A GIS-BASED METHOD FOR ESTIMATING THE ENVIRONMENTAL IMPACTS OF ROAD TRAFFIC

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abstract**:** This paper describes a system which links land use information and output from travel forecasting modelling procedures through a simple GIS for the estimation of the environmental impacts of road traffic. GIS usage provided for spatial analysis, improved display capacities and data integration capabilities. The system consists of four modules which permits for the estimation and evaluation of the environmental consequences of transport network planning proposals being tested. The outputs from the system are presented in easy to understand maps and graphical formats. The results of noise emissions from a pilot study are presented.

1. INTRODUCTION

While modern transportation plays a vital role in contributing to the economic development of nations, and enhances the quality of life of its citizens, it has also been a major contributor to the degradation of the environment. In particular, road transport which due to its flexibility and convenience in providing door-to-door delivery service and access to residential land uses supply the bulk of the transport needs in urban areas, is the major source of noise, air pollution, and problems such as congestion, safety and lack of access.

Community concerns with environmental issues in recent times suggests that environmental consequences of transport will become a contributory factor in the shaping of urban transport policies. This calls for a practical and efficient manner of determining the environmental effects of any transport planning proposal. Current practice for tackling these environmental concerns usually involves an environmental impact assessment (EIA) of planned projects, usually for specific links where changes will occur. While these are necessary to provide ameliorative measures for the worst environmental implications of any project, they are usually carried out many years after the transport network plans are in place, at which time any modification at the network level is usually difficult. While, during the travel demand modelling process, the effect of changes in urban form and transport infrastructure are considered, tested and evaluated, there is generally no consistent feedback on the environmental consequences of the different options being tested.

It is against this backdrop that the current project at Griffith University is being conducted. The main aim is to develop a system that will allow the determination of the environmental impacts of road traffic in a practical and efficient manner. The idea was to develop a simple GIS-based system and tools which can permit the integration of existing mapping systems, existing transport planning systems and existing environmental prediction models into an effective information system and planning tool for transport related environmental effects. The system is intended to be used as an add-on module to existing transport forecasting models by transport planners in the estimation and evaluation of the environmental effects of transport planning proposals. Specific objectives of the project include:

- to develop methodologies for the collection and extraction, from existing mapping and information systems, of additional land use data. The data is required to supplement the outputs from transport demand models for use in the estimation of the environmental effects of road traffic.
- to develop a system which integrates land use information, transport models and environmental models to provide information on the current state of the environment with respect to the effects of road traffic. The system should be capable of being used to assess transport planning options and policies at the city-wide, regional or local area, with respect to their environmental effects.

This paper describes the development and the main components of the system. The paper also presents the results for applying the system to estimate noise exposure in a pilot study with two transport planning proposals.

2. DESIGN CONSIDERATIONS

The main concept that underpin this project is the knowledge that most of the input data required for modelling the environmental impacts of traffic are contained in travel demand models (Brown and Patterson 1990, Taylor and Anderson 1988, Loudon and Quint, 1993). Also in existence are accurate and validated environmental models for predicting the environmental impacts from road traffic. The thrust of the project is thus one of developing an interface to integrate the output from transport models and environmental prediction models. The design of such a framework is complicated by the need to understand not only the different transport demand models in use and their output formats but also factors such as vehicle age which affect the exhaust emissions from individual vehicles, and the effects of the local topological and meteorological conditions. Thus while modelling of environmental emissions is relatively simple, useful information of their impacts can only be obtained by combining emission information with land use information about a spatial distribution of sensitive receptors. Hence, to estimate the actual environmental impacts on the community, detailed information on the locations and nature of the sensitive land uses are also required.

To address the problem, GIS is used in order to facilitate the integration of the output from transport models, the land use information and the emissions prediction models. GIS capabilities (eg. spatial analysis tools, graphics and data integration capabilities) provide an enhanced capacity for the management and analysis of spatial data and the creation and improvement in the way environmental information is produced. In particular, its display capabilities provide an improvement on the evaluation and quality control of data and results. GIS also has features for working on different levels of data aggregation, although at the moment there is the need to develop a procedure for automating such work process (Nielsen and Jocabsen 1996). This is important especially when working with data provided on a detailed level of aggregation that need to be adjusted according to the planning context in order to make it possible to shift between different levels of aggregation. For example, with GIS it may be possible to estimate the environmental impacts of traffic at the micro level and aggregate it to obtain the effect at the macro level. The increasing trend in the use of GIS in transport planning will also make it possible for more of the zonal based data (eg. land use and demographic data) to be available for modelling the environmental impacts of traffic. It is anticipated that GIS will form an integral part of transport planning modelling in the future (Jensen and Ferreira 1992), and hence in environmental modelling of transport plans.

Another design consideration was the type of GIS software to use. The approach was to define a diversified GIS software in terms of capabilities, availability to a wide range of users, computing power, useability, and budget consideration. Having the diverse background and magnitude of the potential users in mind, the conclusion was to adopt a simple PC based system. Another factor in choosing the basic GIS software was the defined need to integrate images and other data with the vector and tabular data that are the backbone of any geo-referenced data management system that is being considered. This factor was triggered by the desire to enable the use and incorporation of photologging data as well as incorporating images from other data sources. The ability to incorporate images of features adds a new dimension to the system in terms of analysis, decision-making and display. A recent survey in Australia found that the most popular GIS software among transport professionals were MapInfo and PC ARC/INFO (Losee and Brown 1996). Since MapInfo is inexpensive, easy to use and could perform the work at hand equally well as does PC ARC/INFO it was decided to initially developed the system as a MapInfo application, and later, perhaps, as a PC ARC/INFO application.

Also of consideration was the approach to be adopted in integrating the models and the GIS. Several methodologies and approaches have been adopted in integrating GIS into transport planning applications (Affum and Taylor 1996, Taylor 1995, Trinidad and Marquez 1994, Shaw 1989). In particular, to integrate GIS and transport planning for environmental evaluation purposes, two main methods are in use: the complete integration method and the add-on approach. The complete integrated approach involves development of new forecasting packages or modifying existing ones to run entirely within the GIS to produce outputs useful for environmental evaluation as well as transport planning. As a unified package, it might be more effective for transport planners and encourage them to undertake environmental planning. The main disadvantages of this method relate to the time and effort required in re-development or modification of the existing model. Another potential disadvantage is the extent to which transport planners may be committed to their existing forecasting models. The add-on approach aims to augment existing transport models. It merely provides an extension to the models already being used, and hence planners would only need to learn how to use the add-on program. Its main disadvantage involves the issue of compatibility and how to design a single program to fit on each of the many different transport models in use. This add-on approach was adopted so as to enable its use by as many transport planners as possible irrespective of the transport model in use. It eliminates the need to re-program existing transport demand models.

Last but not the least is the user interface design. The idea was to design the system to be open, user-friendly and simple. The term open is used here in the sense that it allows the addition of more applications as need and data becomes available and also to allow the analysis to be carried out at any spatial scale level. To facilitate ease of usage the interface needs to be simple and user friendly.

3. THE COMPONENTS OF THE SYSTEM

The system is designed as a practical program for the estimation and evaluation of the environmental impacts of road transport proposals within MapInfo. It is ideal for use by transport planners in evaluating the environmental consequences of each transport scenario being tested. It thus provides the capabilities for testing different hypothesis about traffic management schemes and urban form. The results of the system enable both a global analysis as well as a local analysis. Computations are on a link by link basis and aggregated to obtain the overall network level impacts. It is developed using the MapBasic programming language. It contains four main modules (namely Data_manager, Models, Output and Scenarios) each of which contains a group of functions and tools used to perform specific purposes as described below. The modules are embedded in a form of tool-box like structure and operates in the form of pop-up and pull-down menus. It is easy to use, completely mouse driven and uses the standard MapInfo tables. The user is presented with a step by step guide to all operations. All input data and output are saved in MapInfo format keeping everything simple and uniform.

3.1 Data_manager module

This module serves as a data capture and input facility system. It presents options that enables the user to create and manage the input data required in the analysis. It has three sub-modules namely "network", "raster image capture" and "workspace", each of which performs a separate and unique function. Through these the system organises and manages the input data files into a single unified data sharing facility for use by all the separate environmental models.

The "network" module assists the user in generating a MapInfo map layer from the output data files generated from the transport forecasting model. These are the node file (usually defined by the node number and the x-, and y-coordinates and the link description file which also contains the links flows, speed, etc. The spatial layer created is termed the LINKS TABLE. The attribute data associated with each link in this layer are the assignment results from the transport model. Additional attributes may be added interactively by the user.

The "raster image capture" module enables the user to create input file containing land use information by heads-on digitising (that is digitising based on screen image). It uses aerial photographs (raster images) of the area, road network layer, and a comprehensive cadastral database containing detailed information on each property in the area. When activated the program overlays the street network layer onto the raster image. The user then clicks on the border of the building (serving as the facade) and automatically specified parameters for that land use are registered. These include the locational x-, and y-coordinates, the distance from the street centre-line to that property (setback), the nearby or associated street link identification number and distance from start node of the link. These results are saved to a land use data file in MapInfo format. The accuracy of the values obtained depends on the accuracy of the coordinates of the street network being used. The street network must therefore be digitally accurate in order to obtain accurate location of each property.

An alternative method which is currently being investigated for use in the capture of the locational information of land use receptor points from raster images employs pattern recognition techniques. This technique distinguishes between the dwellings and other features on the raster maps based on colour and shape of a collection of pixel in the image. As a first step a program capable of doing the above may place an outline around each environmentally sensitive feature to create a new layer. The new layer which is still an image requires a second program to determine the digital coordinates of the property boundaries so created. Once the coordinates of the boundaries are know the setbacks and other spatial information may be computed by overlaying street network layer on this new property layer. This approach when possible may provide a fully automated tool for capturing land use data from raster maps.

The "workspace" module is used to build a new workspace or open an existing workspace to be used in the analysis. A workspace in MapInfo is a term used to represent a saved configuration of a MapInfo working session. It details which MapInfo Tables and windows opened and used in any particular session. This module organises the various used files and tables into a unified data sets and also helps keep track of all the various processes and outputs during any modelling session.

3.2 Models module

This module presents options for the estimation and evaluation for a range of planned environmental effects namely:

- traffic noise;
- air pollution;
- energy consumption;
- stormwater run-off; and
- visual effects.

Each of the above activities is carried out using a separate module but share a common data structure and make use of the graphics display of the GIS in displaying the output results. At this stage only the noise and visual effects modules are operational The noise module is used to estimate link-based noise emissions and immissions from road traffic. A detailed description of the noise module is provided in section 4.

The air pollution module will use a model for predicting the main air pollutant emissions (namely carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and lead (Pb)) along each link and the subsequent application of an air-shed dispersion model (eg the Canyon and Gaussian models) to disperse the estimated emissions given metrological data and using the links as the pollution sources. The effects of each of these and their combined effects on the community and the proportion of the community experiencing critical pollution levels are then estimated.

The Energy consumption module will employ existing energy consumption models (eg. such as those of Taylor, 1992) to determine energy usage along each link and the network energy intensity. It is expected that the consumption of the main fuel used namely petrol, unleaded petrol, liquefied petroleum gas and diesel fuel will be computed.

Various pollutants such as tyres, oil, petrol, eroded materials, and deposited exhaust fumes (eg. lead) from cars most often find their way into the drainage system and ultimately into water bodies. Empirical models (such as those by Hall and Hamilton 1991, Peterson and

Batley 1992) may be use to determine the quantities of these pollutants due to the road traffic. These will then be modelled to determine their effects on the receiving environment by integrating the transport, stormwater movements and the aquatic ecological systems (Losee and Brown 1996).

The visual effects module is designed to provide no computational functions but serves more as a planning and administrative tool. It was added to provide the user a tool for viewing photographs of specific links, intersections and special roadway features of interest. It allows the user to click on a link or intersection or a feature of interest after which an associated plan image of the feature will be displayed. The process is achieved by tying the individual road features in the network layer to scanned or aerial photographs of the network. The MapInfo raster image functions are then used to display the images. A digital camera is used to capture major links and intersections. Each photograph is related to the geographic location as an image representation of the feature in the system. It should be noted that several images may be acquired for a particular geographic feature. In such situations the system offers the variety of images to the user who may choose to view some or all.

3.3 Output module

Normally, the results for each environmental model for any transport scenario are displayed immediately after processing on the screen for viewing and subsequent printing. At a later stage during the modelling process, the output module enables the user to re-view on the screen and to generate hard copies, output results of previous runs. The output results are shown in the form of map displays, graphical charts are tabular text files. Typical examples of these are shown later in figures 2 to 4. The output provides planners immediate information about the impact of alternate proposals and policies in the very early design stage. The output may be used to provide an overall transport network plan for the region including identifying key transport corridors and protecting them from inappropriate development (see Figure 2 and 3). Also it may be used to direct transport and urban investments to appropriate areas and hence may be used in developing strategic policies. These results may be used to provide an up-to-date reports on the state of the transport system environment. The information gain from such reporting should encourage a move from mere reporting to a proactive means of planning for a better urban environment.

3.4 Scenario module

The "scenarios" module is used to evaluate the environmental effects of different transport planning alternatives to aid in the selection of a preferred option. During the modelling session, the system keeps track of the outputs of each scenario for any environmental model being run. This module uses these results to evaluate the environmental effects of any two scenarios that have been tested. The option is therefore available only when the results of the environmental impacts of at least two transport planning proposals are available. The output from the evaluation include comparative charts depicting the difference in values (see figures 5 to 7), a map display indicating the links on which differences exist between the environmental impacts due to the two scenarios and a tabular text file showing the summarise results of the evaluation.

4. THE NOISE MODEL

The noise model implemented is based on the UK CoRTN 1988 method (UK DoT 1988). The implemented version enables the prediction of the $L_{10,\ 18h}$ or $L_{10,\ 1h}$ noise levels. Studies have shown that the effect of road noise is mostly experienced by the first front rows of dwellings along the road (Brown and Lam 1994). The model was therefore design to estimate the noise impacts on the frontal dwellings only. This eliminates the complex calculation involved in estimating the noise impacts at the second and subsequent rows of dwelling due to the need to take into account the shielding effects provided by the front rows. During processing, the program runs the MapBasic noise application and displays the pop-up menu shown in Figure 1. It contains three main options: "input data", "output" and assumptions". The nature and parameters on the menu changes depending on which one of the three options is selected. The "input data" form (see Figure 1) is used to select the MapInfo TABLES and the relevant data parameters to use in the calculations. The "output" options provide a form for specifying the types of output desired namely noise emissions, immissions, emission and exposure reports and whether the $L_{10,\ 18h}$ or $L_{10,\ 1h}$ noise index is required. The critical criteria levels used to define high and excessive noise levels are also specified using this form. The "assumption" view provides a form for specifying the parameter values to use in the calculations of the various corrections to apply to the basic noise levels due to gradient, road surface conditions, sound barriers, etc. These can be specified individually for each link or default values applied to the entire network or based on the road type.

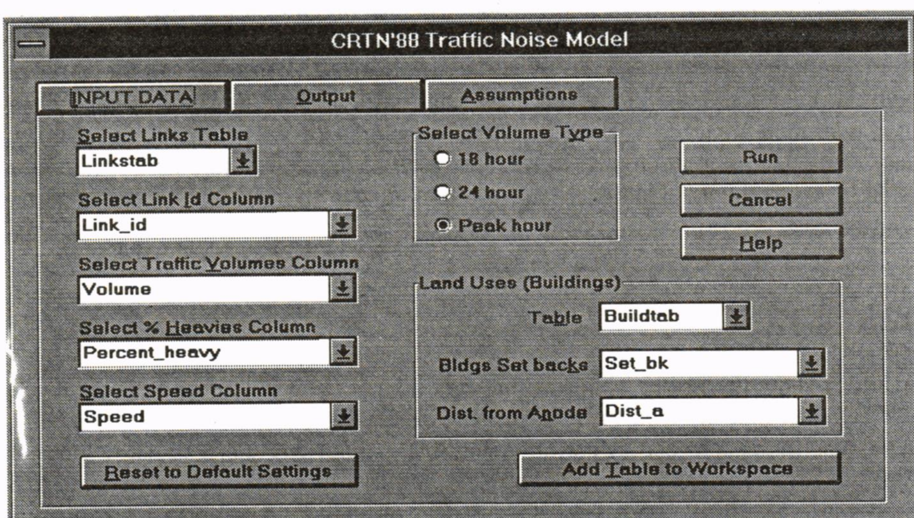

Figure 1: Input data form for the noise module

The outputs from the model are displayed immediately on the screen from which hard copies may be generated. These outputs can also be viewed at a later stage during the modelling stage using the "output" module. They include a series of display maps and graphical charts of the noise emissions, immissions and summary statistics of the number of dwellings exposed to various noise levels. Typical examples of such output displays are as shown later in this paper. Currently, reflection of noise from the opposite facade is ignored.

5. RESULTS OF PILOT STUDY

5.1 Study area

As a case study the completed noise module program was used to model noise levels for the Civic area in Canberra, the Australia Capital Territory. This area lies in the central heart of the city. While actual modelled transport data and land use data have been used, no attempt has been made to validate the outputs, and results presented here are intended to illustrate the noise modelling process rather than to provide accurate noise exposure data for that area. In particular, while future transport flow patterns have been used, only existing land use data as at 1994 have been input to the model. Estimated traffic for two scenarios for the future year 2016 was extracted from the entire modelling output of the ACT strategic model of Canberra. Scenario 2 used a slightly different network with the road classification type for some streets modified. The area contained 354 links. The proportion of heavy vehicles were assumed based on the road type. The road surface was assumed to be dense asphalt with zero percent gradient assumed for all links. Accurate values could be used if available.

5.2 Land use data collection

The setbacks of buildings from the roadway were measured manually from 1:2500 scaled orthophoto maps of the area. These maps contain detailed outlines of the road network and boundaries of dwellings. Only setbacks from the road to the first row of residential buildings (dwellings) were measured. In all, setbacks of 1740 frontage dwellings were measured. Each of these buildings was associated with a link. Some dwellings were associated with more than one link (eg dwellings situated between two roads and those at the corner of the intersection of two roads). The raster capture procedure described above was not used to obtain the additional land use data due to the inability to obtain raster images of the area.

5.3 Results

Figures 2 to 4 show the results obtained for scenario 1. Figure 2 shows the noise levels generated by each link grouped in three ranges (which may be classified as acceptable, high and excessive noise levels). A cut-off values of $L_{10,\,18h}$ noise levels of 63 dB and 68 dB are adopted to define high and excessive levels (ie. levels from 63 dB to 67 dB are referred to as high while 68 dB and above are classified as excessive). The noise emissions are computed at a distance of 10 m from the source. The results showed that about 78 percent of the links (277 links) in the area generated high and excessive noise emissions. As expected, they are the roadway links that carry heavy traffic flows. Even though this figure does not directly depict the existence of noise problems, it has the ability to isolate transport corridors that generates high noise emissions which is helpful in the planning and developments of the adjacent land use by provided prior information on the noise exposure.

Figure 3 on the other hand shows how the noise exposed dwellings are distributed across the network and represents what is termed noise immissions (that is when the impact of the noise on adjacent dwellings are taken into consideration). The links are shaded according

Figure 2: Noise emissions from each link at a facade 10 m from road centre line. No facade correction is applied. (Number of links in each class intervals are given in brackets)

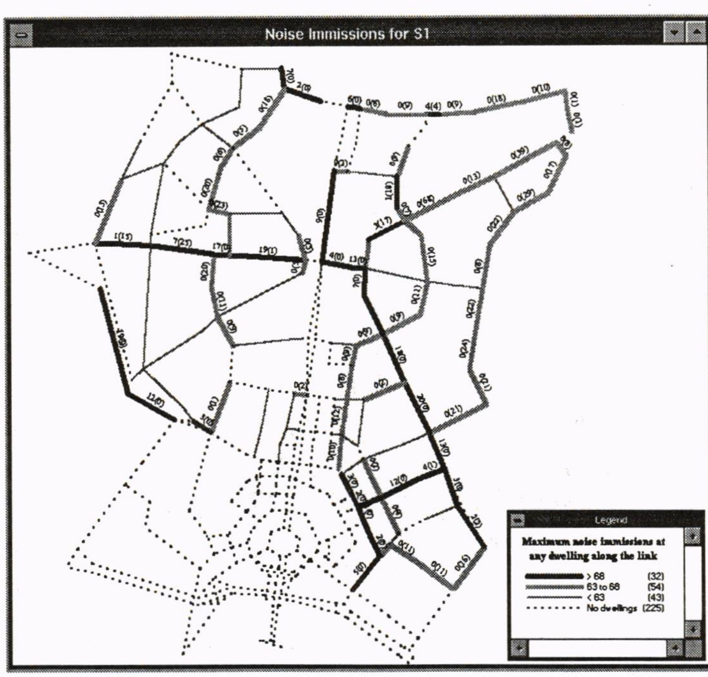

Figure 3: Noise immissions from each link to a facade of dwellings. Facade corrections applied. Link labels show the number of dwellings exposed to excessive noise levels with the number exposed to high levels of noise in brackets.

to the maximum noise immission at the facade of any dwelling located along the link. It should be noted that some dwellings along any particular link may experience a lower noise level than those depicted in the figure depending on the distance of the dwelling from the road centre line. Link labels show the total number of dwellings along the links exposed to excessive noise levels with the number exposed to high levels of noise in parentheses. The display thus depicts where noise problems exist and their magnitude. The figure indicates that excessive noise problems are limited to dwellings on 32 links while those on an additional 54 links experienced high noise levels. Such a display as opposed to that of Figure 2 is of particular importance in directing the planner to focus attention on where traffic noise problems exists within the network.

Comparing the results shown in Figures 2 and 3 indicate that most of the links generating high levels of noise emissions (as shown in Figure 2) resulted in no noise impacts. It is found that dwellings on only 86 of those links is exposed to unacceptable levels of noise immissions. Of course, there may be other sensitive land uses not considered in this case study, such as schools, hospitals, non-air conditioned offices, etc., or passive open spaces. Details of the location of these land uses could be collected to model the noise impacts at these places, but are currently not included in the model.

Figure 4 shows the distribution of traffic noise levels at the facade of the front row dwellings in the study area. The number of dwellings in the area exposed to high and severe noise levels are 247 and 765 respectively. This type of figure could also be used to monitor the distribution of noise impacts in the area with time.

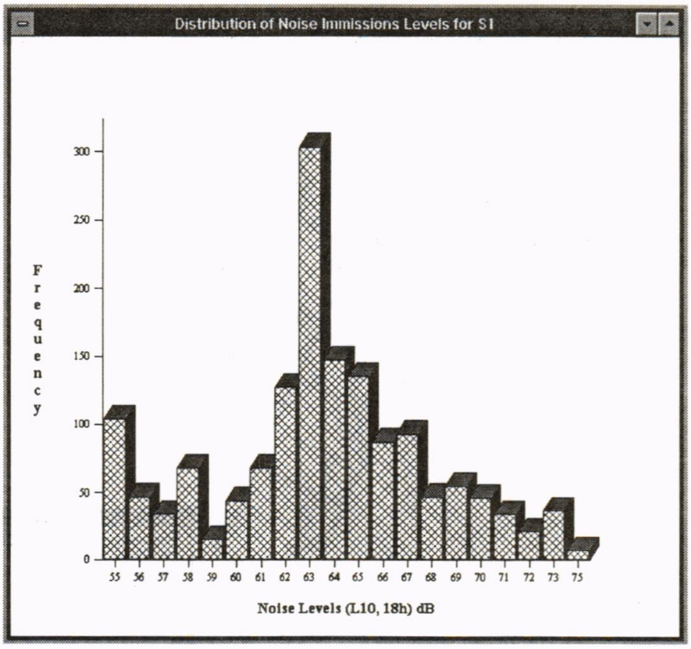

Figure 4. Traffic noise distribution at facade of dwellings (frequency of dwellings with noise levels less than 55 dB not shown)

Table I and Figures 5-7 depicts the results of comparing the noise impacts of transport planning scenario 1 (S1) and scenario 2 (S2). Table I provides the overall statistics for the entire network being modelled. It shows the total number of dwellings and links exposed to high and excessive noise levels. These values show that in terms of noise impacts scenario 1 is better than scenario 2.

Table I: Summary of scenario testing results

Parameters	Scenario 1	Scenario 2
Dwellings (exposed to high immissions levels)	765	886
Dwellings (exposed to excessive immissions levels)	247	296
Links (impacting high immissions levels)	62	71
Links (impacting excessive immissions levels)	32	40
Links (generating high emissions levels)	122	157
Links (generating excessive emissions levels)	154	142

Figure 5 shows the distribution of noise exposure of all dwellings obtained from the two scenarios on the same chart for comparison purposes. It shows that on the whole, the frequency for scenario 1 was more than those of scenario 2 for low noise levels and less in the high noise levels. This findings is made clearer by Figure 6 where the difference in frequencies levels (S1 values minus S2 values) is shown. Figure 7 portrays identical information to Figure 6 except that in this case, it shows in a map display form, where on the network each scenario is performing better than the other in terms of the noise impacts on the front row dwellings. The labels shown on each link is the difference in the number

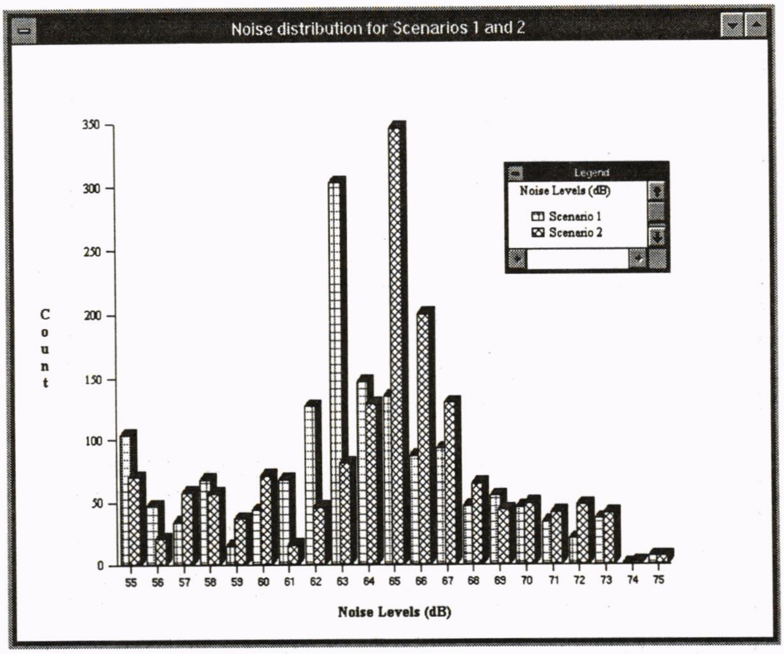

Figure 5. Distribution of the difference in noise impacts between scenario 1 and 2.
(Positive values imply high frequency value for scenario 1 and negative values the reverse)

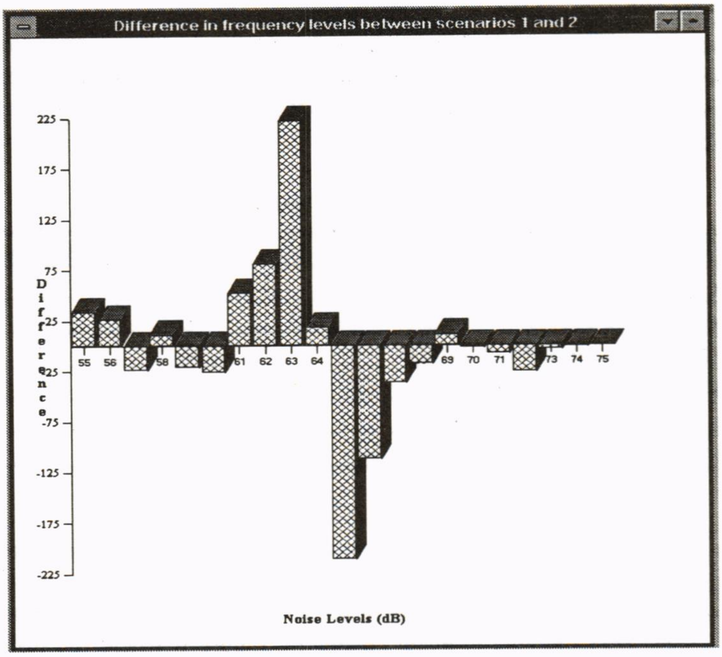

Figure 6. Traffic noise distribution at facade of dwellings
(Difference is given by S1 minus S2 values)

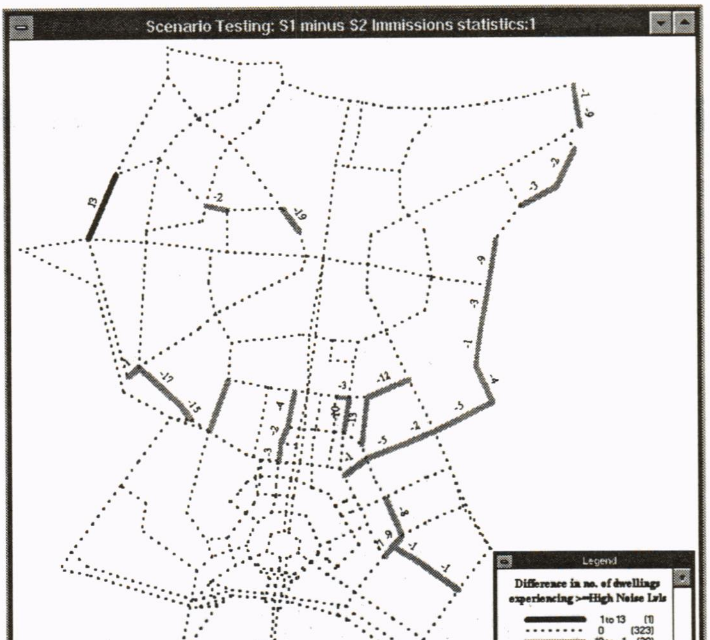

Figure 7. Display showing links where differences exist between the noise impacts due to scenarios 1 and 2. (Link labels shows the difference between the number of dwellings between the two scenarios falling within the high noise level zones).

of dwellings exposed to high and excessive noise levels computed as scenario 1 values minus those of scenario 2. In this example, only on one link did scenario 1 resulted in more dwellings (13 dwellings) exposed to high and excessive noise levels than scenario 2 compared to those on 30 links where scenario 2 resulted in more dwellings (183 dwellings) exposed to high and excessive noise levels than scenario 1.

6. CONCLUSIONS

A GIS-based system for the estimation of environmental emissions and their impacts on the adjacent land uses (immissions) has been described. The system is simple to use and provides outputs in an easily understood maps and graphical formats. The use of GIS provides for improved display capabilities, data integration and spatial analysis, and also enables it to be applied at any spatial scale levels.

The output provides immediate information to planners on the impact of alternate proposals and policies during the modelling stage. It gives the transport planner an entirely new insight into the way environmental effects of transport proposals are viewed and analysed. It could be used to identify key environmentally sensitive transport corridors and links and protect them from inappropriate development. Also it may be used to direct transport and urban investments to appropriate areas and hence may be used in developing strategic policies. Equally important is the capability of the system to be used to provide a State of Environment reporting on the impact of road traffic on the community.

The system described is still under-development. Efforts are currently under-way to use the raster-capture module to capture the details of all residential and environmentally sensitive land uses within Brisbane using a raster image of the city and the Brisbane City Council's mapping system as the source of land use information.

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