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GIS in road environmental planning and management

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Abstract

The urban growth of the last few decades has resulted in increasing demands for infrastructure in urban sites. Access to and quality of road transport systems is often considered an index of industrial and social development. The construction of new roads may ease congestion and reduce travel time, but it is also a host of environmental impacts. It is increasingly recognised that it is necessary to develop and upgrade transport systems so that the physical, social and environmental impacts are minimised. The development of Environmental Impact Assessment (EIA) tools and methodologies is critical to ensuring that all potentially adverse impacts are identified and assessed, and are given consideration in the decision-making process. One tool that has considerable potential for supporting road EIA and ultimately planning is the Geographical Information System (GIS). The same tool is also employed to account for uncertainties in the EIA process. More specifically GIS is used to investigate how different traffic volumes will influence noise levels using a case study.

1 Introduction

Roads often bring significant economic and social benefits, but they can also have substantial negative impacts on communities and the natural environment. As the public becomes more aware of the adverse repercussions and legislation on a national and international level becomes tighter, there is a growing demand for the techniques and skills needed to incorporate environmental considerations into road planning and management. It is perceived that Environmental Impact Assessment (EIA) is an excellent preventive planning tool, provided that it is implemented early in the project development process.

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EIA aims to assess the potential impacts of a proposed project on the environment in advance with potential to improve decision-making [4]. One tool that has considerable potential for supporting road EIA is the Geographical Information System (GIS). GISs are computer systems used for storing, retrieving, analysing and displaying spatial data. Considering the spatial nature of many environmental impacts, GIS provide a useful platform for the EIA process as they can account for the fact that many impacts are functionally related to the distance of a location from a project.

They can be employed to provide information concerning the sensitivity of the existing environment; identify direct impacts such as the passage of a proposed road through a site of archaeological importance; incorporate sophisticated models to enable the prediction of indirect impacts such as the spread of air pollution; perform spatial analysis and modelling; and contribute to the reduction of risks and uncertainties involved in the process. The way that GIS can contribute to different EIA stages is illustrated in the following section.

2 The EIA Process and the GIS contribution

Road planning involves several different stages starting with the need for the development stage, feasibility, engineering design, construction and operation and maintenance. On the other hand, the most important stages of the EIA process are:

- Before the preparation of the Environmental Statement (ES), (initial stages)
- During the preparation of the ES;
- Mitigation of impacts and public participation; and
- After the preparation of the ES (post development).

The Environmental Statement (ES) is the legal documentation, which includes all the information pertinent to the proposed project, together with the actual assessment of impacts. It is important therefore to synchronise environmental studies with the project development process to minimise environmental impacts. Ideally therefore an EIA should be considered and provided for from the outset in the budget of all road projects. The potential contribution of GIS to the different EIA stages is investigated in the following.

2.1 Initial stages

At the preliminary stages of the EIA process, GISs can assist in positioning the proposed road into a geographical context, describe the project's surrounding environment and topography (Figure 1). During screening, GIS, due to its mapping and data gathering capabilities, can precisely identify the geographic context and ensure that the project requires an EIA (e.g. identify whether a proposed project requires an EIA due to its proximity to a sensitive land-use, such as an ancient woodland). Since projects, which need an EIA, are often

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defined by reference to their proximity to certain features or other spatial consideration, this will enable projects that do not require a full EIA to be screened out. GISs could also speed up the scoping process by the creation of databases of local information. The databases will be constantly up-dated by consultees on different areas such as ecology, archaeology, noise, and air quality. Subsequently, the risk of neglecting a number of pertinent environmental factors that might be impacted by the proposed development is minimised.

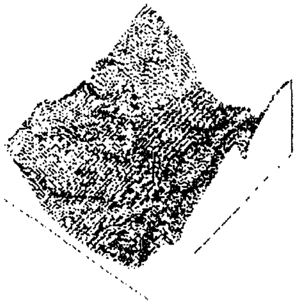

Figure 1: Digital Elevation Map (DEM) for the area also illustrated in Figure 3, and 3-Dimensional orthographic perspective DEM of the study area

2.2 Preparation of the ES

During the preparation of the ES, typical GISs operations such as overlay analysis can beneficially contribute to the identification of impacts. For example, if the air pollution map is overlaid with the residential land-use map, possible adverse impacts can be investigated. Typical operations such as overlaying are much more powerful, accurate and flexible in a GIS and there are no restrictions on the number of layers used. New maps are automatically produced and different computations can easily and quickly be made, increasing both the quality of presentation and accuracy of data. Combinations of GISs modelling tools with existing process models enable the rapid and objective prediction of impacts. Using a GIS, alternatives including the 'do-nothing' option can be compared. Sensitivity analysis can be carried out rapidly and different assumptions can be checked on whether and how they could alter decision-making.

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2.3 Mitigation and public participation

GIS as a tool for modelling and spatial illustration of impacts could further be used to indicate locations that should be preferred or avoided. In cases where the only effective mitigation measure is to abandon the project altogether, GISs could be used to rapidly evaluate other alternatives. Furthermore, interactive analysis of GISs along with the necessary tools such as on-screen digitising allows for the computerised design of potential mitigation measures. Conversely, if CAD packages are employed, then results imported to a GIS will enable the revision of different designs. In terms of public participation, GISs, due to their visual display capabilities can assist in the better illustration of a proposed development to the public. If combined with multi-media and visual technologies, their visualisation and presentation capabilities could further be enhanced. In this respect, misinformation about the proposed development can be prevented.

2.4 Post ES

For the post-development stages, GIS can serve as a database for processing and storing monitoring data. It enables the comparison of the actual outcomes with the outcomes that had been predicted and illustrates the changing values of impacts with time contributing to environmental management and sustainability (Figure 2).

Year	1997	2005	2010	2015
Predicted Noise Levels	X1	X2	X3	X4
Actual Noise Levels	Y1	Y2	Y3	Y4
Compare	i.e. If X-Y <0 then go back to models, more mitigation, check thresholds			

Figure 2: Noise Impact Map for a proposed route for a residential area – GIS Database for monitoring and auditing predictions with actual impacts

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3 Accounting for uncertainty

The straightforward use of GIS in EIA is not novel and represents an obvious application of developing technology to EIA. The authors are currently engaged on research into an aspect of the application of GIS, which has hitherto received scant attention, namely the GIS's ability to account for uncertainties.

There are many aspects of uncertainty associated with the EIA process. The following classification may be used:

- Uncertainty about what the environment is. For example:
  - the impact of a project on species A cannot be assessed with accuracy unless there is accurate information about the population, status and distribution of A in the environment under consideration
  - the impact of a project on the hydrogeological regime in an environment unless an accurate assessment of the current regime is available
- Models used to compute physical impacts have limitations. For example:
  - empirically derived models are not applicable to all conditions
  - theoretically constructed models depend on assumptions which may not be valid in the given conditions
  - interactions between impacts may not be fully modelled; for example, the physical location of a project may cause fauna to move its location. The impact of pollutants on that fauna needs to take into account the revised location rather than the original location.
- Models to compute ecological impacts are very sensitive to the actual conditions in place at any time and one cannot place high confidence on the results of simulations. For example:
  - noise transmission depends upon ground cover (which may vary over time) and atmospheric directions (which obviously change over short time scales)
  - subsurface transmission of pollutants depends on groundwater conditions, which will vary over time

Uncertainties consequently will affect the accuracy of predictions and ultimately the decisions taken. GIS offers a platform from which issues of probability and confidence in predictions can be addressed. Ranges may be attached to predictions reflecting the degree of confidence in the solution and different weighting combinations can be incorporated to identify areas that show greater sensitivity or potential for development. GISs can be used to generate sensitivity data and hence prioritise data collection; if, for instance, the relationship between parameter A and parameter B is such that whatever the changes in A there is little change in B, then no further information may be needed. However, where the effect is much more variable, there may be a need for further information.

Furthermore, the physical and socio-economic environments evolve over time and space. As such the standard approach to EIA based on data collected at a specific time and place, can often be out-of-date before the planning or

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development are completed. Such changes in time and space can be modelled in the GIS environment to allow spatial and time predictions of environmental interactions. Thus, plans could be made for how to handle present and future needs promoting therefore the ultimate goal of sustainability. Clearly the best check on the accuracy of predictions is to check on the outcomes of the implementation of a project after the decision which concerns the stages of monitoring and auditing. Conversely, the monitoring of outcomes of similar projects may provide useful information for the project in hand. Eliminating uncertainties in the EIA process is almost impossible but GIS can certainly assist in reducing them.

4 Using GIS as an analysis/sensitivity tool

The use of mathematical models for impact prediction is relatively commonplace. One of the major difficulties when assessing environmental impacts is the accuracy of input parameters. GIS provides an effective basis for an integrated sensitivity input parameter analysis tool. In the following, it will be examined how one of the most important factors in any road EIA, the traffic volume, can affect different noise predictions. Although the specific factor can influence a number of other parameters (such as air quality), the present paper will investigate only noise levels.

Application is illustrated using the A69 Sunderland to Carlisle trunk road Haltwhistle Bypass, UK as a case study [2]. The principal function of the bypass was to relieve traffic using the A69 through Haltwhistle. The road has now been constructed and was opened to the public in 1997. Several alternatives were considered before the final decision was made. The GIS selected as, the development platform, was 'IDRISI' [1].

Figure 3 illustrates some of the land-uses. The existing route (A69), the actually constructed bypass (Green) and one of the alternatives considered are superimposed. An area of 3.25 km × 2.71 km was considered following the area studied in the Environmental Statement. Each block (pixel) corresponds to a 20 m x 20 m area of land.

The assessment of **Road Noise** is based upon the Manual for the Calculation of Road Traffic Noise [3]. The analysis was simplified to consider a single segment only with the basic noise level being derived solely from the estimated traffic flow. The attenuation of noise is a function of distance from the road. No account is taken of screening. One further simplification that should be considered is that the road under consideration is assumed to be the only source of road noise in the area. Minor roads and side-roads are neglected.

A simplified **Road Noise Impact Model** was therefore developed which was subsequently implemented into the GIS IDRISI (for a more analytical description of the model development see [5]). The application of the model produced impact maps illustrating how the different alternatives including the do-nothing scenario would affect different areas. The focus of the present study is the residential area.

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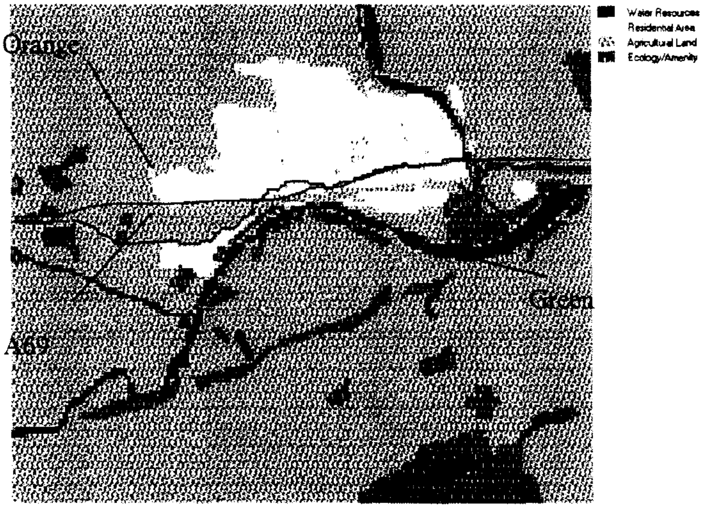

Figure 3: Land-use map for Haltwhistle

Figure 4 compares the three routes in terms of the percentage of the residential area falling within specified noise ranges. The Green route, which represents a bypass for Haltwhistle, is likely to result in reduced noise levels when compared with the A69 and the orange route. That is because the Green route is positioned to the south of the residential area, whereas the other two routes go through the residential area. These predictions are in broad agreement with the findings of the published Environmental Statement. It should be noted however that the model used was rather simplified and many effects which were given full consideration in the ES were not accounted for here. However, it is entirely feasible to implement every stage of the road noise calculation procedure [3].

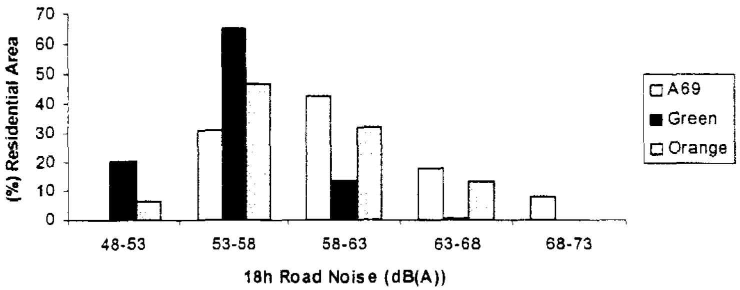

Figure 4: Comparison between road noise impacts for the A69 and the two alternative routes

The comparisons in Figure 4 were based on the predictions of traffic flows presented in the ES. The Road Noise Impact Model was further used to investigate how different traffic flows could make a route less or more

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favourable. Sensitivity analysis was undertaken to investigate how the noise levels would fluctuate in accordance with different traffic values. In this case, the traffic flow initially predicted was altered in the range of ±75% in 25% intervals. Some of the results are illustrated in Fig. 5-6.

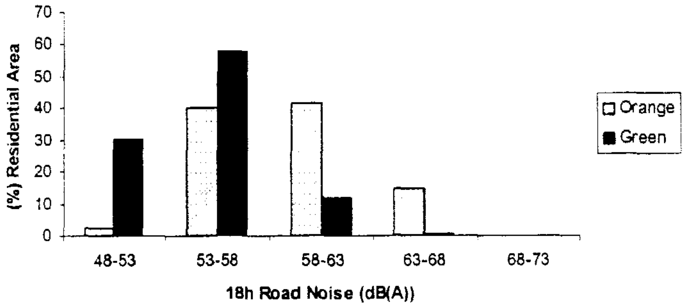

Figure 5: Comparison between road noise impacts for the two alternatives assuming an increase of 25% in traffic flows.

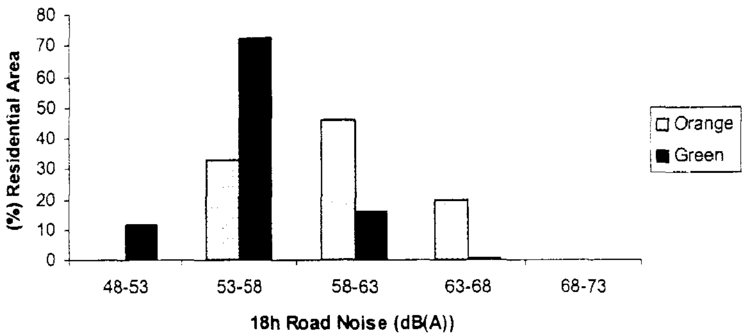

Figure 6: Comparison between road noise impacts for the two alternatives assuming an increase of 50% in traffic flows.

It could be said that the increased noise levels were expected. However what makes GIS a particularly useful tool at this stage is the speed and accuracy with which it enables such calculations for many different combinations. It can also increase the level of presentation since it can illustrate in a clear manner differences in predictions.

In Figure 7 the residential are of Haltwhistle has been extracted, and the predicted noise levels for the green route have been subtracted from the orange route noise levels assuming there is a 50% increase in the traffic flows originally predicted. As anticipated, most of the area would experience a substantial reduction in road noise levels (typically 0 – 6 dB(A)) with the green route, which is positioned further to the south than the orange route.

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In the immediate vicinity of the orange route reductions are even more substantial (6 – 18 dB(A)).

Figure 7: Difference between road noise levels for the residential area of Haltwhistle for the green and orange routes if traffic flows increase 50% from the original predictions

The development of a more rigorous and automated sensitivity GIS tool which will employ a set of deterministic and simulation methods, depending on the parameter examined, to investigate different input parameter combinations and how they can affect decisions seems to have a lot of potential. Such a tool would certainly be advantageous at the preliminary stages of planning where different scenarios are examined and could suggest areas that show potential or should be avoided.

5 Conclusions

Urban growth has resulted in considerable development in the area of urban transport. This development in turn has resulted in significant degradation of the environment. Environmental Impact Assessment is now a well-known process that focuses on the effects of projects on the environment and naturally, planning and management move to more strategic approaches to satisfy the goals of sustainable development. One tool that has considerable potential for supporting road planning and management through the EIA process is the GIS since it recognises the spatial variability of impacts. Despite the well-acknowledged

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capabilities of GIS for EIA, it seems that it is better known as a tool for map and report preparation, rather than data modelling and analysis.

The research presented in this paper has demonstrated that GISs can serve as a platform for data modelling and analysis but also as a tool for uncertainty calculations. In particular GIS was employed to investigate how different traffic volumes will influence noise levels. A Road Noise Impact Model was produced. The model is relatively simplistic and the intention is for the model to be refined at a later stage. The model was applied to a real case study and the results produced are in broad agreement with the published Environmental Statement. The model was also used to investigate the sensitivity of the outcomes when traffic flows were changed. Noise levels for the alternatives examined were quickly calculated and clearly presented.

Suggestions were made on how the GIS sensitivity tool can be further enhanced to provide clearer insight on the impact of different alternatives and how uncertainty with respect to input parameters can be further investigated. Future work will consider the investigation of other input parameters and their incorporation in a single GIS sensitivity tool.

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