (1999). Preconception of barriers' noise reduction effectiveness was the most affecting factor in determining the overall preference for the barriers when the noise level was relatively low (55 dB), while aesthetic preference for barriers came to be the most determinant one when noise level was relatively high (65 dB).

The results of Hong & Jeon (2014) are informative and indicate potential improvement that could be made for the evaluation of noise barriers by evaluating their overall environmental performance. However, one limitation of Hong & Jeon (2014) is the use of static images to present noise barriers for road traffic in their experiment. It failed to present moving traffic which should be visible in some barrier scenarios, while moving traffic has been shown to be influential on perceptions of both sound (Fastl, 2004) and visual (Gigg, 1980; Huddart, 1978) environmental qualities. Moreover, there is a lack of investigations on the effects of background landscape and receiver distance to road on the perceived barrier performance in previous multisensory-based noise barriers studies. Background landscape is not only one of the decisive factors in determining the visual effect that a certain development can have on human viewers (Landscape Institute and Institute of Environmental Management and Assessment, 2013), it is also influential on noise perception (Mulligan et al., 1987; Viollon et al., 2002) and can thus affect the perceived acoustic performance of the barriers. Receiver distance to road is also not only critical for visual impact assessment (Landscape Institute and Institute of Environmental Management and Assessment, 2013), but for the measured net benefit that barriers can have on certain receivers as well (Highways Agency, 1995). Herman et al. (1997) showed that perceived effectiveness of barriers was also distance-dependant.

Therefore, the aim of this study is to investigate the overall performance of noise barriers in mitigating the integrated visual and noise impact of motorways, taking into consideration their effects on reducing noise and visual intrusions of moving traffic, but also potentially inducing visual impact themselves. Specifically, the study is to answer the following questions: (1) Are noise barriers always beneficial in mitigating the integrated impact of motorways and how beneficial are they given different traffic levels, receiver distances to road and background landscapes? (2) How do barriers of different acoustical and visual characteristics differ in their performance in the varied scenarios? (3) Do aesthetic preference for barriers and preconception of their noise reduction effectiveness influence the perceived overall performance of them? A laboratory experiment was carried out to obtain subjective responses to computer-visualised video scenes representing different experimental scenarios, including scenes without motorways, scenes with motorways, and scenes with motorways and barriers varying in size and transparency. Performances of barriers were compared in terms of reductions in perceived integrated impact of motorways in different scenarios.

6.2. Methods

6.2.1. Design of the experimental scenarios

Three barrier scenarios were designed to represent barriers varying in transparency and size: 3 m tall timber barrier, 5 m tall timber barrier, 5 m tall transparent barrier. Timber material was preferred over metal, concrete, brick etc. for the opaque barrier because timber barriers are the most commonly used type of barriers for mitigation of road traffic noise in the UK (Kotzen & English, 2009). The height of timber barriers in the UK rarely exceeds 3 m (Kotzen & English, 2009; Morgan, 2010) and there was a general restriction on barrier height of 3m in the UK to avoid visual intrusion (Highway Agency, 2001). However, timber barriers are recently increasing in height and those in the Europe can reach 4-5 m tall (Kotzen & English, 2009; Morgan, 2010). So the heights of 3 m and 5 m were used for the two timber barrier scenarios, which are realistic in scale and typical for the visual concerns while offer adequate difference in noise reduction. Transparent barriers can be made from several materials and there is less restriction in their heights. The height of 5 m, the same as the taller timber barrier, was used for the transparent barrier to control noise reduction. Two scenarios without barriers, one with the motorway only and one with a tree belt partially screening the motorway, were also designed to offer comparisons, as well as a baseline scenario without motorways.

Two distances of receiver to the motorway, 100 m and 300 m, were chosen for this study. 100 m was chosen for the short distance scenario instead of a very close distance (e.g. 2 m in Hong &Jeon (2014)), since relatively far receiver positions are more common and realistic in cases of motorways, and noise reduction by barriers can still be significant at 100 m even when the ground is absorbing (Highways Agency, 1995). 300 m was chosen for the long distance scenario because this is around the threshold beyond which barriers may only offer negligible noise reduction (Highways Agency, 1995) while people can still be adversely affected by noise of high volume traffic (Kotzen & English, 2009) and be visually affected by the barrier (Highways Agency, 1993; Jiang et al., 2015). People in the 300 m distance scenarios are not likely to be the group that the barriers are aimed to benefit, the idea is to see what potential environmental effects, positive or negative, that barriers can still have on this group.

Two traffic levels, 2046 vehicle/hour with 10% HGV, and 10928 vehicle/hour with 20% HGV, were designed for this study. The values of these chosen traffic flows and compositions were determined based on the annual traffic count of UK motorways (Department for Transport, 2014; Highway Agency, 2004), aiming to make adequate difference between the two levels while keep them representative and reasonable for a motorway like M1. Speed of 110km/h was assigned to cars and 90km/h assigned to HGVs according to the UK motorway speed limits (GOV.UK, 2014).

Two types of background landscape, natural and residential landscapes, which are typical along the motorway corridors in the UK, were conceived for this study. A summary of the experimental scenarios can be found in Figure 6.1.

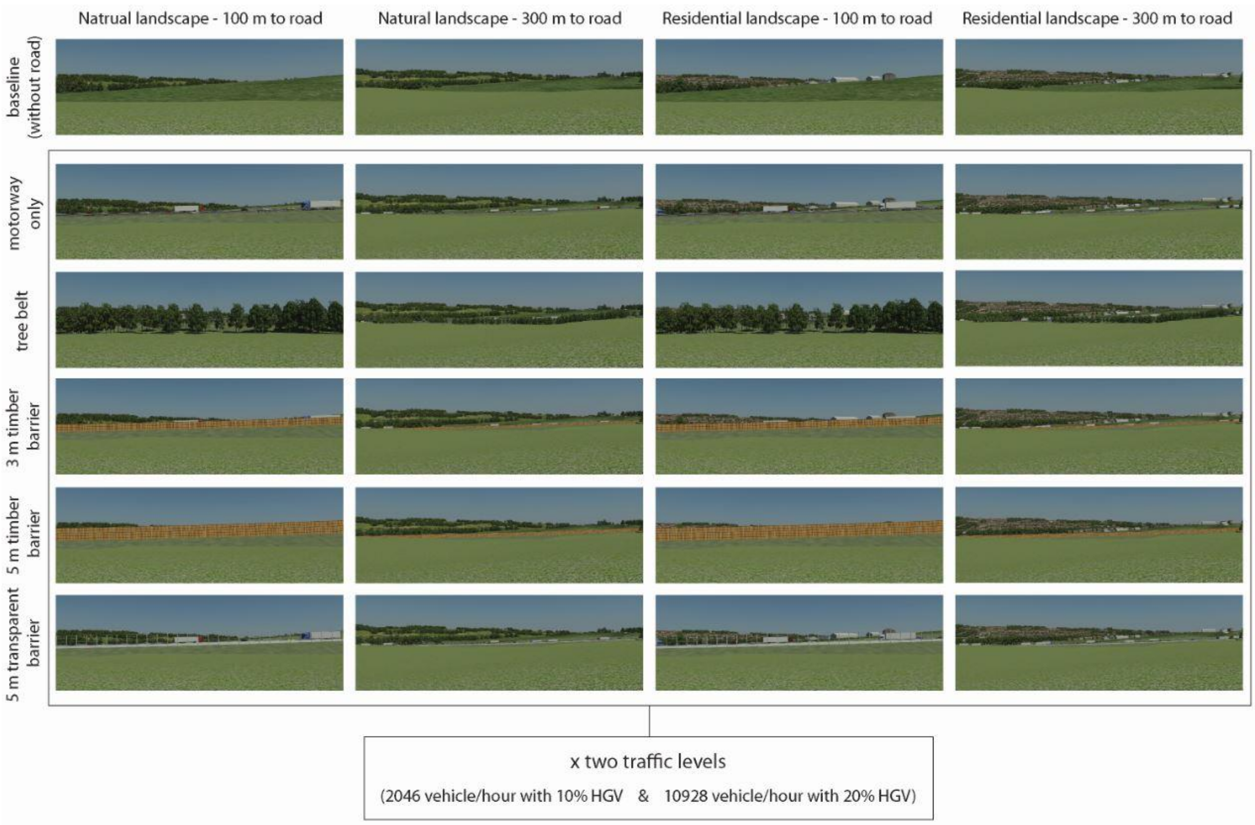

Figure 6.1. Designed experimental scenarios (Enlarged image content is provided in Figures 10.7, 10.8, 10.9 and 10.10 in Appendix 6).

6.2.2. Preparation of visual stimuli

Choosing and modelling of the base site are described in Section 3.2.1.2. The designed natural and residential landscape scenarios were created based on the 3D model of the base site by changing the amount of buildings and trees. Barriers for the three barrier scenarios were modelled according to parameters and photos demonstrated in Kotzen & English (2009) and Morgan (2010), and then added alongside the motorway for each scenario. Animations of moving traffic were made for the two traffic levels, with 10 cars and 1 HGV for the low level and 49 cars and 12 HGVs for the high level in 20 seconds which was the length of each video scene that would be rendered. The motorway was removed in baseline scenarios. Two viewpoints, 100 m and 300 m away respectively from the near edge of the motorway, were assigned in the models for the two distance scenarios. Cameras to capture views from the two viewpoints were set 1.6 m above the ground facing perpendicular to the motorway.

The captured views were rendered into video scenes with the animations of moving traffic. The resolution of the rendering was 1800 × 600 pixels at a frame rate of 30 fps. Each video scene was 20 seconds long. The scenes of baseline scenarios, where there was no moving traffic, were still images and each lasted 10 seconds. In total, 40 video scenes and 4 image scenes were produced, and were merged in a random order to create a single long video, with the scene number (Scene 1 to Scene 44) appearing for 3 seconds before each scene and a 3-second blank interval after each scene. Another long video was made with scenes in reversed order. The two videos would be equally but randomly assigned to the participant sessions to eliminate the possible effect of scene order.

6.2.3. Preparation of audio stimuli

Acquisition of audio recordings of motorway traffic is described in Section 4.2.2. A 20-second sample was extracted from each of the full 230 m and 350 m audio recordings for audio reproduction. The recording sample was calibrated with the signal of a 01dB Cal01 Calibrator (94 dB/1 kHz) using a Neumann KU

100 dummy head and the playback system (see Section 6.2.4) that would be used for the experiment. The obtained sound equivalent level of the 20-second sample from 230 m was 70.4 dB(A), and that from 350 m was 63.1 dB(A).

The required sound pressure level at receiver position in each scenario was calculated using the noise prediction software CadnaA. For the calculation, the absorption coefficient of the ground, which was grassland in this study, was set as 0.5. The UK CRTN model was used to calculate the noise levels with and without barriers (Department of Transport, 1988). Tree belt was treated as without barrier. The obtained $LA_{10,18h}$ levels were further converted to LAeq,18h levels (Abbott & Nelson, 2002). The calculated levels for each scenario are shown in Table 6.1.

Table 6.1. Sound pressure level at receiver position for each scenario.

Scenario			Sound pressure level (dB(A))				
			Without barrier	**Tree belt**	**3 m timber barrier**	**5 m timber barrier**	**5 m transparent barrier**
High traffic level	**Short distance**	**Natural landscape**	73.9	73.9	64.4	62.1	62.1
		Residential landscape	73.9	73.9	64.4	62.1	62.1
	Long distance	**Natural landscape**	66.9	66.9	62.1	61.3	61.3
		Residential landscape	66.9	66.9	62.1	61.3	61.3
Low traffic level	**Short distance**	**Natural landscape**	65.4	65.4	56.0	53.7	53.7
		Residential landscape	65.4	65.4	56.0	53.7	53.7
	Long distance	**Natural landscape**	58.4	58.4	53.6	52.8	52.8
		Residential landscape	58.4	58.4	53.6	52.8	52.8

To produce audio files for received traffic noise without barrier, the original recordings, from 230 m for high traffic level and from 350 m for low traffic level, were edited using Adobe Audition CS6, either by increasing or by decreasing the overall levels. To produce audio files for received traffic noise with barrier, the levels of the audio files for without barrier were further edited in one-octave band. Since CRTN does not provide spectrum information, Maekawa's chart (Maekawa, 1968) was used as a guidance to help decide noise reduction on each octave band. When using Maekawa's chart, the traffic was seen as a line source located at the centre of the motorway and 0.15 m (as a trade-off between 0.3 m for engine noise and 0.01 m for tyre noise) above the road surface, and static path-length difference at the point with shortest distance to the receiver was used. Although the approach was not rigorous and Maekawa's model was developed for point source, the use of the chart here was only to provide a rough spectrum shape of the attenuation. The produced audio files were again calibrated to check if their playbacks meet the required levels.

For baseline scenarios without motorway, bird song was used as audio stimulus, since it was the main background sound at the recording site. Audio recording of bird sound was obtained in a quiet suburban park and an 8-second sample was extracted for use. The played-back level of the extracted sample was 47.8 dB(A).

The audio files were then added to the soundtracks of the videos

6.2.4. The experiment and procedure

Thirty participants (15 male and 15 female), aged 18-27 (Avg. = 21.1, S.D. = 2.1), with normal hearing and normal or adjusted to normal vision, were recruited via email invitation within the university. Each participant session took about 25 minutes and the participant received a small amount of cash as compensation for his/her time.

The experiment was carried out in a 3.5m × 3.5m × 2.3m anechoic chamber. The videos were played by an ASUS X550C laptop and projected via a Hitachi ED-X33 LCD projector onto a 203 cm × 152 cm screen 2.2 m away from where the participants were seated. Sound was presented to participants via a pair of Beyerdynamic DT 770 Pro headphones.

During the experiment, participants were asked to rate the overall pleasantness of each scene using visual analogue scale, that is, by marking a "×" on a bar which was 100mm long on the printed questionnaire and had only "low pleasantness" and "high pleasantness" labelled at the two ends. Before start, participants were told that the term overall pleasantness in this study concerned mainly visual pleasantness and sound pleasantness, but the purpose of this study was not mentioned. When the video of the 44 scenes ended, participants were shown on the screen an image of the three barriers used in this study (Figure 6.2), and asked to rate the aesthetic quality and noise reduction effectiveness of each barrier, based on their own preference or knowledge, regardless of what they had seen or heard in the earlier video session.

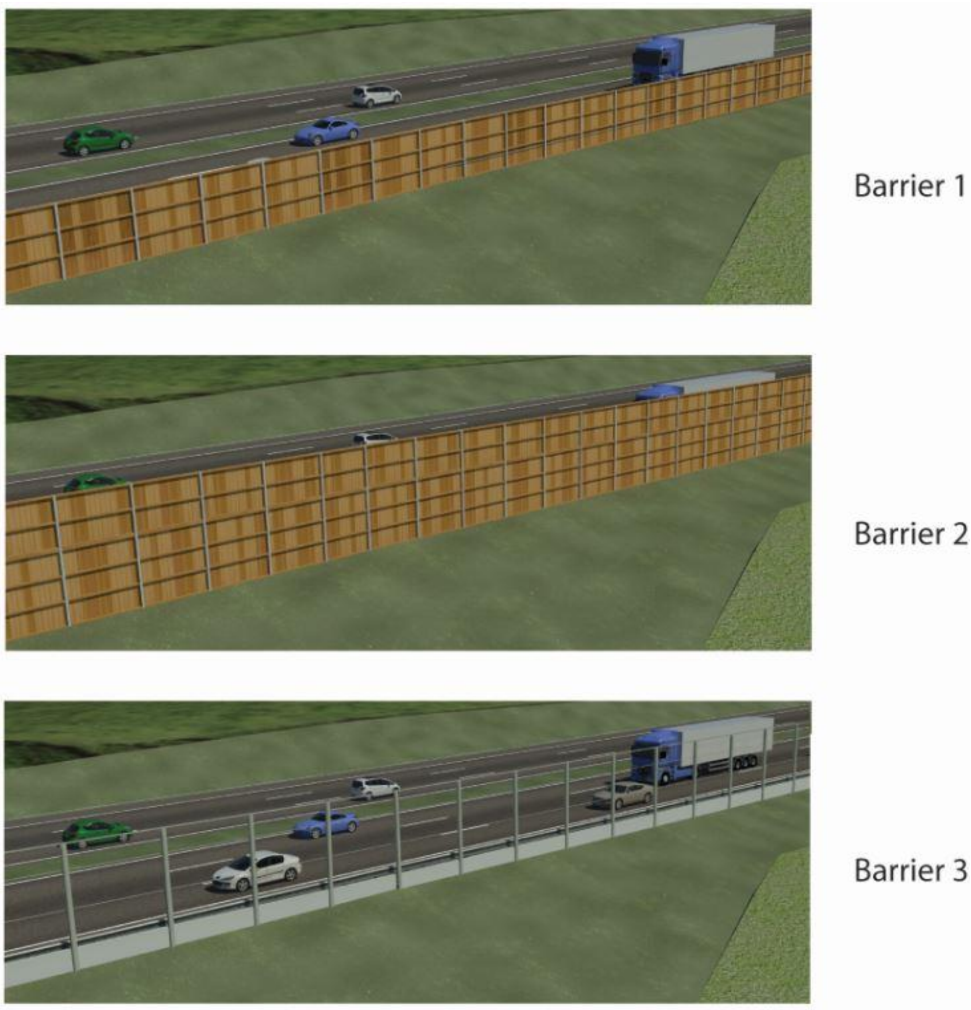

Figure 6.2. Image of the three barriers for aesthetic and effectiveness ratings.

6.2.5. Analysis of the results

Overall pleasantness of each scene was measured on questionnaires as the length from the low-pleasantness end of the visual analogue scale bar to the marked “×” on the bar in millimetre. So possible overall pleasantness scores would range from 0 to 100. The perceived integrated impact of motorway in each scene with motorway (including motorway only, motorway with barrier, and motorway with tree belt) was calculated by subtracting the overall pleasantness score of the scene from overall pleasantness score of the corresponding baseline scene without motorway. Possible integrated impact scores would thus range from -100 to 100, where a negative value means the motorway enhances the overall pleasantness whereas a positive value means the motorway decreases the overall pleasantness, the larger the absolute value the higher the degree of impact. The mitigation effect of each barrier or the tree belt was measured as reduction in integrated impact as compared to the corresponding scene with motorway only.

The five barrier conditions: motorway only, tree belt, 3 m timber barrier, 5 m timber barrier and 5 m transparent barrier, were treated as the five levels of the barrier condition variable. Within-subject ANOVAs were run to analyse the effects of barrier condition, traffic level, distance and background landscape on the perceived integrated impact of motorways, and to compare the mitigation effect of barriers in each traffic, distance and landscape scenarios. Correlation analysis was undertaken to test the relationship between aesthetic preference for barriers, preconception of effectiveness of the barriers, and perceived integrated impact reduction by the barriers. All statistical analysis was carried out using IBM SPSS Statistics 21.

6.3. Results

6.3.1. An overall analysis of the results

A $5 \times 2 \times 2 \times 2$ within subject ANOVA was carried out for an overall analysis of the effects of barrier condition, traffic level, distance and background landscape on the perceived integrated impact of motorways. The results are listed in Table 6.2. It shows that all the four factors had significant main effect on the perceived integrated impact. The values of partial eta squared show that barrier condition had an medium effect, which is smaller than that of traffic level and distance but larger than that of background landscape, on the perceived integrated impact. Within the effect of barrier condition, marginal mean comparison shows that, while integrated impact was significantly higher without barrier than in any other barrier conditions ($p < .001$), no significant difference was found between any of the other barrier conditions, which indicates that, generally the three barriers and the tree belt could all reduce the integrated impact of motorways, however, despite of their differences in visual appearance and noise reduction ability, their general performance over the eight experimental scenarios (2 travel levels × 2 distances × 2 background landscapes) was largely the same with each other.

Significant interaction effect related to barrier condition was found between traffic level and barrier condition; between distance and barrier condition; among traffic level, distance and barrier condition; and among background landscape, distance and barrier condition. It indicates that barrier performance might change with specific scenarios especially distance and traffic scenarios.

Table 6.2. Results of the ANOVA on the effects of barrier condition, traffic level, distance and background landscape on the perceived integrated impact of motorways (only significant interactions related to barrier condition are listed).

Factor	f	df	p	η^2_p
barrier condition*	27.445	2.997, 86.922	< .001	.486
traffic level	141.426	1, 29	< .001	.830
distance	57.211	1, 29	< .001	.664
background landscape	17.196	1, 29	< .001	.372
traffic level × barrier condition	6.102	4, 116	< .001	.174
distance × barrier condition*	9.807	2.958, 85.789	< .001	.253
traffic level × distance × barrier condition	3.248	4, 116	.014	.101
background landscape × distance × barrier condition	2.939	4, 116	.023	.092

*Assumption of sphericity was violated and Greenhouse-Geisser correction was applied.

To analyse the effect of barrier condition in each individual experimental scenario, eight one-way within-subject ANOVAs were undertaken, using barrier condition as independent variable and integrated impact score as dependent variable. Table 6.3 lists the results. It shows that barrier condition had significant effect in all scenarios except the two with low traffic level at long distance, which means barriers or tree belt made no significant aggravation or mitigation of integrated impact in these two scenarios. The values of partial eta squared indicate that the effect of barrier condition was larger with high traffic level than with low traffic level, at short distance than at long distance, and in residential landscape than in natural landscape.

Table 6.3. Results of the eight one-way ANOVAs on the effect of barrier conditions on integrated impact score.

Scenario			f	df	*p*	η^2_p
High traffic level	**Short distance**	**Natural landscape***	13.806	3.162, 91.705	.000	.323
		Residential landscape*	25.068	2.793, 80.996	.000	.464
	Long distance	**Natural landscape***	11.600	3.004, 87.104	.000	.286
		Residential landscape*	12.771	2.649, 76.828	.000	.306
Low traffic level	**Short distance**	**Natural landscape**	13.379	4, 116	.000	.316
		Residential landscape	14.858	4, 116	.000	.339
	Long distance	**Natural landscape**	1.359	4, 116	.253	.045
		Residential landscape	1.698	4, 116	.155	.055

*Assumption of sphericity was violated and Greenhouse-Geisser correction was applied.

Figure 6.3, together with Table 6.4, compares the mean integrated impact in the five barrier conditions for each experimental scenario. The figure and table show that integrated impact varied to some extents among the barrier conditions as well as across the eight scenarios. Detailed analysis of the comparison is presented in Section 6.3.2 and 6.3.3.

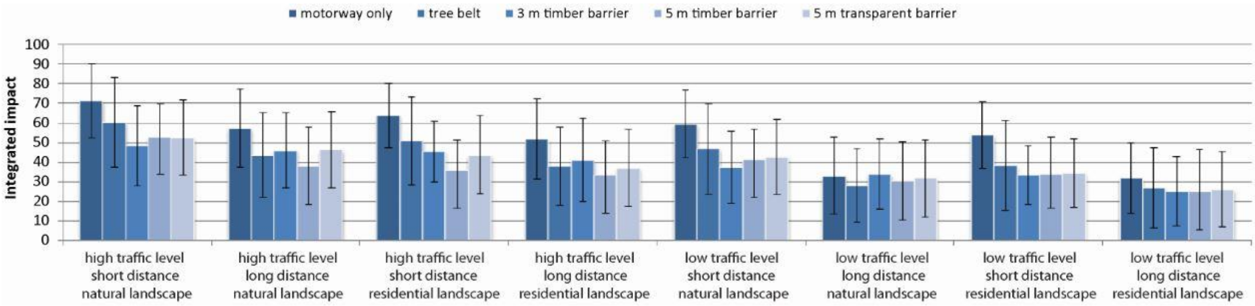

Figure 6.3. Mean integrated impact in the five barrier conditions for each of the eight experimental scenarios. Error bar represents one standard deviation.

Table 6.4. Pairwise marginal mean comparisons of integrated impact scores in different barrier conditions.

Barrier condition (a)	Barrier condition (b)	Mean difference (a-b) (reduction in integrated impact score)							
		High traffic level				Low traffic level			
		Short distance		Long distance		Short distance		Long distance	
		Natural	Residential	Natural	Residential	Natural	Residential	Natural	Residential
Motorway only	Tree belt	11.200*	18.333*	13.767*	13.733*	22.100*	20.533*	5.033	6.700
	3 m timber	23.200*	27.700*	11.300*	10.733*	18.100*	19.833*	-.667	6.933
	5 m timber	18.400*	20.267*	19.500*	18.067*	16.667*	19.467*	2.600	5.733
	5 m transparent	18.933*	12.833*	11.067*	14.733*	12.567*	15.533*	1.367	5.000
Tree belt	3 m timber	12.000*	9.367*	-2.467	-3.000	-4.000	-.700	-5.700	.233
	5 m timber	7.200	1.933	5.733	4.333	-5.433	-1.067	-2.433	-.967
	5 m transparent	7.733	-5.500	-2.700	1.000	-9.533	-5.000	-3.667	-1.700
3 m timber	5 m timber	-4.800	-7.433	8.200*	7.333	-1.433	-.367	3.267	-1.200
	5 m transparent	-4.267	-14.867*	-.233	4.000	-5.533	-4.300	2.033	-1.933
5 m timber	5 m transparent	.533	-7.433	-8.433	-3.333	-4.100	-3.933	-1.233	-.733

* The mean difference is significant at the .05 level, Bonferroni correction applied.

6.3.2. Comparison of barriers with motorway only and tree belt

It can be seen in Figure 6.3 that integrated impact in the three barrier conditions was consistently lower than that in the motorway-only condition. Pairwise comparisons in Table 6.4 show that the reductions in integrated impact by barriers were all significant in scenarios where the effect of barrier condition was significant. It suggests that the use of barriers, when effective, was always beneficial in mitigating integrated impact of motorways.

The mitigation effect of 3 m timber barrier was highest in the high traffic × short distance × residential landscape scenario, followed by in the high traffic × short distance × natural landscape scenario, with a reduction in mean integrated impact score of 27.2 and 23.2 respectively. Generally, the mitigation effect was larger with high traffic level than with low traffic level, and larger at short distance than at long distance. The mitigation effect of 5 m timber barrier was relatively constant across all the scenarios in which it was significant, with reductions in mean integrated impact score ranging from 16.7 to 20.3. The mitigation effect of 5 m transparent barrier was highest in the high traffic × short distance × natural landscape scenario, with a reduction in mean integrated impact score of 18.9. The mitigation effect varied to some extent across the scenarios in which it was significant, but did not show clear tendency in relation to scenario types.

Compared to tree belt, the three barriers did not show many significant differences. Only 3 m timber barrier, in the high traffic × short distance scenarios where the potential impact of motorways was highest, reduced integrated impact significantly more than the tree belt did. No other significant difference was found between 3 m timber barrier and tree belt, 5 m timber barrier and tree belt, or 5 m transparent barrier and tree belt. However, there did seem to be some tendency that 5 m timber barrier reduced integrated impact slightly more than tree belt did when traffic level was high and slightly less than tree belt did when traffic level was low.

6.3.3. Comparison between the three barriers

Comparing 3 m timber barrier with 5 m timber barrier in Table 6.4, significant difference was only found in high traffic × long distance × natural landscape scenario, where 5 m timber barrier reduced integrated impact 8.2 more than 3 m timber barrier did. However, although insignificant, the mean differences suggest some tendency that, when traffic level was high, 5 m timber barrier was more effective than its 3 m counterpart at long distance and less effective than its 3 m counterpart at short distance; when traffic level was low, the difference between their performances became less clear.

Comparing 3 m timber barrier with 5 m timber barrier, significant difference was only found in the high traffic × short distance × residential landscape scenario, where 3 m timber barrier reduced integrated impact 14.9 more than 5 m transparent barrier did. However, the mostly negative mean differences, despite their insignificance, imply that 3 m timber barrier seemed likely to be more effective than 5 m transparent barrier in most scenarios.

No significant difference was found between 5 m timber barrier and 5 m transparent barrier in any scenarios. But again, the mostly negative mean differences imply that 5 m timber barrier seemed likely to be more effective than 5 m transparent barrier in most scenarios.

6.3.4 Aesthetic preference and preconception of noise reduction effectiveness

Figure 6.4 shows participants' aesthetic preference for the three barriers used in this study and their preconception of the barriers' noise reduction effectiveness. On average, participants did not have strong aesthetic preference for any of the barriers over the other two. One-way ANOVA shows no significant difference among the three barriers: $F(1.515, 43.946) = 1.467$, $p = .241$, $\eta^2_p = .048$. The error bars show some variation among individual participants though. As for preconception of noise reduction effectiveness, significant difference was found among the three barriers: $F(1.337, 38.772) = 28.889$, $p < .001$, $\eta^2_p = .499$. Participants generally considered 3 m timber barrier less effective than 5 m timber barrier and 5 m transparent barrier ($p < .001$ in both cases); and considered 5 m timber barrier and 5 m transparent barrier equally effective (p = 1), yet again the error bars indicate some variation among individual participants . No significant correlation was found between aesthetic preference and preconception of effectiveness ($p = .064$).

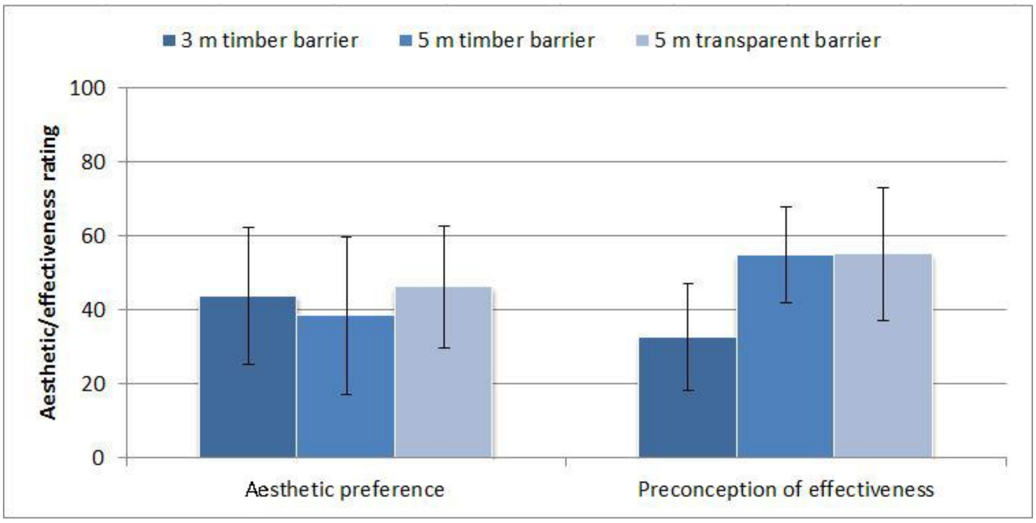

Figure 6.4. Mean scores of aesthetic preference for barriers and preconception of barriers' noise reduction effectiveness. Error bar represents one standard deviation.

Correlations between aesthetic preference for barriers and integrated impact reduction, and between preconception of their noise reduction effectiveness and integrated impact reduction, were carried out for each of the eight experimental scenarios, to analyse if they have any connections with the perceived environmental performance of barriers at individual participant level. Table 6.5 shows the results. Significant and positive correlation at low level was found between aesthetic preference and integrated impact reduction in all the residential scenarios, which implies that in residential landscape, barriers regarded as more aesthetically pleasing had some slight advantage in achieving better environmental performance. No significant correlation was found in natural scenarios however. As for preconception of noise reduction effectiveness, significant correlation of it with integrated impact reduction was only found in one of the eight scenarios, being positive at low level.

Table 6.5. Correlations of integrated impact reduction with aesthetic preference for barriers and with preconception of barriers' noise reduction effectiveness.

	Pearson's r							
	High traffic level				Low traffic level			
	Short distance		Long distance		Short distance		Long distance	
	Natural	Residential	Natural	Residential	Natural	Residential	Natural	Residential
Aesthetic preference	.190	.257*	.128	.237*	.153	.240*	.180	.270**
Preconception of effectiveness	-.009	.236*	.183	.134	-.130	-.038	-.009	-.088

$^{*}p < .05$; $^{**}p < .01$

6.4. Discussion

6.4.1. Are noise barriers always beneficial and how beneficial are they?

The results of this study show that noise barriers were always beneficial in mitigating the integrated visual and noise impact of motorways in varied traffic, distance and landscape scenarios where the effect of barriers were significant, which means that the positive effects of barriers, e.g., noise reduction and/or visual screening, always outweighed the negative effects, e.g., themselves as visual intrusion. In scenarios with low traffic level at long distance, where the potential integrated impact of motorways was low, the effects of barriers became insignificant, which could either be that they had no perceivable positive or negative effect in such scenarios, or that their positive and negative effects were offset with each other and cancelled out. So while the targeted groups at short distances can benefit from barriers, those at long distances are not likely to suffer a decrease in environmental quality caused by the barriers.

As for how beneficial they were, the barriers did not show much advantage over tree belt, which was shown to be effective in reducing negative visual impact of motorways (Jiang et al., 2015), but did not offer any actual noise reduction and could even increase the possible noise impact by increasing people's sensitivity to the noise (Watts et al. 1999). The similar overall environmental benefits of barriers and tree belt found in this study indicates the high importance of visual factors in mitigating the integrated impact of motorways. Nevertheless, noise issue might still be the priority concern when traffic level goes high. In scenarios with high traffic levels in this study, there were some tendencies that barriers offered larger reductions in the integrated impact than tree belt did.

6.4.2. How do barriers of different characteristics differ in performance in varied scenarios?

While the tested barriers varied in size and transparency, they did not differ significantly in how effective they were generally over the eight environmental scenarios. They did show some difference in individual scenarios however. In terms of difference by barrier size, 5 m timber barrier seemed to perform better than 3 m timber barrier at long distance but not at short distance despite its larger noise reduction. This is probably due to the overwhelming visually intrusive and/or sight restricting effects of tall opaque barriers at close distances, and would support Highways Agency (2001)'s general restriction on barrier height for avoiding visual intrusion. It might also be related to the degrees of visibility of the moving traffic, since Aylor & Marks (1976) has shown greater perceived loudness when noise source was totally obscured, and in this study, with the 5 m timber barrier at short distance, moving traffic was totally invisible behind the barrier, while in other barrier and distance scenarios, moving traffic was always visible at low or high degrees.

In terms of performance difference by barrier transparency, there was no clear tendency over individual scenarios in this study. It seems though that 5 m transparent barrier was the least efficient barriers in most scenarios. This might be partly explained by the result found in Joynt & Kang (2010) that transparent barrier was perceived as less efficient than opaque barriers in noise reduction, and partly be explained by that while offering the same or higher noise reduction, transparent barrier reduced nearly no visual impact caused by moving traffic.

6.4.3. Are aesthetic preference and preconception of noise reduction effectiveness influential?

Aesthetic preference for barriers showed some positive correlations with the perceived barrier performance in this study. However, significant correlations were only found in residential scenarios. This might be related to the larger effect of barrier condition in residential scenarios than in natural scenarios as shown by the values of partial eta squared in Table 6.3, It might be explained by that natural landscape tends to be more vulnerable to visual intrusion and any barrier structure would be similarly deemed visually negative, while in residential landscape, barriers of different visual characteristics would be judged with larger variations. Positive contribution of aesthetic preference to overall performance of barriers was also found in Hong & Jeon (2014) which was in an urban context, while inversed contributions of preconception of noise reduction effectiveness was shown at difference noise levels, which shows some congruence with the generally insignificant correlations found between preconception of noise reduction effectiveness and barrier performance in this study. Overall, based on the results of these two studies, there is some confidence to say that aesthetic preference for barriers has potential positive influence on the perceived environmental performance of barriers especially in built-up areas, while the influence of preconception of noise reduction effectiveness is less clear.

6.5. Conclusions

This study aimed to investigate the overall performance of noise barriers in mitigating the integrated visual and noise impact of motorways, considering both of their acoustical and visual effects on perceived environmental quality, in various traffic, distance and landscape scenarios. Using computer-visualised video scenes and motorway traffic noise recordings, experimental scenarios, covering five barrier conditions, two traffic levels, two distances to road and two background landscape types, was presented to participants for their subjective response in a laboratory experiment.

The results of this study show that noise barriers were always beneficial in mitigating the integrated impact of motorways, or made no significant changes in environmental quality when the impact of motorways was low at long distance. The mitigation effect of barriers was only similar to that of tree belt which did not offer any noise reduction. But barriers did show some tendency to be more effective than tree belt when traffic level went high.

Barriers varying in size and transparency did not differ much in their overall performance over the experimental scenarios generally, although the transparent barrier tended to be the least effective in most scenarios. There seems to be some difference by barrier size at different distances however. Taller opaque barriers tended to perform better than shorter ones at long distance but not at short distance despite their larger noise reduction, possibly due to their negative visual effect.

While no clear influence of preconception of barriers' noise reduction effectiveness was shown on perceived barrier performance in this study, significant positive correlations were found between aesthetic preference for barriers and integrated impact reduction by barriers in residential scenarios, implying the importance of barrier aesthetic design when considering the overall environmental performance of the barriers.

Chapter 7 Integration of the results for impact assessment: demonstrations of possible mapping applications

Using findings in the previous chapters on visual impact and integrated visual and noise impact of motorways, this chapter demonstrates some possible mapping applications for impact assessment. Maps of visual impact of motorways, including impact from moving traffic, were produced combining the results of Chapter 3 and Chapter 4. Maps of the integrated impact of visual intrusion and noise were generated based on the results of Chapter 5 and Chapter 6. For comparison, maps of noise impact were also produced, using noise exposure maps produced by commercial noise analysis software and exposure–effect transformation developed by other studies. The chapter first reviews visual and noise impact assessments and mappings in current practice, and defines the type and validity of the impact maps to be demonstrated (Section 7.1). Then detailed methods of mapping for visual, noise and integrated impacts are presented, as well as the produced impact maps (Section 7.2). Finally, implications and potentials of these maps for impact assessment are discussed and concluded (Section 7.3).

7.1. Background and definitions

For both visual impact and noise impact, impact maps are commonly produced and used during the assessment of large scale projects. Impact maps can help identify existing problems, potential risk, as well as possible mitigation measures and opportunities for improvement.

Visual impact maps produced for road projects in practice are usually viewshed maps which only show the extent of visibility of the road in the assessed region. Recently it is recommended to refer this type of maps to as Zone of Theoretical Visibility (Landscape Institute & IEMA, 2013). This type of maps can be helpful for identifying areas that will be potentially affected, however, information on the magnitude of the impact, as the degree of change in landscape quality that would arise from the road project (Highways Agency, 2010), and the significance of the impact, as perceived by viewers based on their sensitivity to the change in landscape quality (Highways Agency, 2010), can hardly be provided. Some simple attempts are made to include to some extent the viewer sensitivity in assessment with the viewshed maps by weighting the affected areas by land use (Federal Highway Administration, 1988).

Similar to the case of visual impact, the most widely used noise maps for assessment are not really noise impact maps, but noise exposure maps, which present the distribution of noise exposure levels expressed by calculated indices for a defined region and period. The Directive 2002/49/EC (European Commission, 2002b) requires all EU member states to produce maps of exposure of environmental noise from major roads, railways and airports and in large urban areas. This type of noise maps are useful for visualising and assessing the noise environment, however, it is the impact of the noise, rather than the noise exposure, that ultimately matters. A simple step to produce noise impact maps based on noise exposure maps is applying exposure–effect relationships to noise exposure, such as the $L_{A10,\ 18h}$ - % bothered relationship used in Highways Agency (2011). The noise impact in thus derived impact maps only reflects average responses of receivers of different sensitivities in different contexts, which can be seen as an analogue of the magnitude of impact in the case of visual impact. While information of receivers can be simply presented by overlapping multiple maps, attempt of more advanced noise impact mapping which integrates receiver content sensitivity into a single produced impact map has also been made (Klæboe et al., 2006).

This chapter demonstrates some possible mapping applications using the results of this study. Maps of visual impact of motorways, including impact from moving traffic, were produced combining the results of Chapter 3 and Chapter 4; for comparison, maps of noise impact were also produced, using noise exposure maps and exposure–effect transformation; finally, maps of the integrated impact of visual intrusion and noise were generated based on the results of Chapter 5 and Chapter 6. Since individual viewer/receiver sensitivity was not an issue addressed in this study, the impacts shown in the derived maps are all at the “magnitude-of-the-impact” level, which nevertheless is still more advanced than the most prevalent exposure maps. It should be noticed however that this chapter is only a demonstration of the possible prototype of more advanced tools that can be developed to assist the assessment of visual and noise impacts of motorway projects. The impact calculation methods developed in this chapter are only based on empirical studies involving small samples and covering limited ranges of predictor variables, which is by far not sufficient to be valid for practical use. More results from studies and surveys on related topics are required to allow meta-analysis to enable the development of more valid calculation models.

7.2. Method

7.2.1. Maps of visual impact of motorways with moving traffic

Maps of visual impact of motorways with moving traffic were produced based on maps of visual impact without moving traffic derived using the model developed in Chapter 3 and with impact weightings calculated based on the results in Chapter 4.

The detailed procedure of mapping of impact without moving traffic can be found in Chapter 3, Section 3.3.4.2. To take account the height of traffic in the viewshed analysis, a 4 m offset of target points was applied according to Highways Agency (1993)'s suggestion.

For the weighting of impact from moving traffic, the lowest and highest traffic volumes, which were 5464 vehicle/hour, 10% HGV, and 10944 vehicle/hour, 20% HGV, were chosen for demonstration. The weighting of the lowest additional impact from moving traffic was set as 0, weightings in other scenarios were calculated relative to it according to Table 4.3 in Chapter 4. The calculated weightings are shown in Table 7.1.

Table 7.1. Weightings of additional visual impact from moving traffic

	Low traffic level		**High traffic level**	
	residential	**natural**	**residential**	**natural**
100m	9.8	18.7	20.9	29.8
200m	1.1	10	12.2	21.1
300m	0	8.9	11.1	20

The viewpoints in the map of impact without moving traffic were then categorised into the six distance and landscape scenarios shown in Table 7.1 for weighting of each traffic condition. Viewpoints with a distance to road between 0 to100 m were categorised into the 100 m scenario, 100 to 200 m into 200 m scenario, and 200 to 300 m into 300 m scenario. Viewpoints with percentage of buildings in the viewshed larger than 10% in either foreground or midground were categorised into residential scenario and the others into natural scenario. All the viewpoints were then applied with the corresponding weightings and the maps of visual impact with moving traffic were generated and shown in Figure 7.1.

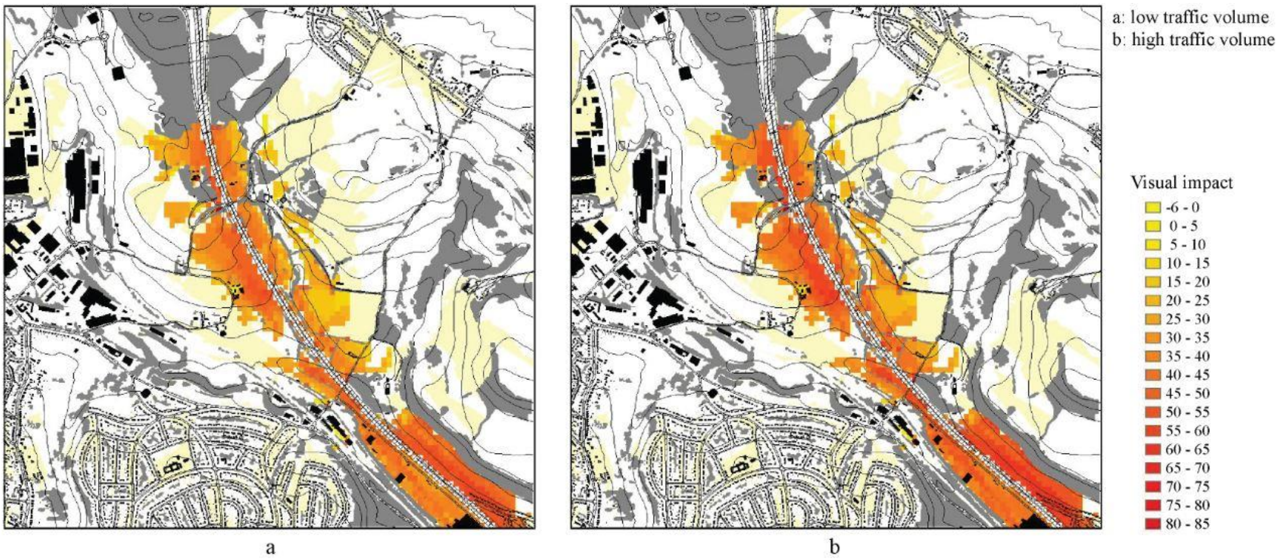

Figure 7.1. Maps of visual impact with moving traffic

7.2.2. Maps of noise impact

The maps of noise impact were produced based on noise exposure maps calculated in the commercial noise prediction software CadnaA and with the exposure-effect equation used by Highways Agency (2011).

The two traffic conditions with the lowest and highest noise emission levels in Chapter 5, which were 79 dB(A) L_{10} and 87.6 dB(A) L_{10}, were chosen for demonstration, for scenarios both with and without noise barrier. The mapping grid in CadnaA were set 25 m × 25 m which was of the same resolution as the visual impact maps. The ground absorption coefficient was set as 0.5. Zero reflection was set for both buildings and barriers. The barriers were 3 m tall and modelled on both sides along the entire segment of the motorway. This was not supposed to be realistic barrier scenarios, but only for demonstration purpose and to be consistent with the scenarios used in mapping of the integrated impact.

Having derived the noise exposure maps, the noise exposure level in each grid cell was transformed into percentage of people bothered very much or quite a lot by traffic noise using the equation given in Highways Agency (2011):

$$\% \text{ bothered} = 100/(1 + e^{-\mu}) \tag{7.1}$$

where $\mu = 0.12(L_{A10,18h}\ \text{dB}) - 9.08$

The produced maps of noise impact are shown in Figure 7.2.

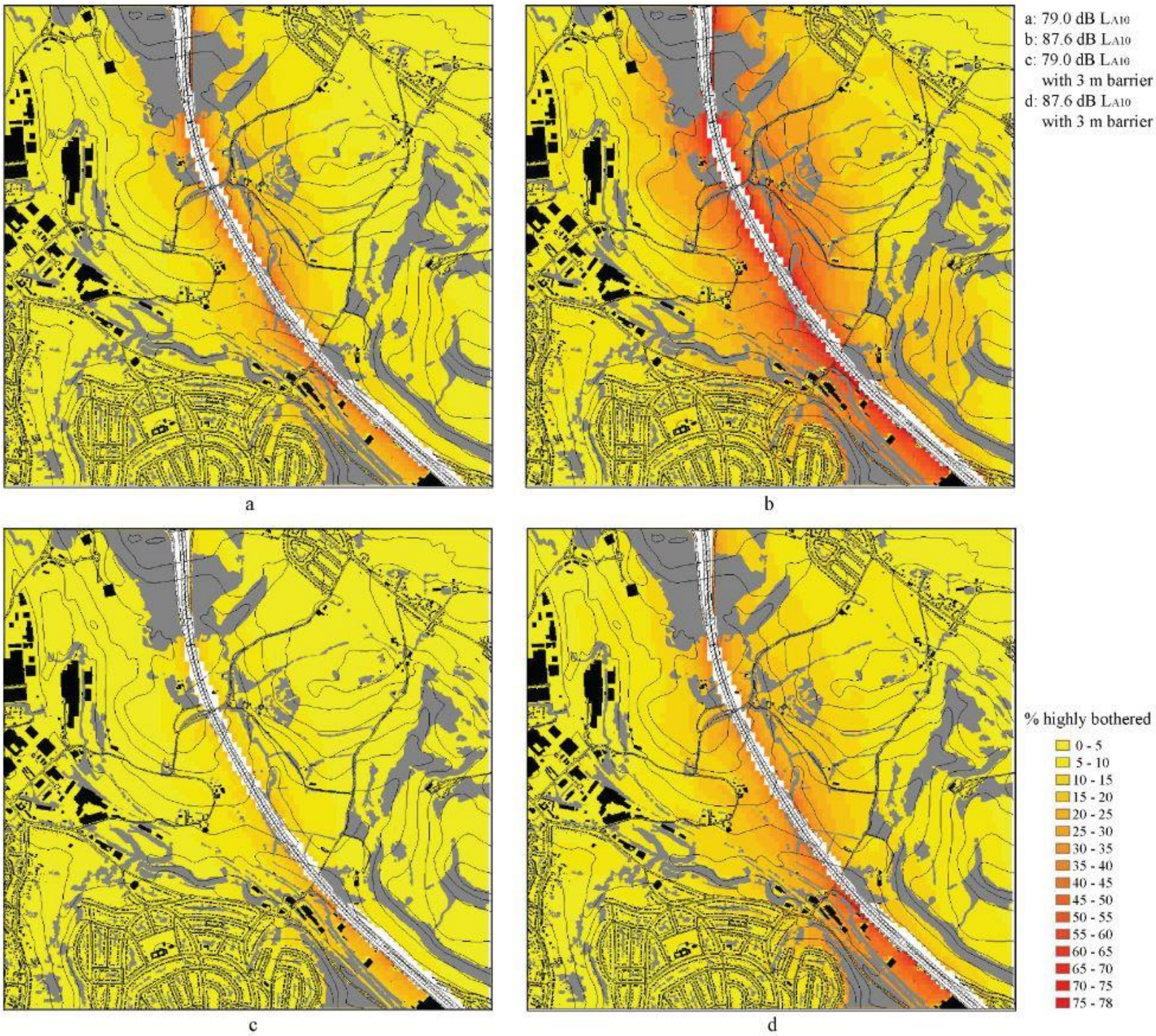

Figure 7.2. Maps of noise impact showing percentage of people highly bothered by noise.

7.2.3 Maps of the integrated impact

The maps of the integrated impact were produced based on noise exposure maps calculated in the commercial noise prediction software CadnaA and with the integrated impact calculation equation developed in Chapter 5. Integrated impact with noise barriers were further adjusted according to the results in Chapter 6.

The two traffic conditions with noise emission level of 79 dB(A) L_{10} and 87.6 dB(A) L_{10}, which were the only two traffic conditions used in Chapter 6, as well as the traffic conditions used to demonstrate the noise impact maps, where chosen for demonstration. With the already derived noise exposure levels, integrated impacts without noise barrier were calculated using the regression equation developed in Chapter 5:

$$\text{Integrated impact} = 2.49(L_{A10,18h}\ \text{dB}) - 117.323 - \mu \qquad (7.2)$$

where μ = 7.298 if the landscape type is natural; = 0 if the landscape type is residential

Since there was a 300 m limit for impact analysis in this study, the integrated impact mapping was also set with a 300 m limit and within the viewshed generated in the visual impact mapping procedure. The receiver points, which were the grid cells in the noise exposure maps and were equivalent to the viewpoints in visual impact mapping, were categorised in to natural and residential scenarios using the same criteria as used in the visual impact mapping procedure.

For integrated impact with barrier, the 3 m timber barrier used in Chapter 6 was chosen for the barrier scenario. To calculate integrated impact with barrier, integrated impact without barrier was adjusted according to the “motorway only” – “3 m timber barrier” comparisons in Table 6.4. To decide which adjustment to use for each receiver point, the receiver points were further categorised into short-distance (0 to 150 m) and long-distance (150 to 300 m) scenarios.

The produced maps of the integrated impact are shown in Figure 7.3.

7.3. Discussion and conclusions

Although the produced maps here were not meant to be valid, there are still some implications for discussion. From Figure 7.1 and Figure 7.2, it can be seen that the visual impact and noise impact have very similar distribution. This is because visual impact was shown to be highly influenced by traffic volume and distance to road in this study, which are also two of the dominant factors in deciding the level of noise exposure. Although visual impact is further influenced by visual landscape which does not usually change the acoustical environment, the influence of visual settings found on sound perception suggests that even higher correlation between perceived visual impact and noise impact might be possible.

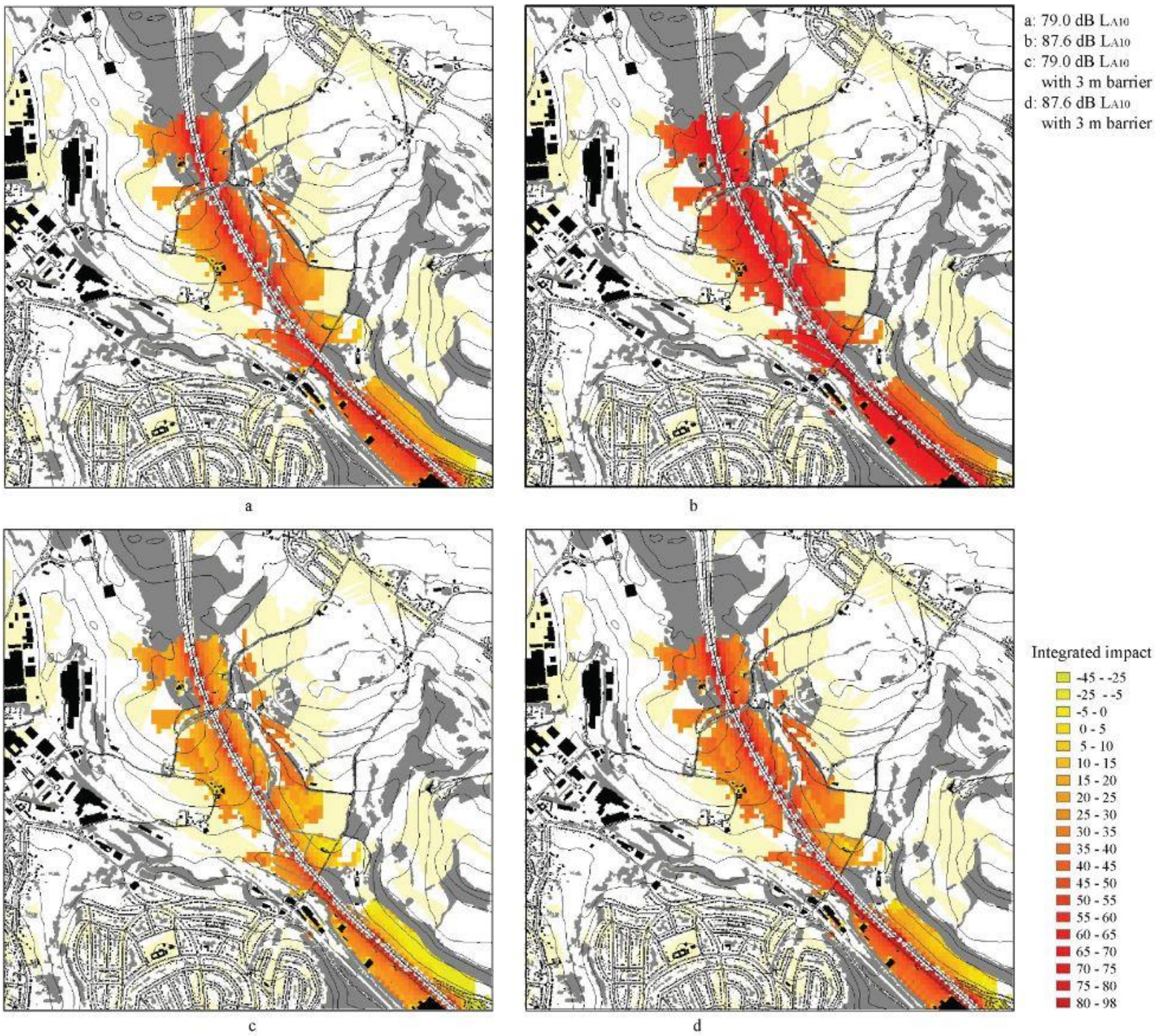

Figure 7.3. Maps of integrated impact of visual intrusion and noise

Comparing Figure 7.3 to Figure 7.2, it can be found that the weighting effect of landscape scenario on the calculated integrated level, which is based on noise exposure level, is not obvious, as the integrated impact distribution still remains similar to that of noise impact which is quite symmetrical along the motorway, while the landscape characters are different on the two side of the motorway. One reason might be that only a very small part of the receiver points were categorised into residential scenario on this case site using the simple binary categorisation, which has homogenised the otherwise more diverse landscape characters. Another possible reason could be the extremely low impact levels appearing at very a few receiver points probably due to over extrapolation of the calculation equation. These low levels enlarge the overall impact scale which makes the difference of 7.298 between the two landscape scenarios less obvious. Nevertheless, as shown in Chapter 5, traffic volume and distance to road are indeed much more influential than landscape on integrated impact.

The difference between noise impact and integrated impact becomes much more obvious in scenarios with the 3 m timber noise barriers. While noise impact still generally decreases by distance, there is an increase in integrated impact at certain distances due to the fluctuation of the overall environmental performance of the barriers at different distances. This kind of information will be helpful for the optimisation of barrier design and placement. However, it should be noticed that there might not be a clear threshold line at which the increase of impact occurs in reality, or there might not even be any increase but only some changes in the decrease rate. The clear increase lines shown in the maps here are due to the discrete categorisation of distance scenarios for the application of barrier mitigation adjustment.

In conclusion, these maps show possible improvement that can be made in current visual impact and noise impact assessments of motorway projects, and potentials of being developed into powerful tools to assist decision making, with results from more studies and surveys on related topics available, including those covering the topics of receiver context and sensitivity.

Chapter 8 Conclusions and Further Research

8.1. Research findings

This study aimed to achieve a better understanding of the visual and noise impacts of motorways and their integrated impact on the environmental quality via an aural-visual interaction approach, to contribute to more reliable and efficient assessments of the impacts. This study was based on perceptual experiments involving human participants using computer-visualised scenes and edited audio recordings as experimental stimuli.

Firstly, this study investigated the effects of characteristics of road projects and character of existing landscapes on the perceived visual impact of motorways, and developed a GIS-based prediction model to map the impact. At this stage the potential visual impact of moving traffic was not considered. The results of the investigation showed that introducing a motorway into a landscape could cause significant visual impact. Installation of noise barriers, especially the opaque timber barriers, further increased the visual impact, while tree screening considerably reduced the impact. The resulted visual impact tended to be lower on sites that were less visually attractive with more buildings in the views, and scattered trees between the motorway and the viewpoint offered a visual absorption effect which slightly reduced the visual impact. *Presence of timber barrier, Presence of transparent barrier, Amount of buildings in the viewshed in midground, Amount of trees in the viewshed in midground, Amount of buildings in the viewshed in background, Amount of trees in the viewshed in background, Percentage of buildings in the viewshed in foreground, Percentage of buildings in the viewshed in midground, Percentage of trees in the viewshed in background, Percentage of trees in the viewshed, and Distance to road* were identified as predictors for the visual impact prediction model which was applied in GIS to generate maps of visual impact of motorways in different scenarios.

Secondly, perceived visual impact of motorway traffic in different but controlled traffic, landscape and distance conditions was investigated and the effects of traffic noise on the impact examined. The results showed significant visual impact induced by motorway traffic, and the higher the traffic volume, the higher the impact. Specifically, composition of traffic could change the impact dramatically when traffic flow was low but not when traffic flow was high. Consistently higher visual impact was found in the natural landscape than in the residential landscape, indicating a significant effect of landscape types. The effect of landscape types seemed largely independent from the effect of traffic condition, which suggested that it might be possible to simplify VIA of motorway projects by separating the assessment of these two components. The effect of viewing distance was also significant and largely independent, and there was a rapid-to-gentle decrease of visual impact by distance. Significant effect of traffic noise on the perceived visual impact was found by comparing impact with sound to impact without sound. Generally, the effect of noise was consistent and increased visual impact by a relatively constant level despite the changing noise levels, traffic conditions, landscape types, and viewing distances. There was a possible interaction effect between distance and noise but would require further studies to draw more confident conclusions.

With the above findings on visual impact and knowledge on noise impact in current literature, the study then addressed the two impacts in an integrated approach, investigating the effects of traffic condition, distance to road and background landscape on the perceived integrated impact of visual intrusion and traffic noise of motorways, and exploring how indicative noise exposure is to the perceived integrated impact. The results showed that traffic condition was the most influential factor. Specifically, it was the traffic volume as expressed by noise emission level that strongly influenced the perceived integrated impact while traffic composition did not make noticeable differences. Distance to road was the second most influential factor, followed by background landscape. Generally, perceived integrated impact increased steadily by noise emission level, decreased in a rapid-to-gentle pattern by distance to road, and was consistently higher in natural landscape than in residential landscape. A regression model using noise level at receiver position and type of background landscape as predictors was developed. The model can predict about a quarter of the variation in the perceived integrated impact, which is similar to the prediction power of noise exposure to noise annoyance found in social surveys.

Subsequently, the combined acoustical and visual performance of noise barriers in mitigating the perceived integrated impact of motorways was investigated, given different barrier characteristics, traffic levels, receivers' distances to road and background landscapes. It was found from the results that noise barriers were always beneficial in mitigating the integrated impact of motorways, or made no significant changes in overall environmental quality when the impact of motorways was low at long distance. The mitigation effect of barriers was only similar to that of tree belt which did not offer any noise reduction. But barriers did show some tendency to be more effective than tree belt when traffic level went high. Barriers varying in size and transparency did not differ much in their performance over the experimental scenarios generally, although the transparent barrier tended to be the least effective in most scenarios. There seems to be some difference by barrier size at different distances however. Taller opaque barriers tended to perform better than shorter ones at long distance but not at short distance despite their larger noise reductions, possibly due to their negative visual effect. While no clear influence of preconception of barriers' noise reduction effectiveness was shown on perceived barrier performance in this study, Significant positive correlations were found between aesthetic preference for barriers and integrated impact reduction by barriers in residential scenarios, implying the importance of barrier aesthetic design when considering the overall environmental performance of the barriers.

Lastly, using the above results of this study, impact mappings as possible prototype of more advanced tools to assist impact assessment were demonstrated. Overall, these maps show possible improvement that can be made in current visual impact and noise impact assessments of motorway projects, and their potentials of being developed into powerful tools to assist decision making.

8.2. Limitations and further research

The audio and visual stimuli produced for the experiments in this study were based on a real base site which is a segment of the UK M1 motorway in a semi-rural area. The simulated experimental scenarios are limited to be typical of the rural and semi-rural areas in the UK context, despite the manipulation of land covers in computer visualisation. So it might not be possible to generalise the results of this study for more developed urban context or regions where the landscape character is very different from that in the UK. Also, the experimental scenarios in this study were all outdoors. Visual and noise impacts received indoors will be very different and will require additional studies.

This study assumed a sunny day in a warm season for all the experimental scenarios without giving specific definitions. However, for both visual and noise impacts, time of the day, time of the year and weather condition can change the objective exposure of the impact and/or influence people's perception of the impact. Particularly, visual impacts of motorway during daytime and during night time are very different subjects. Visual impact during night time would mainly concern road and vehicle lightings introduced into cherished darkness. Studies specifically on lighting and night time landscape would be needed to cover this issue.

Within the scope of this study, for Chapter 4, 5 and 6, only limited numbers of variables and levels of each variable were selected for investigation, due to the limitation in size of full factorial design. Full factorial design was preferred to enable complete investigations on all the examined variables as well as their interactions, which are the main purposes of this study. However, the results might not be sufficient to develop prediction models with decent precision.

In conclusion, a single study will not be able to cover all the issues but to contribute to complete the knowledge system. To gain a more thorough understanding of visual and noise impacts of motorways and their interactions, and to develop more valid and robust impact prediction models, more studies and surveys on related topics are needed, including topics of receiver context and sensitivity which were not addressed in this study.

References

Abbott, P., G. & Nelson, P. M. (2002). *Converting the UK Traffic Noise Index $L_{A10,18h}$ to EU Noise Indices for Noise Mapping*. Project Report PR/SE/451/02. TRL Limited.

Anderson, L.M., Mulligan, B.E., & Goodman, B.E. (1984). Effects of vegetation on human response to sound. *Journal of Arboriculture, 10*(2): 45-49.

Anderson, L.M., Mulligan, B.E., Goodman, B.E., & Regen, H. Z. (1983). Effects of sounds on preferences for outdoor settings. *Environment and Behavior, 15*(5): 539-566.

Anderson, L. M. & Schroeder, H. W. (1983). Application of wildland scenic assessment methods to the urban landscape. *Landscape Plannin*g, *10*(3): 219-237.

Appleton, K. & Lovett, A. (2003). GIS-based visualisation of rural landscapes: defining 'sufficient' realism for environmental decision-making. *Landscape and Urban Planning, 65*(3): 117-131.

Arenas, J.P. (2008). Potential problems with environmental sound barriers when used in mitigating surface transportation noise. *Science of the Total Environment, 405*(1-3): 173-179.

Aylor D.E. & Marks L.E. (1976). Perception of noise transmitted through barriers. *The Journal of the Acoustical Society of America, 59*: 397–400.

Bendtsen, H. (1994). Visual principles for the design of noise barriers. *Science of the Total Environment, 146–147*: 67–71.

Benfield, J. A., Bell, P. A., Troup, L. J., & Soderstrom, N. J. (2010). Aesthetic and affective effects of vocal and traffic noise on natural landscape assessment. *Journal of Environmental Psychology, 30*(1): 103–111.

Bishop, I. D. (1996). Comparing regression and neural net based approaches to modelling of scenic beauty. *Landscape and Urban Planning 34*(2): 125-134.

Bishop, I. D. (1997). Testing perceived landscape colour difference using the Internet. *Landscape and Urban Planning 37*(3–4): 187-196.

Bishop, I. D. (2002). Determination of thresholds of visual impact: the case of wind turbines. *Environment and Planning B: Planning and Design 29*(5): 707-718.

Bishop, I. D. (2003). Assessment of visual qualities, impacts, and behaviours, in the landscape, by using measures of visibility. *Environment and Planning B: Planning and Design 30*(5): 677-688.

Bishop, I. D. & Hulse, D. W. (1994). Prediction of scenic beauty using mapped data and geographic information systems. *Landscape and Urban Planning, 30*(1–2): 59-70.

Bishop, I. D., Lange, E., & Mahbubul, A. M. (2004). Estimation of the influence of view components on high-rise apartment pricing using a public survey and GIS modelling. *Environment and Planning B: Planning and Design, 31*(3): 439 – 452.

Bishop, I. D. & Miller, D. R. (2007). Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. *Renewable Energy, 32*(5): 814-831.

Bishop, I. D. & Rohrmann, B. (2003). Subjective responses to simulated and real environments: a comparison. *Landscape and Urban Planning*, *65*(4): 261-277.

Blair, W. G. E., Isaacson, L., & Jones, G. R. (1979). A comprehensive approach to visual resource management for highway agencies. In: G. H. Elsner & R. C. Smardon (Eds.), *Proceedings of Our National Landscape: A Conference on Applied Techniques for Analysis and Management of the Visual Resource* (pp. 365-372). Incline Village, Nevada.

Blumentrath, C. & Tveit, M. S. (2014). Visual characteristics of roads: A literature review of people’s perception and Norwegian design practice. *Transportation Research Part A: Policy and Practice, 59*(2014), 58–71.

Bruce, N.S. & Davies, W.J. (2014). The effects of expectation on the perception of soundscapes. *Applied Acoustics 85*: 1–11.

Bruce Hull IV, R. & Bishop, I. D. (1988). Scenic impacts of electricity transmission towers: the influence of landscape type and observer distance. *Journal of Environmental Management*, *26*: 000-000.

Buhyoff, G. J. & Leuschner, W. A. (1978). Estimating Psychological Disutility from Damaged Forest Stands. *Forest Science 24*(3): 424-432.

Bureau of Land Management (1984). *Visual Resource Management Program*. Washington, D.C.: U.S. Department of the Interior.

Carles, J. L., Barrio, I. L., & de Lucio, J. V. (1999). Sound influence on landscape values. *Landscape and Urban Planning 43*(4): 191-200.

Cassidy, T. (1997). *Environmental Psychology: Behaviour and Experience in Context*. New York: Psychology Press.

Chamberlain, B. C. and Meitner, M. J. (2009). Automating the visual resource management and harvest design process. *Landscape and Urban Planning 90*(1–2): 86-94.

Chamberlain, B. C. and Meitner, M. J. (2013). A route-based visibility analysis for landscape management. *Landscape and Urban Planning 111*(0): 13-24.

Churchward, C., Palmer, J. F., Nassauer, J. I., & Swanwick, C. A. (2013). *Evaluation of Methodologies for Visual Impact Assessments* (National Cooperative Highway Research Program – Report 741). Washington, D.C.: Transportation Research Board.

Cohn, L & McVoy, G. (1982). *Environmental analysis of transportation systems*. USA, John Wiley and Sons.

Cote, P. (2006). *Understanding Threatened Urban View Corridors with LIDAR Data*. 2006 ESRI International User Conference, Esri.

Cowley, J. A. & Youngblood, H. (2009). Subjective Response Differences between Visual Analogue, Ordinal and Hybrid Response Scales. Proceedings of the 53rd Annual Human Factors and Ergonomics Society, Safety, San Antonio, TX.

Cloquell-Ballester, V., Torres-Sibille, A., Cloquell-Ballester, V., & Santamarina-Siurana, M. (2012). Human alteration of the rural landscape: Variations in visual perception. *Environmental Impact Assessment Review, 32*(1): 50-60.

Danese, M., Nolè, G., and Murgante, B. (2009). Visual Impact Assessment in Urban Planning. In: B. Murgante, G. Borruso and A. Lapucci ed., *Geocomputation and Urban Planning*. Berlin: Springer, 133-146.

Daniel, T. C. (2001). Whither scenic beauty? Visual landscape quality assessment in the 21st century. *Landscape and Urban Planning, 54*(1-4): 267–281.

Daniel, T. C. & Boster, R. S. (1976). *Measuring landscape esthetics: the scenic beauty estimation method*, Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Day, H. Y. (1967). Evaluations of subjective complexity, pleasingness and interestingness for a series of random polygons varying in complexity. *Attention, Perception, & Psychophysics, 2*(7): 281-286.

Dember, W. N. (1960). *The Physiology of Perception*. New York, Holt, Rhinehart and Winston.

den Boer, L.C. & Schroten, A. (2007). *Traffic noise reduction in Europe: Health effects, social costs and technical and policy options to reduce road and rail traffic noise*. CE Delft.

Department for Transport. Traffic Count. Retrieved April, 2014 from: http://www.dft.gov.uk/traffic-counts/

Department of Transport and the Welsh Office (1988). *Calculation of Road Traffic Noise*. London: Her Majesty's Stationery Office.

Domingo-Santos, J.M., de Villarán, R.F., Rapp-Arrarás, Í, & de Provens, E.C. (2011). The visual exposure in forest and rural landscapes: An algorithm and a GIS tool. *Landscape and Urban Planning 101*(1): 52-58.

Dramstad, W.E., Tveit, M.S., Fjellstad, W.J. & Fry, G.L.A. (2006). Relationships between visual landscape preferences and map-based indicators of landscape structure. *Landscape and Urban Planning, 78*: 465–474.

Esri (2012). "Performing visibility analysis with Viewshed and Observer Points." Retrieved Nov, 2012 from: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html.

European Environment Agency (2014). Noise in Europe 2014. Luxembourg: Publications Office of the European Union

European Commission (1993). "*Towards Sustainability" the European Community Programme of policy and action in relation to the environment and sustainable development*. Retrieved August, 2015 from http://www.abgs.gov.tr/files/SEPB/cevrefaslidokumanlar/5theap.pdf

European Commission (1996). *Green Paper on Future Noise Policy*. Brussels.

European Commission (2001). *Environment 2010: Our Future, Our Choice, 6th EU Environment Action Programme 2001 – 2010*. Luxembourg: Office for Official Publications of the European Communities.

European Commission (2012a). *Common Noise Assessment Methods in Europe (CNOSSOS-EU)*. Luxembourg: Publications Office of the European Union.

European Commission (2002b), *Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise*. Retrieved November, 2014 from http://eur-lex.europa.eu/legal content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN

European Commission (2013). *Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'*. Retrieved August, 2015 from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1386&from=EN

Fastl, H. (2004). Audio-visual interactions in loudness evaluation. In S. Ueha (ed.), *Proceedings of the 18th International Congress on Acoustics* (pp. 1161-1166). Kyoto, Japan.

Faul, F., Erdfelder, E., Lang, A.G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods,39*: 175-191.

Federal Highway Administration (1988). *Visual Impact Assessment for Highway Projects*. Washington, D.C.: U.S. Department of Transportation.

Federal Highway Administration (2011). Highway Traffic Noise - Analysis and Abatement Guidance. Washington, D.C.: U.S. Department of Transportation.

Fidell S, Silvati L, Haboly E. Social survey of community response to a step change in aircraft noise exposure. *J Acoust Soc Am, 111*(1):200–9.

García, L., Hernández, J., & Ayuga, F. (2003). Analysis of the exterior colour of agroindustrial buildings: a computer aided approach to landscape integration. *Journal of Environmental Management, 69*(1): 93-104.

Garré, S., Steven, M., & Culinck, H. (2009). The dual role of roads in the visual landscape: A case-study in the area around Mechelen (Belgium). *Landscape and Urban Planning, 92*(2): 125-135.

Gescheider, G.A. (1997). *Psychophysics: The Fundamentals*. London: Erlbaum.

Gigg, M. F. (1980). *The Visual Intrusion of Moving Traffic*, PhD Thesis. University of Sheffield, Department of Civil and Structural Engineering.

GOV.UK. Speed Limit. Retrieved April, 2014 from: https://www.gov.uk/speed-limits

Grêt-Regamey, A., Bishop, I. D., & Bebi, P. (2007). Predicting the scenic beauty value of mapped landscape changes in a mountainous region through the use of GIS. *Environment and Planning B: Planning and Design, 34*: 50–67.

Groß, M. (1991). The analysis of visibility—Environmental interactions between computer graphics, physics, and physiology. *Computers & Graphics 15*(3): 407-415.

Hadrian, D. R., Bishop, I. D., & Mitcheltree, R. (1988). Automated mapping of visual impacts in utility corridors. *Landscape and Urban Planning 16*(3): 261-282.

Hall F.L. (1980). Attitudes towards noise barriers before and after construction: highway noise abatement. *Transportation Research Record: Journal of the Transportation Research Board*, 740: 7-9.

Herman, L., Finney, M., Clum, C. & Pinckney, E. (1997). Perception of Traffic Noise Barrier Effectiveness: Public Opinion Survey of Residents Living near I-71. *Transportation Research Record: Journal of the Transportation Research Board, 1601*(1): 49-54.

Hetherington, J., Daniel, T. C., And Brown, T. C. (1993). Is motion more important than it sounds?: The medium of presentation in environment perception research. *Journal of Environmental Psychology 13*(4): 283–291.

Highways Agency (1993). *Design Manual for Roads and Bridges, Volume 11, Section 3, Part 5: Landscape Effects*. Retrieved from: http://www.standardsforhighways.co.uk/dmrb/vol11/section3/11s3p05.pdf

Highways Agency (1995a). *Design Manual for Roads and Bridges, Volume 10, Section 5, Part 1:* Design for Environmental Barriers. Retrieved from: http://www.standardsforhighways.co.uk/dmrb/vol10/section5/ha6594.pdf

Highways Agency (1995b). *Design Manual for Roads and Bridges, Volume 10, Section 5, Part 2: Environmental Barriers: Technical Requirements*. Retrieved from: http://www.standardsforhighways.co.uk/dmrb/vol10/section5/ha6695.pdf

Highways Agency (2004). *Design Manual for Roads and Bridges, Volume 13, Section 4, Part 4: Traffic Input to COBA*. Retrieved from: http://webarchive.nationalarchives.gov.uk/20100304070241/http://www.dft.gov.uk/pgr/economics/software/coba11usermanual/part4trafinputtocobarevis315.pdf

Highways Agency (2005). *Design Manual for Roads and Bridges, Volume 6, Section 1, Part 2: Cross-sections and Headrooms*. Retrieved from: http://www.dft.gov.uk/ha/standards/DMRB/vol6/section1/td2705.pdf

Highways Agency (2010). *Design Manual for Roads and Bridges, Interim Advice Note 135/10, Landscape and Visual Effects Assessment*. Retrieved from: http://www.dft.gov.uk/ha/standards/ians/pdfs/ian135.pdf

Highways Agency (2011). *Design Manual for Roads and Bridges, Volume 11, Section 3, Part 7: Noise and Vibration*. Retrieved from: http://www.standardsforhighways.co.uk/dmrb/vol11/section3/hd21311.pdf

Hong, J. Y. & Jeon, J. Y. (2013). Designing sound and visual components for enhancement of urban soundscapes. *The Journal of the Acoustical Society of America 134*(3): 2026-2036.

Hong, J. Y. & Jeon, J. Y. (2014). The effects of audio–visual factors on perceptions of environmental noise barrier performance. *Landscape and Urban Planning, 125*: 28-37.

Hopkinson, R. G. & Watson, N. (1974). *Visual Effects of Road and Traffic, Report to the Department of Environment.* London: Her Majesty's Stationery Office.

Huddart, L. (1978). *An Evaluation of the Visual Impact of Rural Roads and Traffic*. Crowthorne: Transport and Road Research Laboratory.

Hunziker, M., Felber, P., Gehring, K., Buchecker, M., Bauer, N., & Kienast, F. (2008). Evaluation of landscape change by different social groups. *Mountain Research and Development, 28*(2): 140–147.

Hunziker, M. & Kienast, F. (1999). Potential impacts of changing agricultural activities on scenic beauty – A prototypical technique for automated rapid assessment. *Landscape Ecology, 14*: 161–176.

Iverson, W. D. (1985). And that's about the size of it: visual magnitude as a measurement of the physical landscape. *Landscape Journal 4*(1): 14-22.

Kearney, A. R., Bradley, G. A., Petrich, C. H., Kaplan, R., Kaplan, S., & Simpson-Colebank, D. (2008). Public perception as support for scenic quality regulation in a nationally treasured landscape. *Landscape and Urban Planning, 87*(2): 117–128.

Jiang L., Kang, J. & Schroth, O. (2015). Prediction of the visual impact of motorways in GIS. *Environmental Impact Assessment Review, 55*: 59-73.

Jones, G. R., Sorey, D. F., & Scott, C. G. (2006). Applying visual resource assessment for highway planning. In L. J. Hopper (Ed), *Landscape Architectural Graphic Standards* (pp. 130-139). New York: John Wiley & Sons.

Kang, J. (2007). *Urban Sound Environment*. Abington: Taylor & Francis

Kotzen, B. & English, C. (2009), *Environmental Noise Barriers: A Guide to Their Acoustic and Visual Design, Second Edition.* Abingdon: Taylor & Francis.

Klæboe, R., Engelien, E. & Steinnes, M. (2006). Context sensitive noise impact mapping. *Applied Acoustics 67*: 620–642.

Knall, V. & Schuemer, R. (1983). The differing annoyance levels of rail and road traffic noise. Journal of Sound and Vibration, 87(2): 321-326.

Joynt, J. (2005). *A sustainable approach to environmental noise barrier design*. PhD Thesis. University of Sheffield, School of Architecture.

.

Joynt, J. & Kang, J. (2010). The influence of preconceptions on perceived sound reduction by environmental noise barriers. *Science of the Total Environment, 408*(20): 4368-4375.

Lake, I. R., Lovett, A. A., Bateman, I. J., and Langford, I. H. (1998). Modelling Environmental Influences on Property Prices in an Urban Environment. Retrieved Jan, 2013 from:
http://www.geocomputation.org/1998/85/gc_85.htm.

Landscape Institute (2011). *Photography and Photomontage in Landscape and Visual Impact Assessment*. London: Landscape Institute.

Landscape Institute and Institute of Environmental Management and Assessment (2002). *Guidelines for Landscape and Visual Impact Assessment second edition.* London: Taylor & Francis.

Landscape Institute and Institute of Environmental Management and Assessment (2013). *Guidelines for Landscape and Visual Impact Assessment, third edition*. Abingdon: Routledge.

Lange, E. (2001). The limits of realism: perceptions of virtual landscapes. *Landscape and Urban Planning, 54*(1-4): 163-182.

Lange, E. & Hehl-Lange, S. (2005). Combining a participatory planning approach with a virtual landscape model for the siting of wind turbines. *Journal of Environmental Planning and Management, 48*(6): 833-852.

Lange, E., Hehl-Lange, S., & Brewer, M. J. (2008). Scenario-visualization for the assessment of perceived green space qualities at the urban–rural fringe. *Journal of Environmental Management, 89*(3): 245–256.

Lavrakas, P.J. (2008). *Encyclopedia of Survey Research Methods*. Thousand Oaks: Sage Publications, Inc.

Leopold, L. B. (1969). *Quantitative comparison of some aesthetic factors among rivers*. Washington, U.S. Geological Survey.

Lothian, A. (1999). Landscape and the philosophy of aesthetics: Is landscape quality inherent in the landscape or in the eye of the beholder? *Landscape and Urban Planning, 44*(4): 177–198.

Louise, M. (1977). Predicting scenic beauty of forest environments: Some empirical tests. *Forest Science 23*(2): 151-160.

Mace, B., Bell, P., & Loomis, R. (1999). Aesthetic, affective, and cognitive effects of noise on natural landscape assessment. *Society & Natural Resources: An International Journal, 12*(3): 225-242.

Maekawa Z. (1968). Noise reduction by screens. *Applied Acoustics, 1*(3): 157–173.

Maffei, L. (2012). Immersive virtual reality for acoustics applications: more than a tool. 5th Congress of Alps-Adria Acoustics Association 12-14 September 2012, Petrčane, Croatia.

Maffei, L., Masullo, M., Aletta, F., & Gabriele, M. (2013a). The influence of visual characteristics of barriers on railway noise perception. *Science of The Total Environment, 445–446*: 41–47

Maffei, L., Iachini, T., Masullo, M., Aletta, F., Sorrentino, F., Senese, V. P., & Ruotolo, F. (2013b). The effects of vision-related aspects on noise perception of wind turbines in quiet areas. *International Journal of Environmental Research and Public Health, 10*: 1681-1697.

May, D.N. & Osman, M.M. (1980). Highway noise barrier perceived benefit. *Journal of Sound and Vibration 70*(2): 153-165.

McLeod, S.A. (2012). Experimental Method. Retrieved from: www.simplypsychology.org/experimental-method.html

Miedema, H.M., Vos, H. (1998). Exposure–response relationships for transportation noise. *J Acoust Soc Am, 104*(6):3432–45.

Miedema, H.M., Vos, H. (2007). Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. *Behav Sleep Med, 5*(1):1-20.

Morgan, P.A. (2010). The acoustic durability of timber noise barriers on England's strategic road network. Prepared for: Project record 387(387) HTRL for Highway Agency. Wokingham: Transport Research Laboratory.

Mulligan, B. E., Lewis, S. A., Faupel, M. L., Goodman, L. S., & Anderson, L. M. (1987). Enhancement and masking of loudness by environmental factors: vegetation and noise. *Environment and Behavior 1987 19*(4): 411-443.

Nilsson, M.E., Jeon, J.Y., Rådsten-Ekman, M., Axelsson, Ö., Hong, J.Y. & Jang, H.S. (2012). A soundwalk study on the relationship between soundscape and overall quality of urban outdoor places. *The Journal of the Acoustical Society of America, 131*: 3474.

Ode, Å., Fry, G., Tveit, M.S., Messager, P., & Miller, D. (2009). Indicators of perceived naturalness as drivers of landscape preference. *Journal of Environmental Management, 90*(1): 375–383.

Palmer, J.F. (2004). Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts. *Landscape and Urban Planning, 69*: 201–218.

Palmer, J.F. & Hoffman, R.E. (2001). Rating reliability and representation validity in scenic landscape assessments. *Landscape and Urban Planning, 54*(1-4): 149–161.

Perfater M.A. (1979). *Community perception of noise barriers*, vol. 1. Charlottesville, Virginia: Virginia Transportation Research Council.

Pheasant, R., Horoshenkov, K., Watts, G., and Barrett, B. (2008). The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments tranquil spaces-quiet places? *The Journal of the Acoustical Society of America 123*(3):1446–1457.

Poulton, E.C. (1977). Quantitative subjective assessments are almost always biased, sometimes completely misleading. *British Journal of Psychology 68*(4): 409-425.

Roads and Traffic Authority (2009). *Guidelines for Landscape Character and Visual Impact Assessment. Environmental Impact Assessment. Guidance Note EIA-N04*. New South Wales: Roads and Traffic Authority.

Rodrigues, M., Montañés, C., and Fueyo, N. (2010). A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. *Environmental Impact Assessment Review 30*(4): 240-246.

Rogge, E., Nevens, F., and Gulinck, H. (2008). Reducing the visual impact of ‘greenhouse parks’ in rural landscapes. *Landscape and Urban Planning 87*(1): 76-83.

Ruddell, E. J., Gramann, J. H., Rudis, V. A., & Westphal, J. M. (1989). The psychological utility of visual penetration in near-view forest scenic-beauty models. *Environment and Behavior, 21*(4): 393-412.

Ruotolo, F., Maffei, L., Di Gabriele, M., Iachini, T., Masullo, M., Ruggiero, G. & Senese, V. (2013). Immersive virtual reality and environmental noise assessment: An innovative audio–visual approach. *Environmental Impact Assessment Review 41*: 10-20.

Schirpke, U., Tasser, E., & Tappeiner, U. (2013), Predicting scenic beauty of mountain regions. *Landscape and Urban Planning 111*: 1–12.

Schroeder, H. & Daniel, T. C. (1981). Progress in predicting the perceived scenic beauty of forest landscapes. *Forest Science 27*(1): 71-80.

Shafer, E. (1969). Perception of natural environment. *Environment and Behavior, 1*: 71-82.

Shafer, E. L. and Brush, R. O. (1977). How to measure preferences for photographs of natural landscapes. *Landscape Planning 4*(0): 237-256.

Shafer, E. L., Hamilton, J.F, & Schmidt, E.A. (1969). Natural landscape preferences: a predictive model. *J Leisure Res. 1*(1): 19.

Shang, H. & I. D. Bishop (2000). Visual thresholds for detection, recognition and visual impact in landscape settings. *Journal of Environmental Psychology 20*(2): 125-140.

Southworth, M (1969). The sonic environment of cities. *Environment and Behavior, 1*(1): 49-70.
Smardon, R. C., Palmer, J.F., & Felleman, J.P. (1986). *Foundations for Visual Project Analysis*. New York: Wiley.

Smith, E. L., Bishop, I. D., Williams, K. J. H., & Ford, R. M. (2012). Scenario chooser: An interactive approach to eliciting public landscape preferences. *Landscape and Urban Planning, 106*(3): 230-243

Steele, C. (2001). A critical review of some traffic noise prediction models. Applied Acoustics, 62(3): 271-287.

Steinitz, C. 1979. Simulating alternative policies for implementing the Massachusetts scenic and recreational rivers act: The North River demonstration project. *Landscape Planning, 6*(1): 51–89.

Steinitz, C. (1990). Toward a sustainable landscape with high visual preference and high ecological integrity: the loop road in Acadia National Park, U.S.A. *Landscape and Urban Planning 19*(3): 213-250.

Tempesta, T., Vecchiato, D., & Girardi, P. (2014). The landscape benefits of the burial of high voltage power lines-A study in rural areas of Italy. *Landscape and Urban Planning, 126*: 53-64.

Tomlin, C. D. (1983). *Digital cartographic modeling techniques in environmental planning,* Yale University.

Torres-Sibille, A., Cloquell-Ballester, V., loquell-Ballester, V., & Darton, R. (2009). Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms. *Renewable and Sustainable Energy Reviews, 13*(1): 40-66.

Travis, M. R., Elsner, G. H., Iverson, W. D., and Johnson, C. G. (1975). *VIEWIT: computation of seen areas, slope, and aspect for land-use planning,* Dept. of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Tveit, M. S. (2009). Indicators of visual scale as predictors of landscape preference; a comparison between groups. *Journal of Environmental Management, 90*(9): 2882–2888.

Tulen, J., Kumar, A. & Jurriens, A. (1986). Psychophysiological acoustics of indoor sound due to traffic noise during sleep. *J Sound Vib,110*(1):129–41.

U.S. Forest Service (1974). *National Forest Landscape Management: The Visual Management System, Vol. 2.* Washington, D.C.: U.S. Department of Agriculture.

U.S. Forest Service (1995). *Landscape Aesthetics: A handbook for Scenery Management*. Washington, D.C.: U.S. Department of Agriculture.

Viollon, S., Lavandier, C., & Drake, C. (2002). Influence of visual setting on sound ratings in an urban environment. *Applied Acoustics 63*(5): 493–511.

Watts, G., Chinn, L., & Godfrey, N. (1999). The effects of vegetation on the perception of traffic noise. *Applied Acoustics, 56*(1): 39–56.

Weinzimmer, D., Newman, P., Taff, D., Benfield, J., Lynch, E., & Bell, P. (2014). Human responses to simulated motorized noise in national parks. *Leisure Sciences: An Interdisciplinary Journal, 36*(3): 251-267.

Wherrett, J. R. (2000). Creating landscape preference models using internet survey techniques. *Landscape Research, 25*(1): 79-96.

Wilkinson, R., & Campbell, K. (1984). Effects of traffic noise on quality of sleep: assessment by EEG, subjective report, or performance the next day. *J Acoust Soc Am, 75*(2): 468–75.

Wissen, U., Schroth, O., Lange, E., & Schmid, W. A. (2008). Approaches to integrating indicators into 3D landscape visualisations and their benefits for participative planning situations. *Journal of Environmental Management, 89*(3): 184-196.

World Health Organisation (1999). Guidelines for community noise. World Health Organisation.

Wu, Y., Bishop, I. D., Hossain, H. & Sposito, V. (2006). Using GIS in Landscape Visual Quality Assessment. *Applied GIS 2*(3): 18-37.

Zube, E. H., & Pitt, D. G. (1981). Cross-cultural perceptions of scenic and heritage landscapes. *Landscape Planning, 8*(1): 69–87.

Zube, E. H. (1974). Cross-disciplinary and inter-mode agreement on the description and evaluation of landscape resources. *Environment and Behavior*, *6*: 69-89.

Appendices

Appendix 1. Distribution of the 120 images over the 100 questionnaires.

Questionnaire	The 24 images in the questionnaire (shown as Image No.)
questionnaire 1	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,117
questionnaire 2	2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,22,23,24,25,26,118
questionnaire 3	3,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,24,25,26,27,119
questionnaire 4	4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,25,26,27,28,120
questionnaire 5	5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,25,26,27,28,29
questionnaire 6	6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29
questionnaire 7	7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30
questionnaire 8	8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31
questionnaire 9	9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32
questionnaire 10	10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33
questionnaire 11	11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34
questionnaire 12	12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
questionnaire 13	13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
questionnaire 14	14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37
questionnaire 15	15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38
questionnaire 16	16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39
questionnaire 17	17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40
questionnaire 18	18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41
questionnaire 19	19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42
questionnaire 20	20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43
questionnaire 21	21,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48
questionnaire 22	22,26,,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,46,47,48,49,50
questionnaire 23	23,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,47,48,49,50,51
questionnaire 24	24,28, 30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,48,49,50,51,52
questionnaire 25	29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,49,50,51,52,53
questionnaire 26	30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53
questionnaire 27	31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54
questionnaire 28	32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55
questionnaire 29	33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56
questionnaire 30	34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57
questionnaire 31	35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58
questionnaire 32	36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59
questionnaire 33	37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60
questionnaire 34	38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61

questionnaire 35	39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62
questionnaire 36	40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63
questionnaire 37	41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64
questionnaire 38	42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65
questionnaire 39	43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66
questionnaire 40	44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67
questionnaire 41	45,49,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72
questionnaire 42	46,50,52, 53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,70,71,72,73,74
questionnaire 43	47,51,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,71,72,73,74,75
questionnaire 44	48,52,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,72,73,74,75,76
questionnaire 45	53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,73,74,75,76,77
questionnaire 46	54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77
questionnaire 47	55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78
questionnaire 48	56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79
questionnaire 49	57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80
questionnaire 50	58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81
questionnaire 51	59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82
questionnaire 52	60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83
questionnaire 53	61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84
questionnaire 54	62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85
questionnaire 55	63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86
questionnaire 56	64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,88
questionnaire 57	65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,88,89
questionnaire 58	66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,88,89,90
questionnaire 59	67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,88,89,90,91
questionnaire 60	68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,88,89,90,91,92
questionnaire 61	69,73,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96
questionnaire 62	70,74,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,94,95,96,97,98
questionnaire 63	71,75,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,95,96,97,98,99
questionnaire 64	72,76,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,96,97,98,99,100
questionnaire 65	77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,97,98,99,100,101
questionnaire 66	78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101
questionnaire 67	79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102
questionnaire 68	80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103
questionnaire 69	81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104
questionnaire 70	82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105
questionnaire 71	83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106
questionnaire 72	84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107
questionnaire 73	85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108

questionnaire 74	86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109
questionnaire 75	87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110
questionnaire 76	88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106, 107,108,109,110,111
questionnaire 77	89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106, 107,108,109,110,111,112
questionnaire 78	90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106, 107,108,109,110,111,112,113
questionnaire 79	91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106, 107,108,109,110,111,112,113,114
questionnaire 80	92,93,94,95,96,97,98,99,100,101,102,103,104,105,106, 107,108,109,110,111,112,113,114,115
questionnaire 81	93,97,99,100,101,102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120
questionnaire 82	94,98,100,101,102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,118,119,120,1,2
questionnaire 83	95,99,101,102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,119,120,1,2,3
questionnaire 84	96,100,102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,120,1,2,3,4
questionnaire 85	101,102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,1,2,3,4,5
questionnaire 86	102,103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5
questionnaire 87	103,104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6
questionnaire 88	104,105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7
questionnaire 89	105,106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8
questionnaire 90	106, 107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9
questionnaire 91	107,108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10
questionnaire 92	108,109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11
questionnaire 93	109,110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12
questionnaire 94	110,111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13
questionnaire 95	111,112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14
questionnaire 96	112,113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
questionnaire 97	113,114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
questionnaire 98	114,115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17
questionnaire 99	115,116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18
questionnaire 100	116,117,118,119,120,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19

Appendix 2. Pilot online survey comparing visual analogue scale with paired comparison as rating approaches for image assessment.

A pilot online survey was carried out to compare visual analogue scale with paired comparison as rating approaches for image assessment. The survey used a similar template as that used for the main online survey described in Chapter 3, except that two types of questionnaires were employed in the image assessment part: one used visual analogue scale for rating, the same as that in the main survey, and the other used paired comparison where one image was shown on top of another in each pair (positions were randomised in each survey session) and participants were asked to choose “which scene is more visually pleasant”. Upon the start of the image assessment part, participants were randomly directed to one of the questionnaires.

Thirteen images, divided into three sets, were assessed in the survey (Figure. 9.1). Images in Set 1 differed in characteristics of the road project; images in Set 2 differed in character of the background landscape; and images in Set 3 differed in distance to the road and content of vehicles. The order of set and order of image within each set were randomised in each survey session. In the paired comparison questionnaire, images were paired up only with images within the same set. So there were ten pairs in Set 1, and six pairs in Set 2 and six pairs in Set 3.

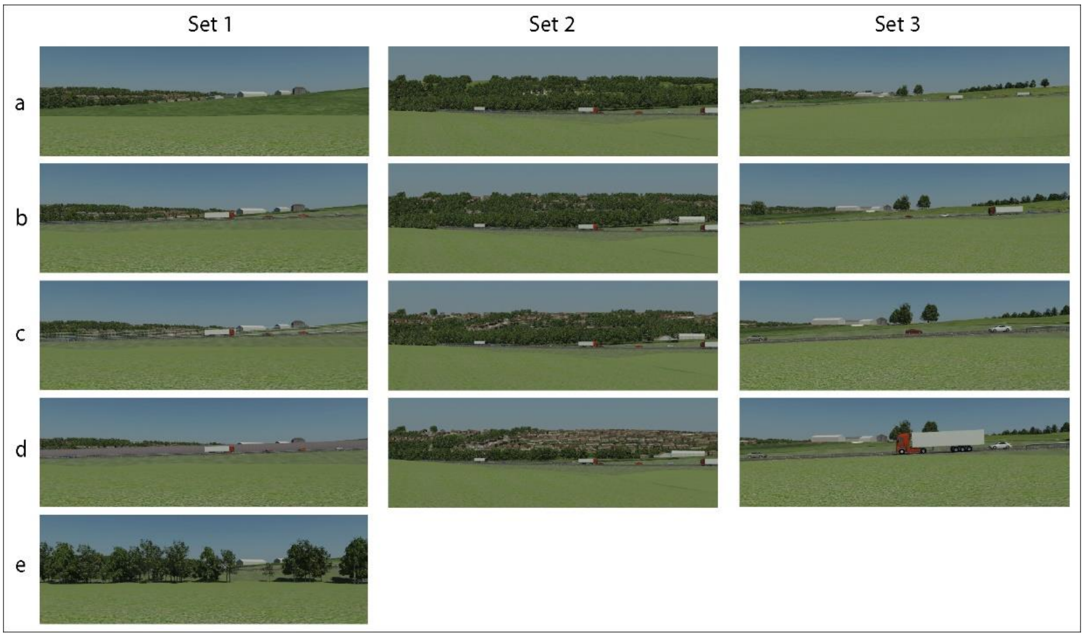

Figure. 9.1. Images used in the pilot online survey.

The survey was broadcasted within the university by email. 56 completed responses were received, 25 for visual analogue scale and 31 for paired comparison. Table 9.1 show the results of paired comparison and Figure. 9.2 compares the results of the two rating approaches. It shows that the two rating approaches obtained highly congruent preferences of participants to the images, especially regarding images differed in characteristics of the road project and distance to the road.

Table 9.1. Results of paired comparison. Total score is the sum of the values of Percentage of selection.

Image	Percentage of selection (%)					Total score
	Set 1-a	Set 1-b	Set 1-c	Set 1-d	Set 1-e	
Set 1-a	-	71	100	90.3	48.4	309.7
Set 1-b	29	-	90.3	100	12.9	232.2
Set 1-c	0	9.7	-	16.1	0	25.8
Set 1-d	9.7	0	83.9	-	6.4	100
Set 1-e	51.6	87.1	100	93.6	-	332.3
	Set 2-a	**Set 2-b**	**Set 2-c**	**Set 2-d**		
Set 2-a	-	9.7	12.9	0		22.6
Set 2-b	90.3	-	35.5	12.9		138.7
Set 2-c	87.1	64.5	-	22.6		174.2
Set 2-d	100	87.1	77.4	-		264.5
	Set 3-a	**Set 3-b**	**Set 3-c**	**Set 3-d**		
Set 3-a	-	67.7	64.5	93.6		36.3
Set 3-b	32.3	-	61.3	93.6		33.4
Set 3-c	35.5	38.7	-	93.6		25.5
Set 3-d	6.4	6.4	6.4	-		18.9

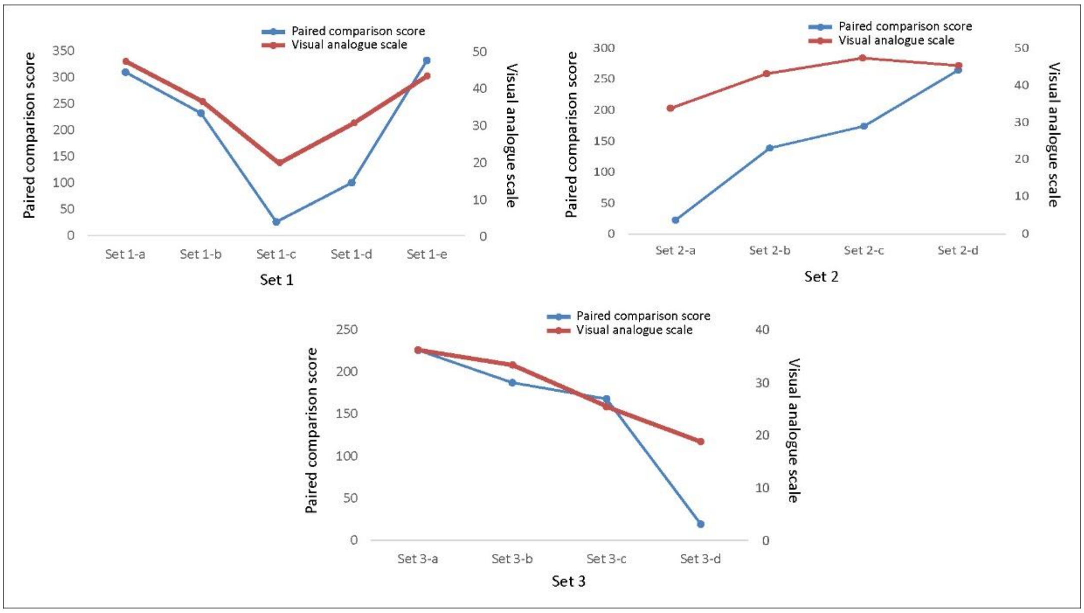

Figure. 9.2. Results comparison between Paired comparison and Visual analogue scale.

Appendix 3. Questionnaire for Lab Experiment 1.

Please rate the visual pleasantness of each scene by marking a X on the scale bar.

For example: low pleasantness ———————— high pleasantness

*For the purpose of this research, visual pleasantness here can be understood as the visual landscape quality, scenic quality, or something similar. Scenes of high visual pleasantness should be enjoyable to view, while those of low visual pleasantness make people feel visually uncomfortable. There are no clear criteria for the rating, you can draw upon whatever value judgements you deemed necessary or simply your instinct when making the assessment.

SCENE 1 low pleasantness ———————— high pleasantness

SCENE 2 low pleasantness ———————— high pleasantness

SCENE 3 low pleasantness ———————— high pleasantness

SCENE 4 low pleasantness ———————— high pleasantness

.

.

.

SCENE 59 low pleasantness ———————— high pleasantness

SCENE 60 low pleasantness ———————— high pleasantness

Appendix 4. Questionnaire for Lab Experiment 2.

You will watch 42 short videos. Each video is 20 seconds long.

Please rate the overall pleasantness (visual pleasantness and sound pleasantness) of the scene shown in each video, by marking a X on the scale bar.

For example:	low pleasantness	———————X———————	high pleasantness

---

SCENE 1	low pleasantness	______________________	high pleasantness
SCENE 2	low pleasantness	______________________	high pleasantness
SCENE 3	low pleasantness	______________________	high pleasantness
SCENE 4	low pleasantness	______________________	high pleasantness
		. . .	
SCENE 41	low pleasantness	______________________	high pleasantness
SCENE 42	low pleasantness	______________________	high pleasantne

Appendix 5. Questionnaire for Lab Experiment 3.

You will watch 44 short videos. Each video is 20 seconds long.

Please rate the overall pleasantness (visual pleasantness and sound pleasantness) of the scene shown in each video, by marking a ╳ on the scale bar.

For example: low pleasantness ———————╳——————— high pleasantness

---

SCENE 1 low pleasantness ______________________ high pleasantness

SCENE 2 low pleasantness ______________________ high pleasantness

SCENE 3 low pleasantness ______________________ high pleasantness

SCENE 4 low pleasantness ______________________ high pleasantness

.

.

.

SCENE 43 low pleasantness ______________________ high pleasantness

SCENE 44 low pleasantness ______________________ high pleasantne

Please do the ratings below based on your own preference or knowledge, regardless of what you have seen or heard in the earlier video session.

Please rate the aesthetic quality of these barriers

Barrier 1	low aesthetic quality	______________________________	high aesthetic quality
Barrier 2	low aesthetic quality	______________________________	high aesthetic quality
Barrier 3	low aesthetic quality	______________________________	high aesthetic quality

How effective do you think these barriers are at reducing noise? Please rate.

Barrier 1	low effectiveness	______________________________	high effectiveness
Barrier 2	low effectiveness	______________________________	high effectiveness
Barrier 3	low effectiveness	______________________________	high effectiveness

Appendix 6. Enlarged images showing the contents of figures 3.3, 4.1, 5.1 and 6.1.

Figure 10.1. Enlarged images showing content of Figure 3.3, part A.

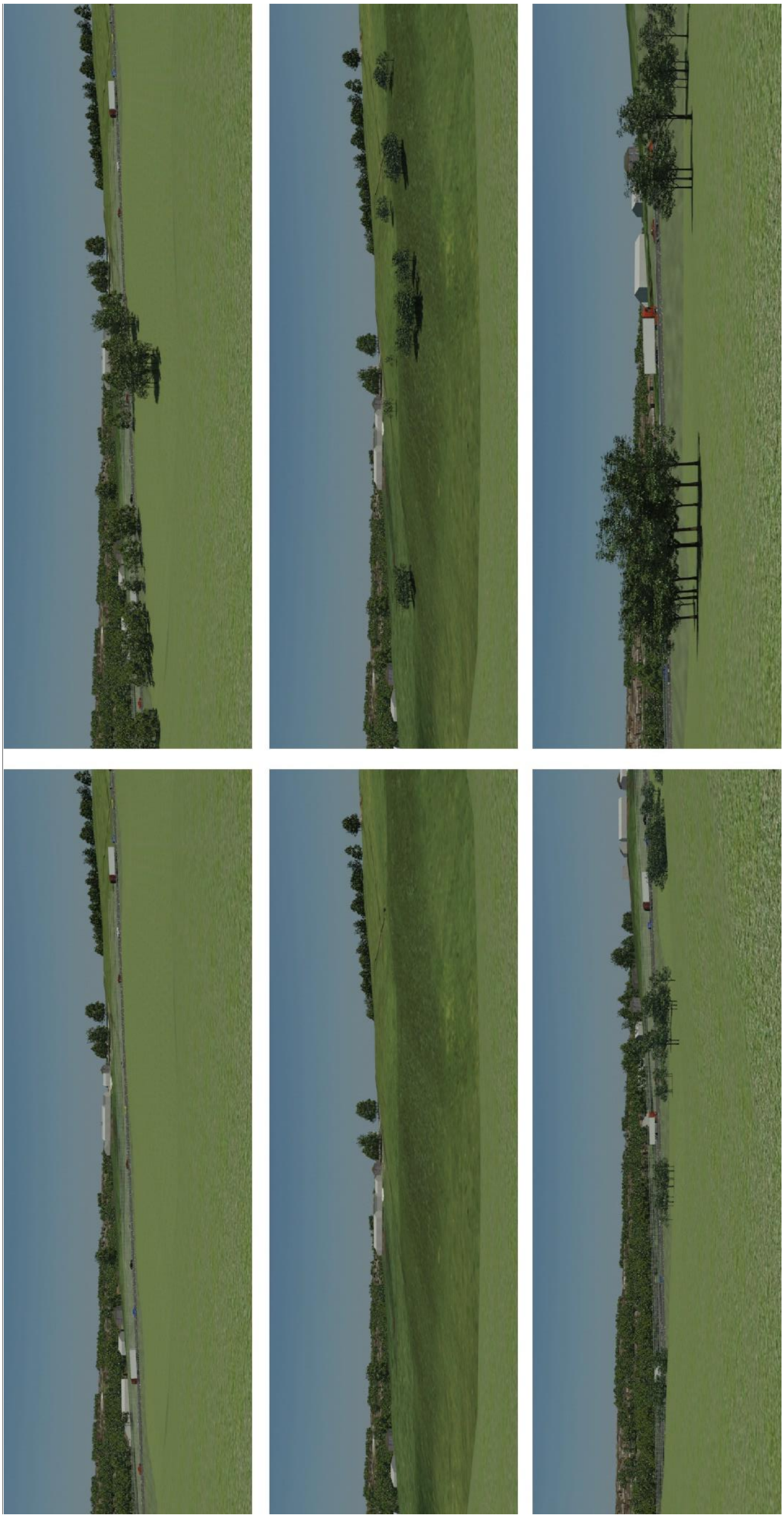

Figure 10.2. Enlarged images showing content of Figure 3.3, part B.

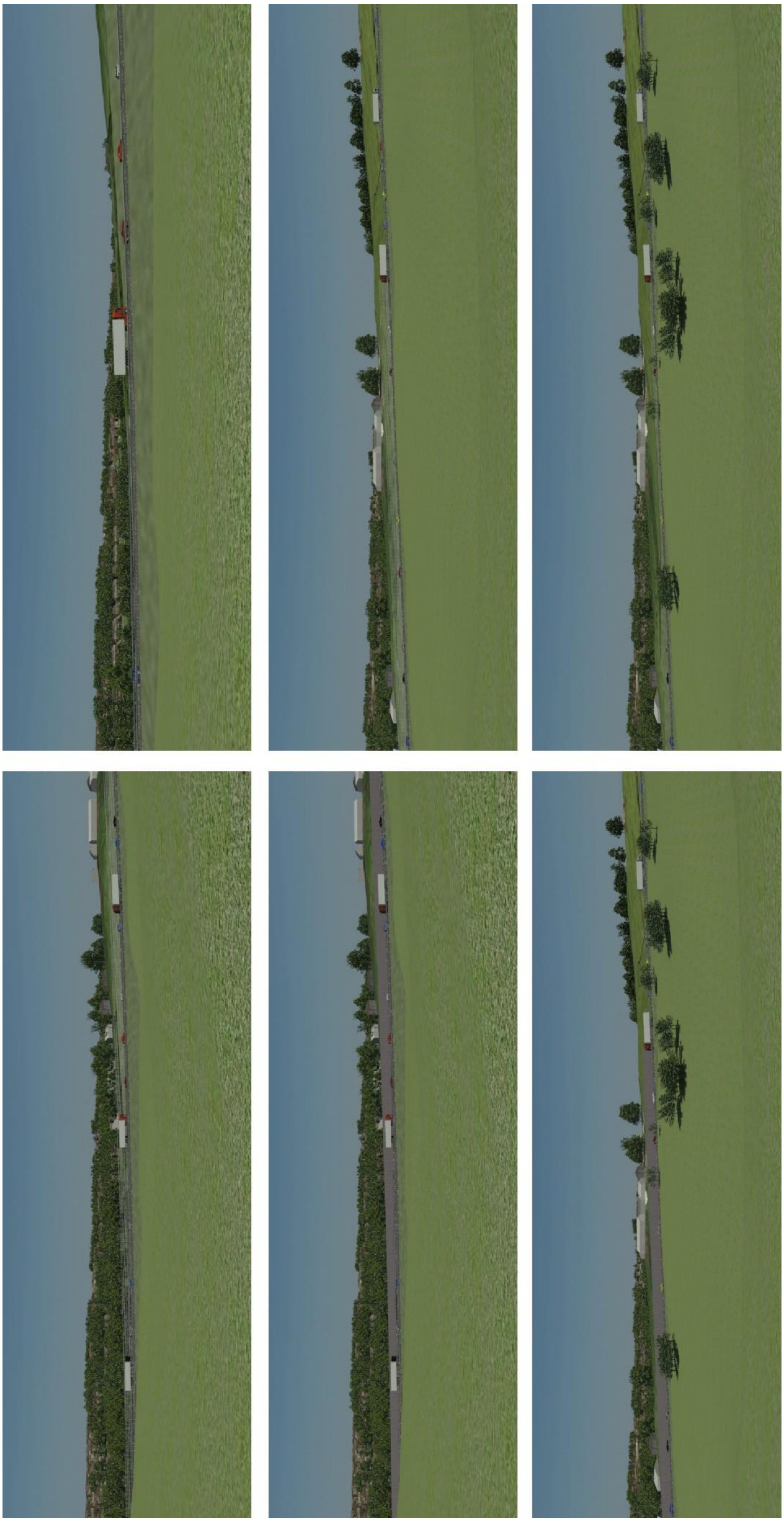

Figure 10.3. Enlarged images showing content of Figure 3.3, part C.

Figure 10.4. Enlarged images showing content of Figure 3.3, part D.

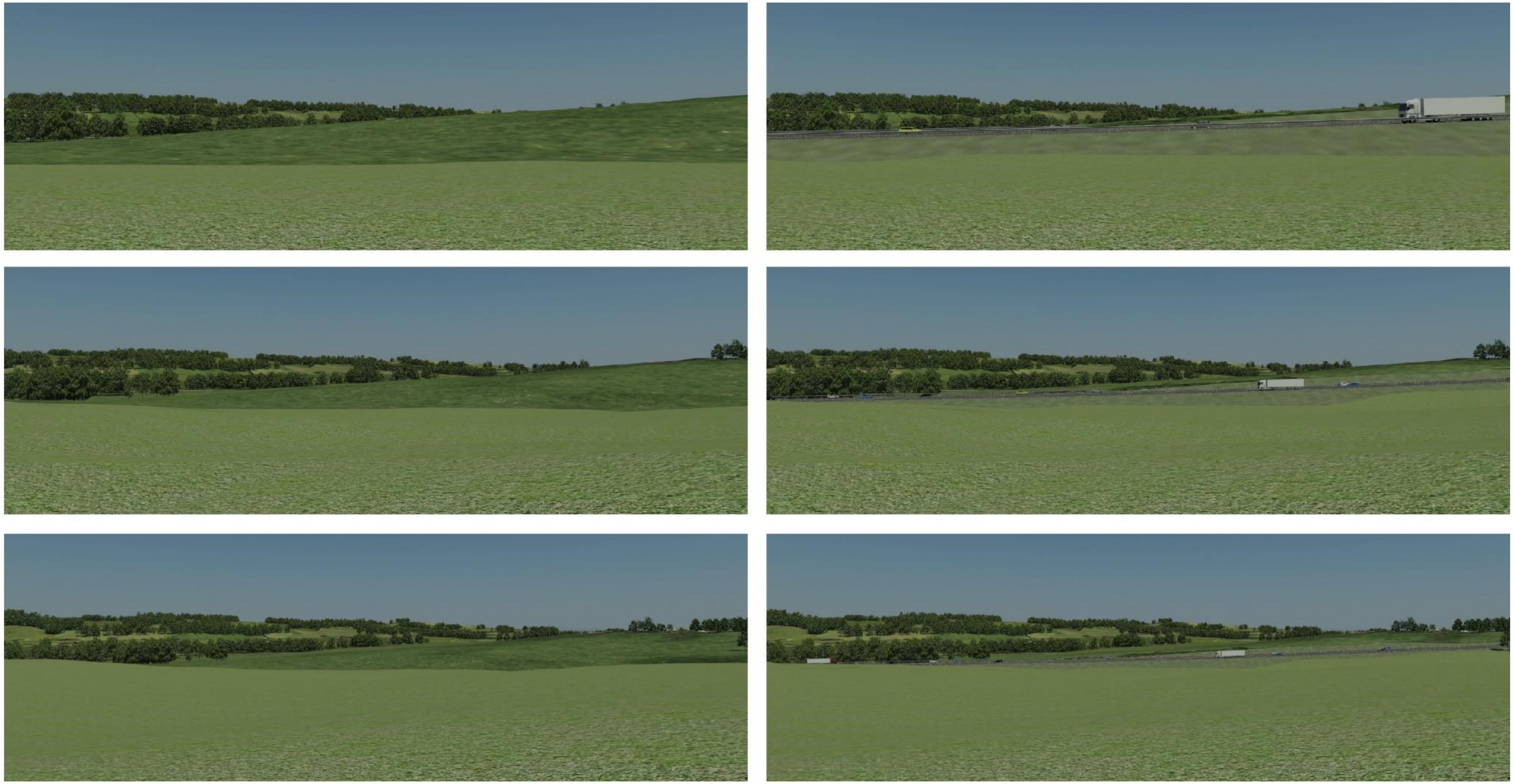

Figure 10.5. Enlarged images showing content of Figure 4.1 and Figure 5.1, scenarios with natural background landscape.

Figure 10.6. Enlarged images showing content of Figure 4.1 and Figure 5.1, scenarios with residential background landscape.

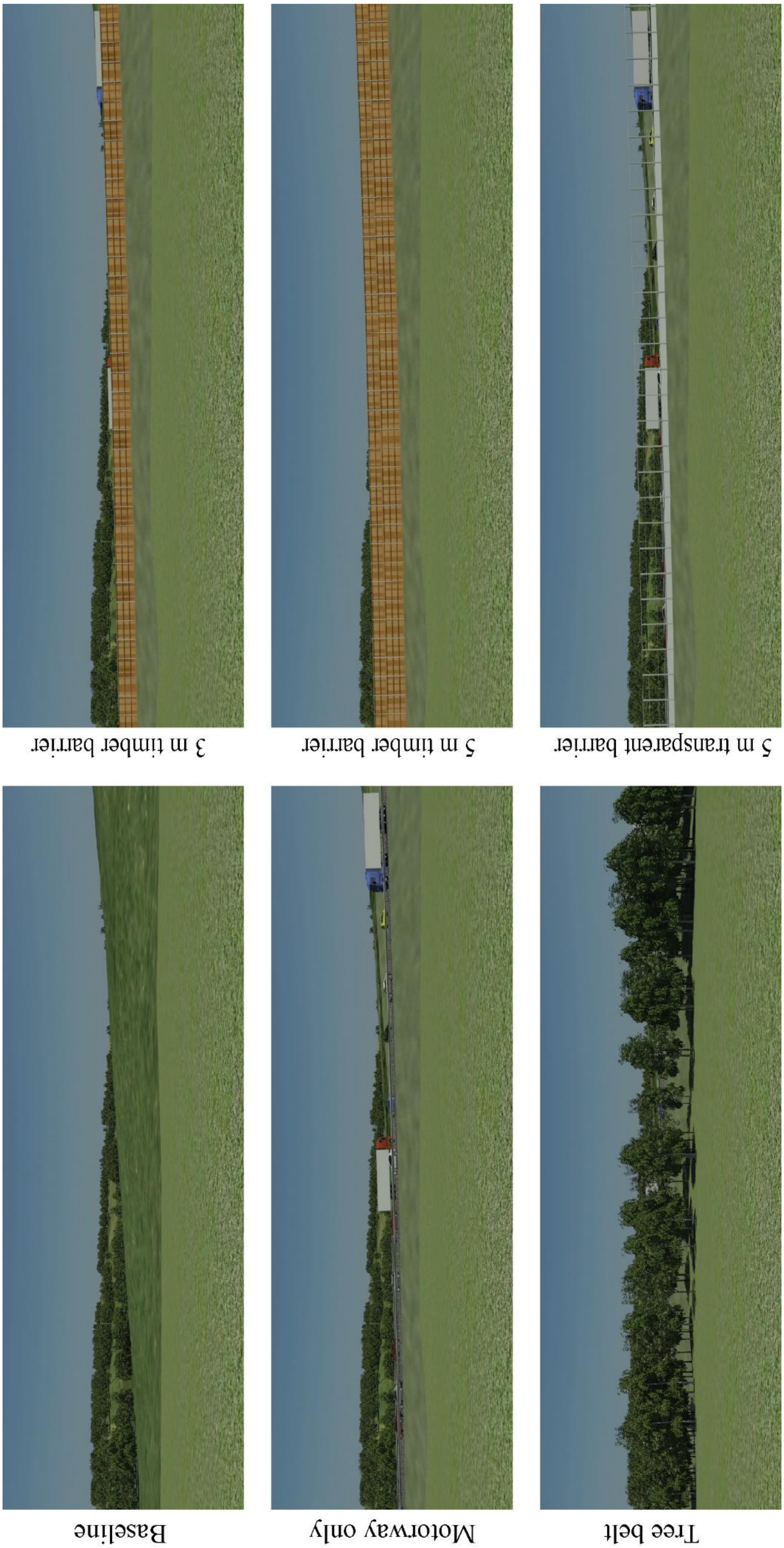

Figure 10.7. Enlarged images showing content of Figure 6.1, scenarios with natural background landscape from 100 m distance.

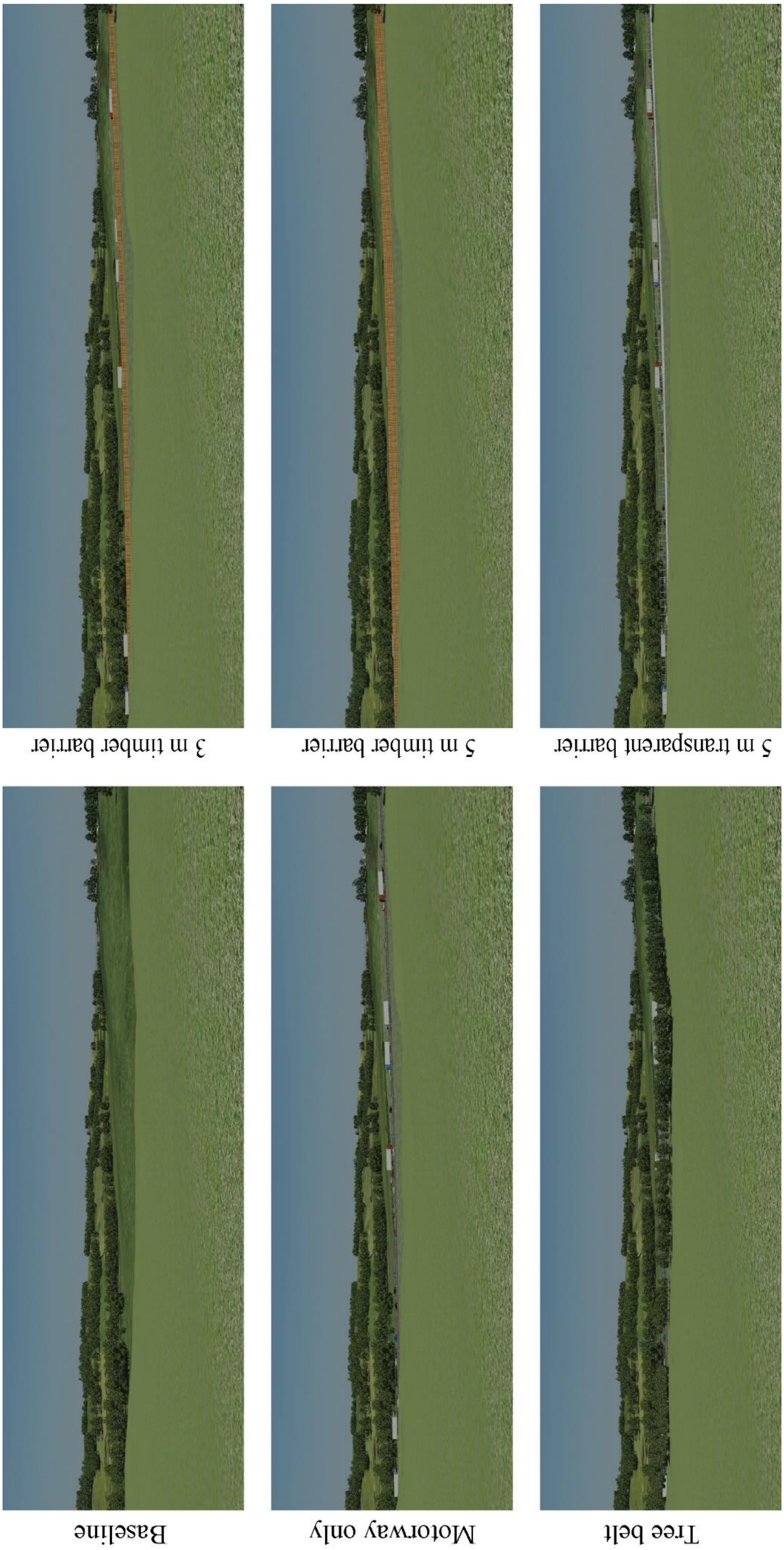

Figure 10.8. Enlarged images showing content of Figure 6.1, scenarios with natural background landscape from 300 m distance.

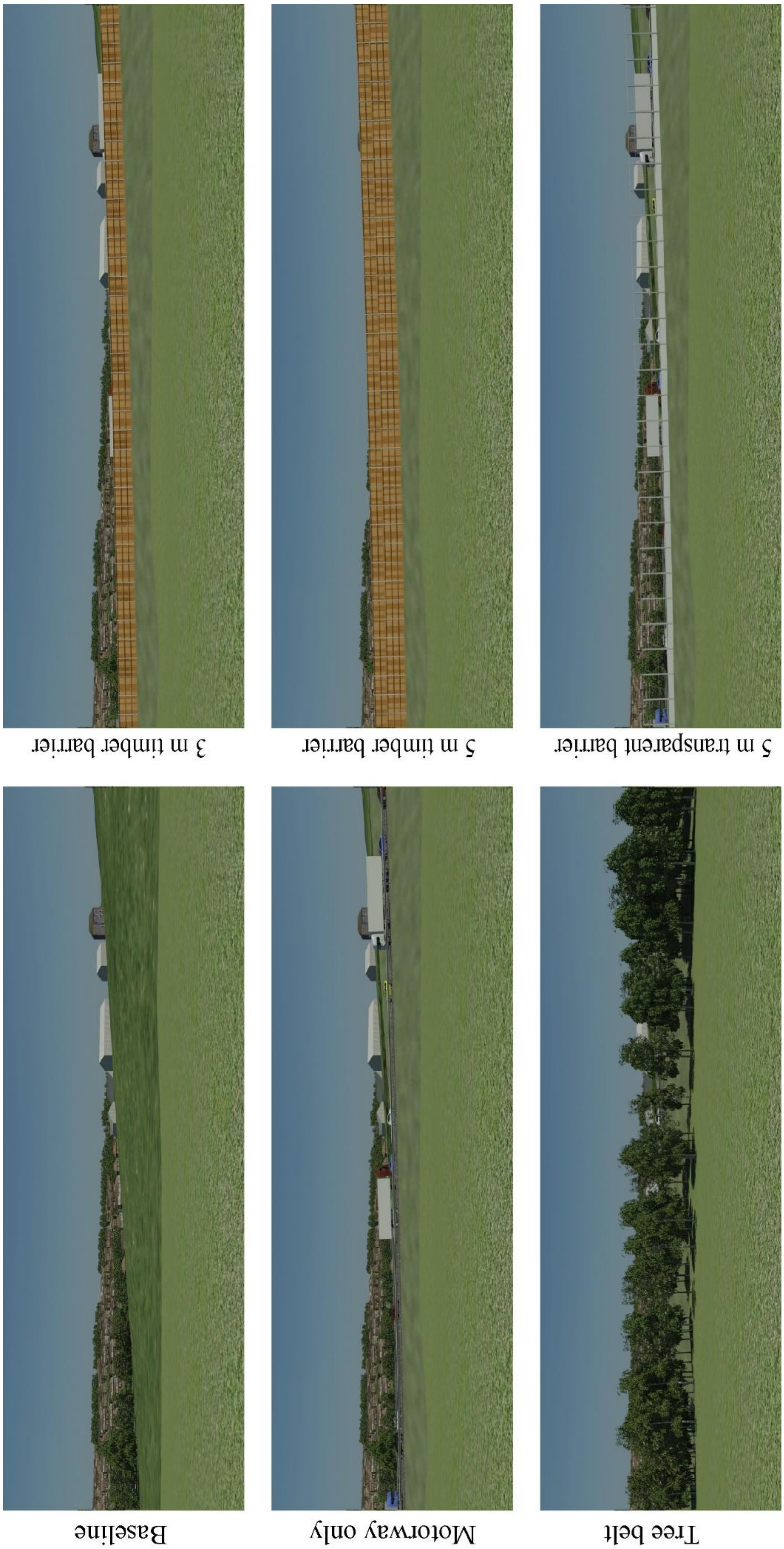

Figure 10.9. Enlarged images showing content of Figure 6.1, scenarios with residential background landscape from 100 m distance.

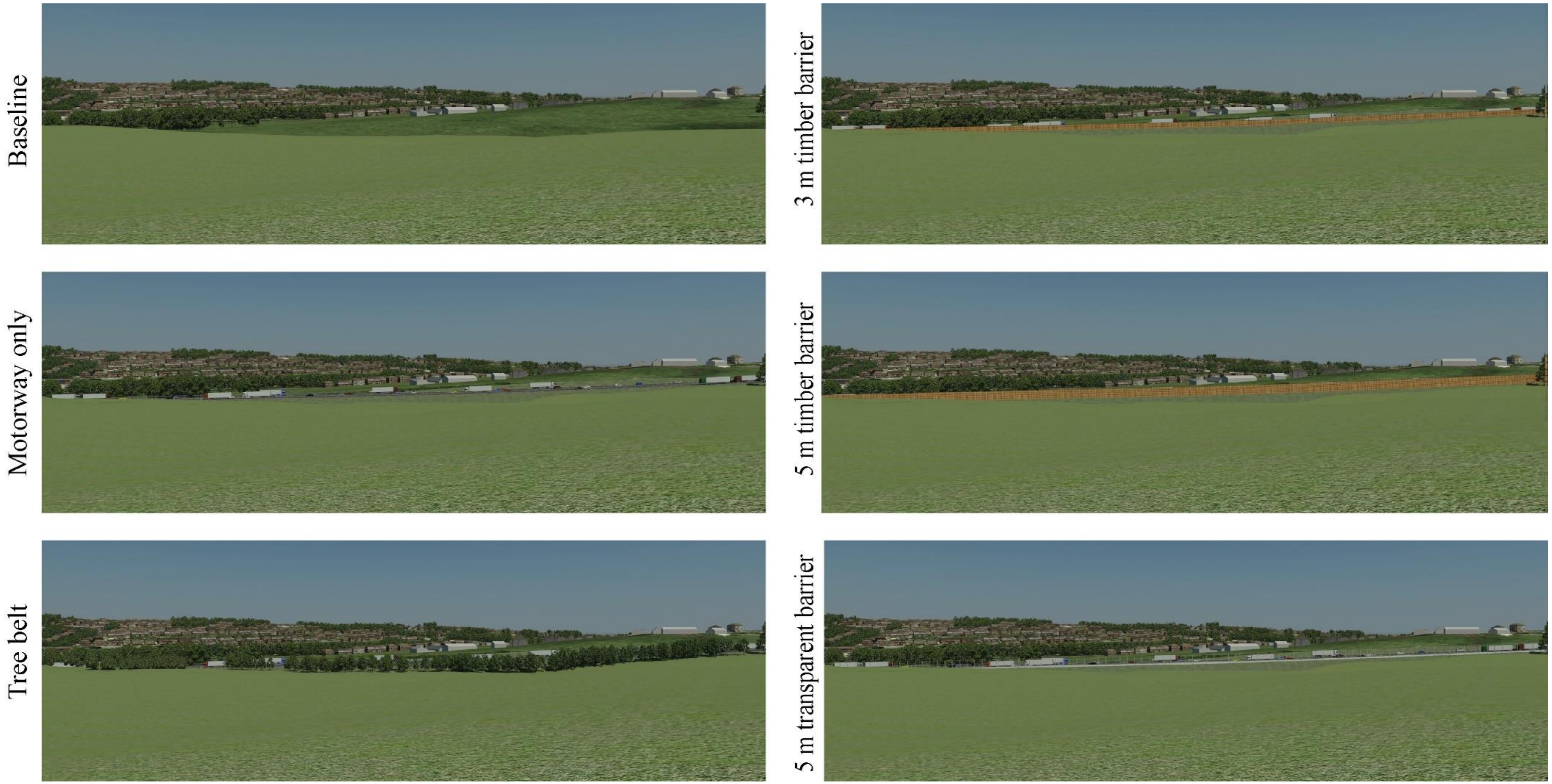

Figure 10.10. Enlarged images showing content of Figure 6.1, scenarios with residential background landscape from 300 m