ESTIMATING URBAN AIR POLLUTION LEVELS FROM ROAD TRAFFIC IN TRAEMS

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Abstract: This paper provides an overview of TRAEMS a GIS-based environmental modelling system designed to provide a practical tool for the estimation and evaluation of the environmental impacts of road transport proposals by transport planners. Developed using MapInfo, TRAEMS is intended for use by transport planners as an add-on module to existing transport planning models. Its development is based on the premise that, the evaluation of environmental impacts of transport should be undertaken at the network modelling stage using the data available from the travel demand modelling process. The system is made up of separate modules, which are used for estimating the environmental impacts of transport namely, noise, air pollution, energy consumption, stormwater pollution and visual impacts. This paper provides a brief overview of TRAEMS and the development and application of its air pollution modelling component.

1 INTRODUCTION

In urban areas, road transport is a major contributor to the degradation of the environment in the form of atmospheric air pollution, pollution of the natural drainage system, noise generation and disturbance to human settlements, as well as safety and accessibility problems. These environmental effects have become a much public concern to the extent that the environmental consequences of transport has become a contributory factor in the shaping of urban transport policies. However, the transport planning process used to provide road network design information for various scenarios in terms of traffic flow efficiencies, generally fail to consider the environmental impacts of such scenarios at the time the transport planning scenarios are being modelled. The current practice for tackling environmental issues involving environmental impact assessment are limited to specific projects, and are usually carried out late in the transport planning process, at which time major modifications at the network level is difficult.

Against this backdrop, a GIS-based system that combines outputs from transport demand models (TDM) with land use information and environmental prediction models for modelling the environmental impacts from road traffic is being developed at Griffith University. This system, known as "the TRansport Add-on Environmental Modelling System (TRAEMS)" was developed using MapInfo GIS. This paper provides a brief overview of TRAEMS and details the development of the air pollution module of the system and its application to a case study using data from Brisbane City.

2. OVERVIEW OF TRAEMS

2.1 What is TRAEMS?

TRAEMS is a GIS-based program designed to provide a practical tool for the estimation and evaluation of the environmental impacts of road transport proposals. It is designed to be used as an add-on program to travel demand models by transport planners to provide them with quality and timely information on the environmental impact of any transport network scenario being tested. TRAEMS was developed using MapInfo MapBasic programming language and operates entirely within MapInfo medium in the form of pull-down menus. The environmental effects considered are traffic noise, air pollution, energy consumption and storm water quality. In developing the system, an open design architecture was adopted. The term open is used here in the sense that, it enables the system to be developed in stages and to allow for the addition of more applications as need and data becomes available. It also allows the analysis to be carried out at any spatial scale level. The program uses the data integration capabilities of the GIS to integrate output data from the transport demand models, land use data and street network infrastructure to generate the required data sets needed for the various environmental modelling analyses involved. The GIS display capabilities allow for the production of high quality outputs in the form of thematic maps and charts.

2.2 Main components of TRAEMS

TRAEMS consists of several individual small programs in the form of modules linked together through a common controller. The over structure with the various modules is shown in Figure 1. It contains four main modules, namely Data manager, Models, Output and Scenario testing. Each of these contains a group of functions and tools used to perform specific tasks as illustrated by various sub-modules and options. All relevant selection options are presented as pop-up dialogue boxes on the screen. Below is a brief description of the four main modules.

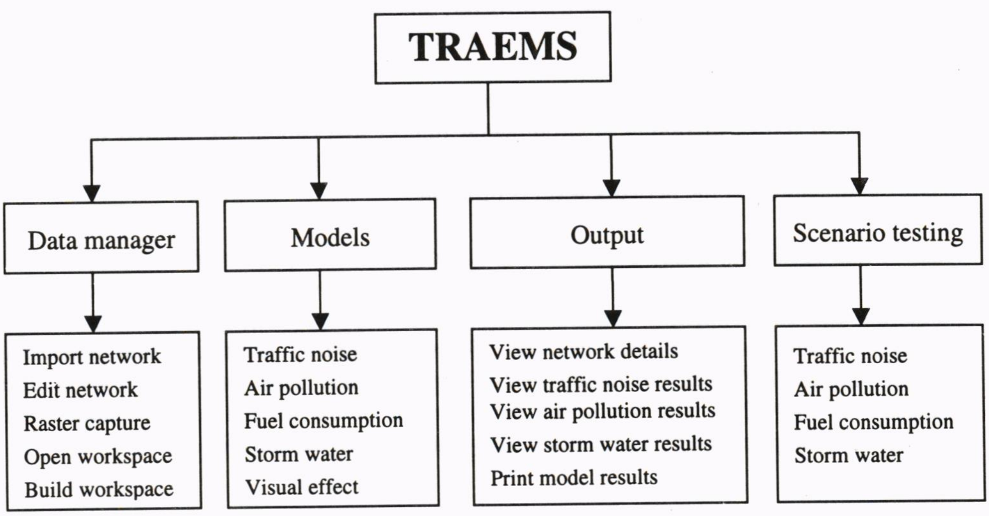

Figure 1: Main components of TRAEMS

The "data manager" module serves as a data capture and input facility system. Through its sub-menus, it enables the user to create a MapInfo map layer from the output data generated from the TDM, and organises the input data files into a single unified data sharing facility for use by all the separate environmental models. It also provides tools for the capture of land use locational information and helps keep track of all the various processes and outputs during any modelling session.

The "models" module presents options for the estimation and evaluation the environmental effects of traffic noise, air pollution, energy consumption, stormwater run-off and visual effects due to road traffic. In computing these effects, emphasis is placed on estimating what is termed immissions rather than just the emissions generated from the operations of the traffic. Immission is defined as the impact or exposure of the generated pollutant on the adjacent land use. Environmental pollutants become a problem only if it affects sensitive land uses, hence immissions modelling is a preferred approach to environmental impact measurement as it provides an unambiguous measure of impact of the pollutant being measured. This, together with the use of GIS and the integration of land use information, differentiates the approach adopted here from other environmental models.

This "output" module is used to view and generate hard copies of model results. The output results come in the form of thematic map displays, graphical charts and tabular text files. Hard copies can be generated at any paper size specified by the user. The size of the hard copies is limited only by capabilities of the printer or plotter being used.

The "scenarios" module is used to evaluate the environmental effects of different transport planning alternatives to aid in the selection of a preferred option. This option is 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 immission values between the scenarios, a map display indicating the links or areas where differences exist between the environmental impacts due to the two scenarios and a tabular text file showing the summarise results of the evaluation.

3. DEVELOPMENT OF TRAEMS

As stated earlier, TRAEMS is designed as an add-on system to transport demand models for use by transport planners for evaluating the environmental impacts of road transport. Its design principles are based on the premise that, the evaluation of environmental impacts of transport scenarios should be undertaken at the transport network modelling and testing stage, using data available from the travel demand modelling process. This is found to be possible because of the data overlap between travel forecasting and environmental modelling as shown in Figure 2.

For TRAEMS to serve its intended purpose (ie. as an add-on system), and capable of use by a whole range of users, it needs to have the capacity to fit onto the current range of transport models in use. Much effort was therefore put into the design of a user interface to ensure that TRAEMS can fit on to any TDM output and thus provide an extension to the models already being used – hence the important inclusion of the term "Add-on" in the acronym for the system.

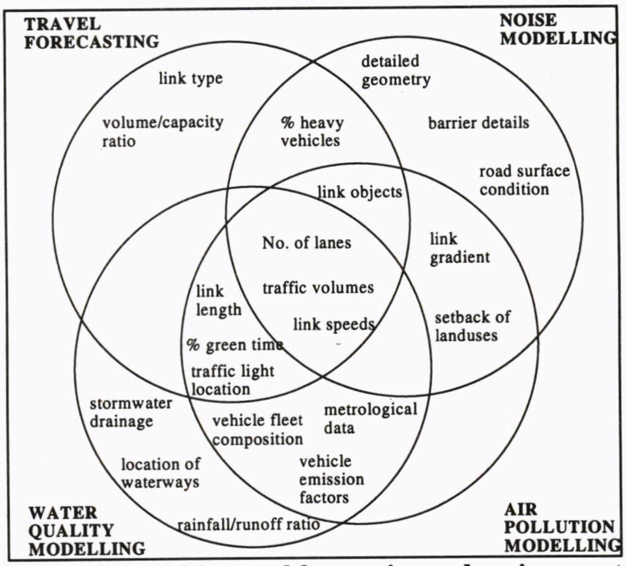

Figure 2: Common data within travel forecasting and environmental modelling
(Source: Tomerini and Brown 1998)

Another consideration in the design of the interface was the knowledge that models tend not to be used if they interfere too much with the way people (in this case transport planners) work. To avoid any interference with current transport models, the interface approach to the integration of GIS and models was adopted. Under this method routines were developed which behave like modules resident within the GIS and operates via a user interface developed using the programming language of the GIS. It does depend on the GIS for data input, output and display capabilities. No changes are made to the transport models. The flow of data between the GIS and the model are as depicted in Figure 3. It depicts the GIS receiving TDM data and output, which are used to generate the various network map layers in the GIS. In addition to the TDM output data, the GIS also receive land use information, which include building setbacks, water catchment details, zonal data and demographic data. From the above data sets, the GIS then generates process data as input for the model and then receives model output for display. The entire process runs transparently to the user via the user interface.

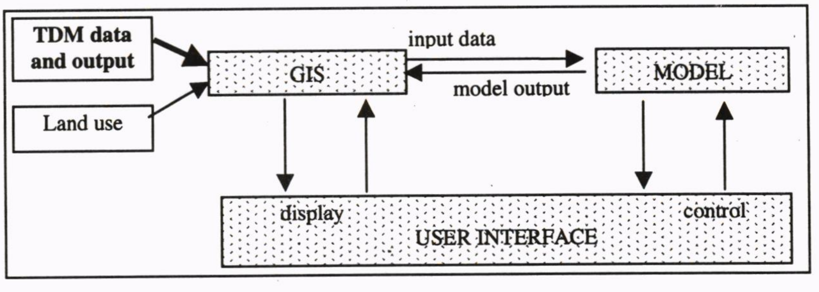

Figure 3: The user interface design of TRAEMS

4. THE AIR POLLUTION MODULE

4.1 Road traffic related air pollutants.

Road transport is a major contributor of air pollution levels in urban areas (ATSE 1997). The main air pollutants from road traffic are carbon monoxides (CO), hydrocarbons (HC), volatile organic compounds (VOC), oxides of nitrogen, (NO_x), oxides of sulphur (SO_2), and fine particulate (such as dust, soot and lead). In addition carbon dioxide (CO_2) is also produced in great quantities (Hickman and Colwill 1982). The pollutants are generated mainly from the incomplete combustion of the fossil fuel used to propel vehicle engines. The magnitudes of the emissions depend on the type and age of vehicle, speed of travel, type of fuel used and to great extent local driving conditions including prevailing meteorological conditions. Due to the large proportion of the air pollutant resulting from road transport, how to maintain safe atmospheric air pollution levels in urban areas require effective control of the pollutants generated from road traffic. Proper monitoring during the planning and operation of transport systems is therefore paramount to any successful air pollution management system. The future of clean air in major cities is therefore linked to future transportation plans for those cities.

4.2 The air pollution emissions prediction model

Generally, predictive models for air pollution from road traffic have been based on an emission rate or factor computed as pollutant mass per kilometre travelled per vehicle (USEPA 1989, USEPA 1985, Nguyen 1995, etc.). The emission factors are computed based on local traffic conditions and vehicle parameters. For vehicles in a given traffic stream, it is assumed that, the general form of the relationship for estimating air pollution emissions from vehicles, *E,* is given by:

$$E = \sum_{i=1}^{n} N_i \cdot P_i \qquad \text{(Eq. 1)}$$

where P = emission factor (in g/km) for vehicle of a particular type/fuel *i*,
N_i = total volume of vehicle type/fuel *i*, and
n = total number of vehicle types into which the vehicle fleet is classified

The air emission model selected for use in TRAEMS was developed based on traffic data (vehicle kilometres travelled and speed) and emission factors obtained from the US and NSW (USEPA 1985 and Pengilly 1989). In developing the emission factors, the vehicle fleet in Australia were classified into three main types based on the vehicle type and fuel used namely:

Light duty petrol vehicles (LDPV) comprising cars and light commercial vehicles;
Heavy duty petrol vehicles (HDPV) comprising medium, and heavy commercial vehicles and buses using petrol fuel; and
Heavy duty diesel vehicles (HDDV) comprising medium, and heavy commercial vehicles and buses using diesel fuel.

The models used to estimate the air pollution emissions from road traffic considered in TRAEMS are given in equations 2 to 4 (USEPA 1985 and Pengilly 1989). For all vehicle types CO and HC emissions are determine from equation 2.

$$E=P \cdot Exp(A + BS + CS^2 + DS^3 + ES^4 + FS^5) \quad \text{(Eq. 2)}$$

NOx emissions for vehicle types LDPV and HDPV are determined using equation 3.

$$E=P \cdot (A + BS + CS^2 + DS^3 + ES^4) \quad \text{(Eq. 3)}$$

For HDDV vehicles NOx emissions are calculated using equation 4 below.

$$E=P \cdot Exp(A + BS + CS^2 + DS^3 + ES^4) \quad \text{(Eq. 4)}$$

where

E = estimated speed corrected emission in g/km (valid for 8-88km/h)
S = average speed on the road link in miles/h
P = city-cycle emission factor in g/km unique for each pollutant
A, B, C, D, E are speed correction factor coefficients which are unique for each pollutant and each vehicle type.

Though the original form of the above models were developed using US data sets, NSW data sets have been used to developed emission factors and coefficients suitable for Australian conditions (RTA 1994). The abilities of the models to take into account differences in speeds on the different segments of the road network and the variations in vehicles types and fuel used permit it to be applied at the network disaggretgate levels, normally employed in TDM.

4.3 Implementation of the air pollution emission models in TRAEMS

In implementing the above models in TRAEMS, each road link or segment as defined in the TDM is considered as an independent line source of pollution with constant traffic variables. The variables include the link-based output from the TDM (speeds, traffic volume, road type, road length, etc) and any other network information available. These are supplemented by the air emission factors and vehicle fleet composition by type of vehicle and fuel used. The implemented components of the air pollution module to date include:

- Prediction of the quantity of CO, HC and NO_x emissions (in grams per kilometre of roadway) emitted by the traffic on each link.
- Division of the study area into equal grid cells of size specified by the user, and the computation of the total emission levels in each grid cell for each pollutant. The total emission in a grid cell is computed as the sum of the emissions from the individual links within each cell.
- Comparison of grid-based emission levels between different transport planning scenarios.

Currently, in progress are the estimation of the near-field effects of link-based emissions and the area-wide dispersion of the pollutants. For the near-field effects, TRAEMS is considering pollutant concentration levels to the first row of dwellings along each link. Here it is assumed that chemical reactions involving the pollutants are negligible. The model adopted is the CHOCK model for predicting the dispersion of pollutants near the roads (Chock 1978). This model was developed based on the Gaussian dispersion model and has been modified to suit the Australian conditions (Simpson, 1989).

The area-wide dispersion of the estimated link-based emissions is being developed based on the USA ATDL model to provide an estimate for the long-term or yearly average dispersion of pollutants (Hanna 1972). Here the final concentration levels of each pollutant will be determined, taken into consideration the topological and meteorological conditions of the area. When this is in place, TRAEMS will have the potential to assess air pollution immissions: for example, the proportion of the community experiencing critical air pollution levels.

4.4 Operating the Air pollution module

When the air pollution module is activated (by selecting it from the options under the Models module) the dialog form shown in Figures 4 is displayed. This form has two views namely, the "input data" view depicted in Figure 4 and the "parameters values" view depicted in figure 5. The menu items on the form changes depending on which view button is selected. Figure 4 is used to select the MapInfo TABLES and the relevant input data items to be used in the modelling process. Figure 5 is used to specify the vehicle emission factors for each vehicle type and fuel used. Since vehicle emission factors are site specific and change over time, this form enables TRAEMS to accommodate changes in vehicle emission factors. Default values for these parameters computed based on Australian wide data are shown in figure 5.

The outputs from this module come in the form of a series of maps showing the various pollutants levels emitted per unit length on each link and the total emissions level for each pollutant in each grid cell. The outputs from the model are displayed immediately on the

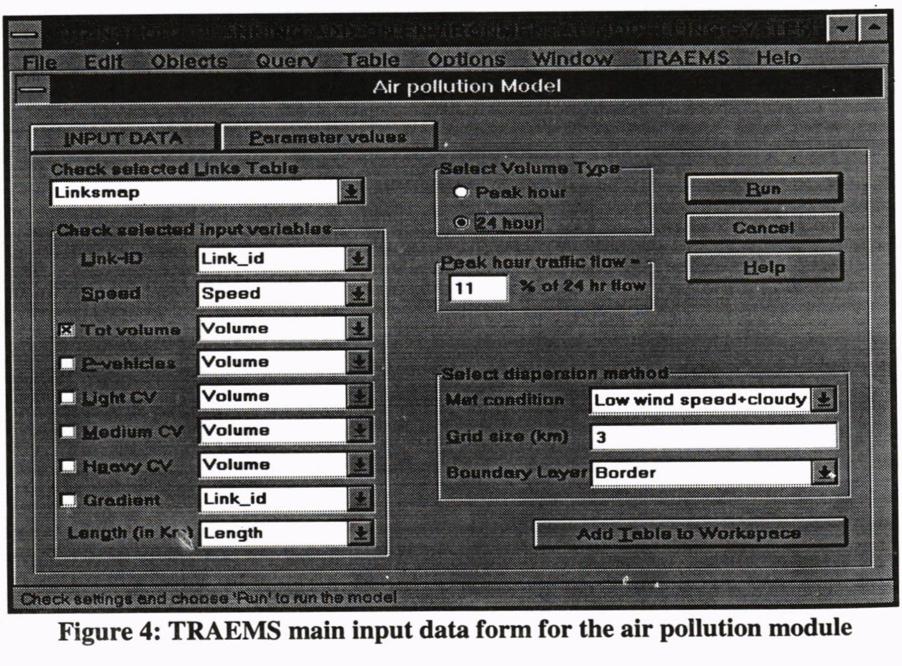

Figure 4: TRAEMS main input data form for the air pollution module

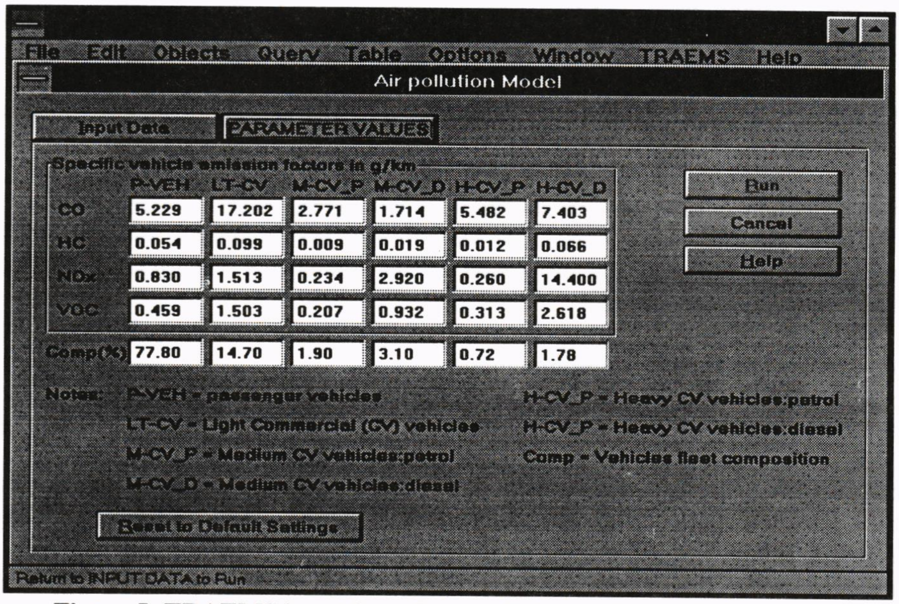

Figure 5: TRAEMS input form for specifying vehicle emission factors

screen from which hard copies may be generated. These outputs can also be viewed at a later stage during the modelling process using the "output" module. Typical examples of such output displays are shown in the next section.

5. CASE STUDY

This section reports on the application of TRAEMS to provide a preliminary NOx emissions levels for Brisbane, a city in Australia. The data sets used in this application are network and traffic data, and air pollution emission factors. The network and traffic data used were obtained from Brisbane City Land Use Transport Study (LUTS) conducted on-behalf of the City Council by Veitch Lister Consulting Pty Ltd, a private consulting firm. This study used 1991 traffic and network details as the base year from which the year 2011 future traffic and network capabilities were estimated. The road network for the 2011 plan included planned improvements involving new and up-graded road projects that have been programmed for completion before the year 2011. TRAEMS imported the output details for both 1991 and 2011 to model the air pollutants for the city. The information obtained included the network node coordinates, link flows, heavy vehicle flows, speeds, link capacity and link type for the base year (1991) plan and the 2011 future scenario.

The results obtained are shown in Figures 6 to 8. Figure 6 shows NOx emitted per unit length on each link, using 1991 traffic data, grouped in four ranges. Figures 7 and 8 depict the total NOx emissions level for each 3-km grid cell for the base year 1991 and future year 2011 respectively. The cells are shaded according to the total pollutant loads generated as computed from all links in the cell. The pollutant loadings for 2011 plan are found to be greater than the base year 1991 values. This increase in pollutant levels can be attributed to the increase in traffic flow accompanied by the speed reductions observed on some sections of the road network.

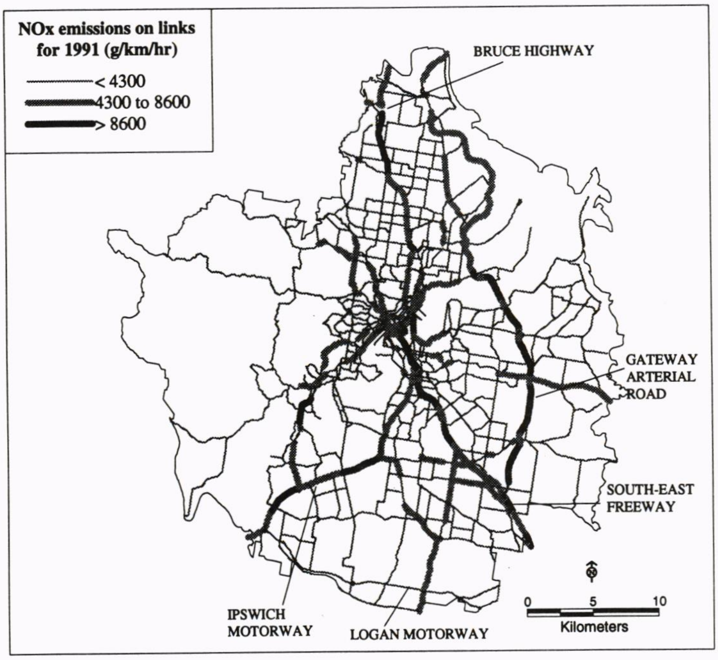

Figure 6: Nitrogen oxides (NOx) emissions on each links in Brisbane City for 1991

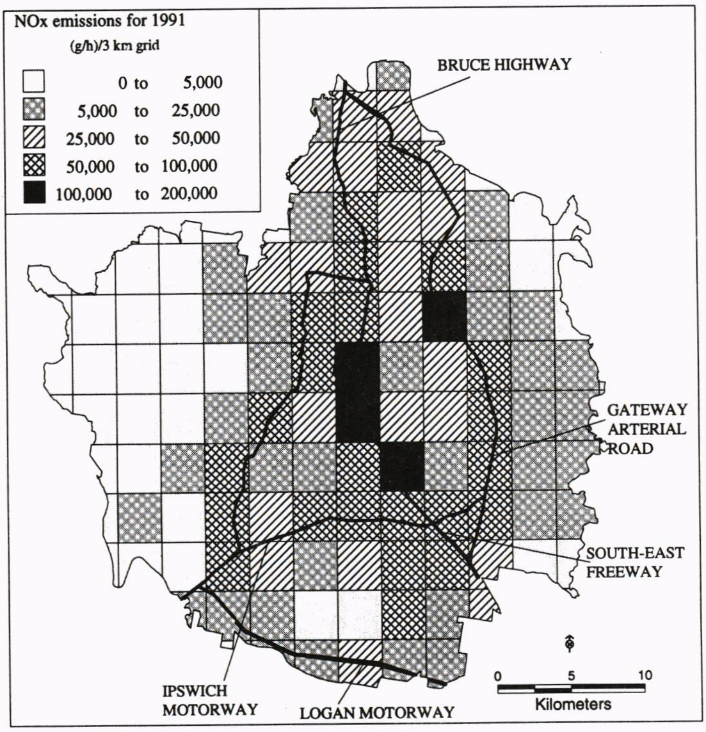

Figure 7: Total NOx emissions levels using 3 km grid cell for 1991

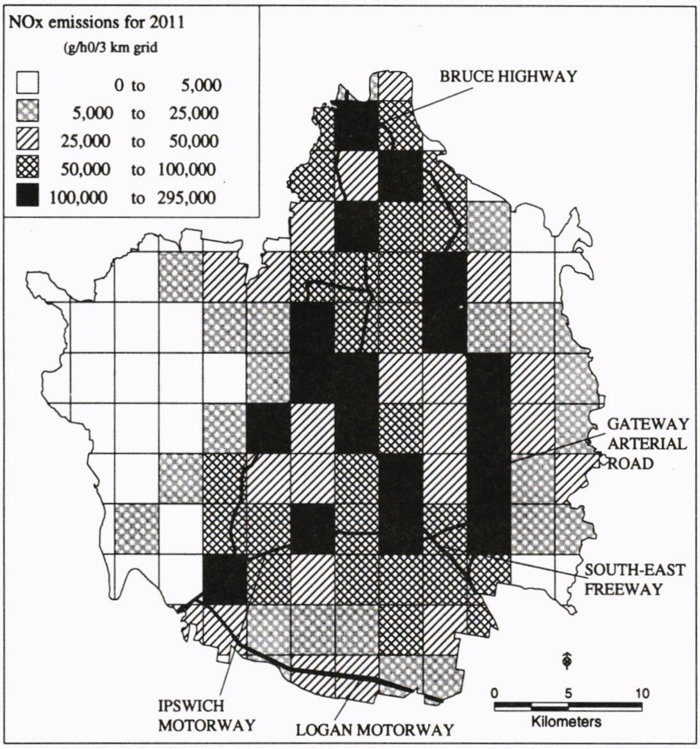

Figure 8: Total NOx emissions levels using a 3 km grid cell for 2011

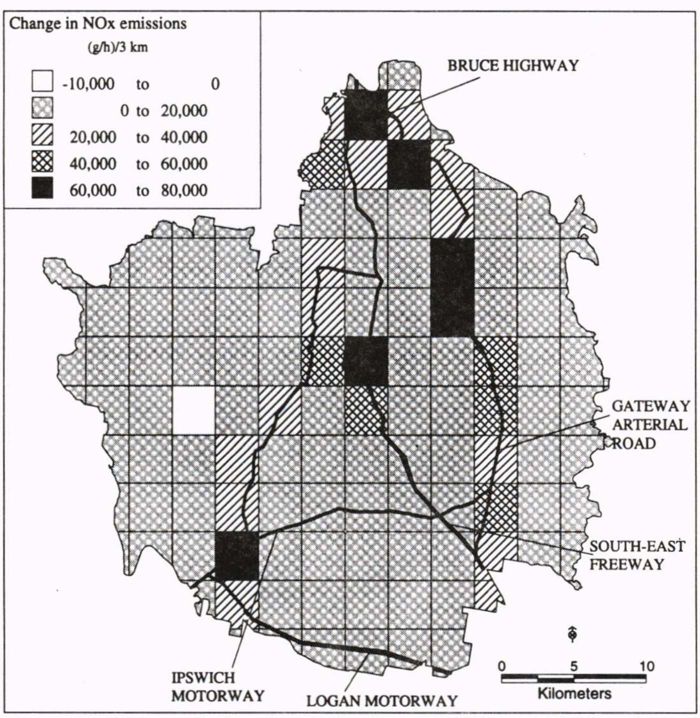

Figure 9: Change in NOx emission levels between 1991 and 2011 using a 3-km grid.

Figure 9 presents changes in NOx emissions between the 1991 and 2011 transport plans. This figure depicts the ability of TRAEMS to assess future transport plans information (in this case the 2011 scenario) and its use in comparing the environmental effects of transport planning scenarios. As an important part of environmental assessment involves predicting future changes in relation to the existing conditions, this ability of TRAEMS to analyse change by taping into the ability of transport planning processes to predict future travel patterns, demonstrates a significant use of the system in planning. With this, areas of greatest adverse changes are easily recognised and can be dealt with using appropriate measures.

6 CONCLUSIONS

A system that allows transport planners to model the environmental implications including air pollution of road transport proposal during the planning stage has been described. The use of the GIS-based computerised system has the advantage of not only permitting the computation and analysis to be performed more rapidly with less effort on the part of the user but also help generate high quality display outputs, which are easy to understand and to interpret. It user friendliness allows the user to perform the analyses for several alternatives providing the much needed information to enable the selection of the best option that minimises the impact of road transport on the environment.

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