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Prediction of the visual impact of motorways using GIS

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ABSTRACT

Large scale transportation projects can adversely affect the visual perception of environmental quality and require adequate visual impact assessment. In this study, we investigated the effects of the characteristics of the road project and the character of the existing landscape on the perceived visual impact of motorways, and developed a GIS-based prediction model based on the findings. An online 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. The result shows that presence of a motorway especially with the timber barrier significantly decreases the visual quality of the view. The resulted visual impact tends to be lower where it is less visually pleasant with more buildings in the view, and can be slightly reduced by the visual absorption effect of the scattered trees between the motorway and the viewpoint. Based on the survey result, eleven 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. The proposed prediction model can be used to achieve efficient and reliable assessment of visual impact of motorways.

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1. Introduction

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 obtainment 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 has drawn on perception-based approach to obtain more precise and reliable judgement (e.g., Anderson and Schroeder, 1983; Bishop and Miller, 2007; Buhyoff and Leuschner, 1978; Louise, 1977; Schroeder and 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 and 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 and Schroeder, 1983; Daniel and 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 have been made in the 1970s. Based on visual judgement made by respondents on site, Hopkinson and 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

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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 and 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 and 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 and 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 study 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 study, 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 at the stage of this study. 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 study 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; and (3) predict the perceived visual impact using the derived model in GIS.

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.

2.1. Visualisation

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 and Hoffman, 2001), in terms of scenario creation and variable control (Bishop and 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 have been examined by research studies (e.g., Appleton and Lovett, 2003; Bishop and 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 and 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 and Hehl-Lange, 2005; Lange et al., 2008; Wissen et al., 2008; Smith et al., 2012).

2.1.2. Base site modelling

A segment of the M1 motorway near Ecclesfield (Sheffield), UK was chosen as the base site for visualisation, covering an area of 2500 m × 2500 m (Fig. 1). It was not intended to study the visual impact of the specific motorway on the specific site, rather, it was just 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) were used for modelling. Detailed information can be found in Fig. 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, and 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 12 m in height and 8 m in diameter, a few shorter trees were set 6 m in height and 4 m in diameter. A random 50%–150% variation in scale was applied to all the trees. Most of the buildings on the site are 2-storey semi-detached houses and the height was set as 8 m. 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 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.

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