TOPIC 1
TRANSPORT AND
LAND USE (SIG)

A SPATIAL DECISION SUPPORT SYSTEM FOR ROAD-BASED TRANSPORT PLANNING

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Abstract

The spatial decision support system described in this paper is being developed as a software tool which integrates land information systems, analytical transport models, transport network information, environmental impact, knowledge base expert systems and geographical information systems (GIS). The system development focuses on the system architecture and system implementation.

INTRODUCTION

In urban transport planning, requirements are changing significantly: computer based models are widely used; economic, social and environmental consequences of alternative plans and policies must be assessed; and the community demands more information. The problem facing many transport agencies is that relevant data and models are scattered amongst different offices and databases. Furthermore, there are incompatability and duplication problems of data and models. Thus, a major requirement of the transport planning process is for the integration of land information systems, analytical models of demand, supply and environmental impact, expert systems and geographical information systems (GIS) into a decision support system. Decision support systems (DSS) are interactive computer–based systems that help decision makers utilise data and models to solve semistructured or unstructured problems (Turban, 1993).

In 1993, a collaborative project between the New South Wales Roads and Traffic Authority (RTA) and the University of New South Wales to build a prototype spatial decision support system for road–based transport planning, evaluation and design commenced. The aim is to develop a computer–based spatial information system encoded for traffic impact analysis that will allow transport planners to explore the economic, social and environmental implications of alternative land–use/transport strategies. It builds on existing technologies of land information systems, database management systems, land–use/transport modelling, environmental impact modelling and GIS. With the aid of the GIS subsystem, different transport planning scenarios can be evaluated graphically in terms of land use, transport networks, travel demand, travel performance, road safety, energy performance, environmental performance, equity/social measures and economic performance.

This paper reports on progress in developing a decision support system. The second section briefly describes the challenges in constructing spatial decision support systems. In the following section, the development of the system architecture and system implementation is described. The fourth section outlines three system applications: the development of a journey–to–work analysis system for the Sydney metropolitan region; the development of a four–step transport model; and an environmental impact assessment model, where we illustrate the integration of a road traffic noise prediction model with the transport model.

SPATIAL DECISION SUPPORT SYSTEMS

A review of the literature suggests that a modern decision support system (DSS) for transport planning has four basic components: a data base, an analytical base, a knowledge base and an user interface. A data base is a collection of interrelated data organised in such a way that it corresponds to the needs and structure of an organisation and can be used by more than one person for more than one application (Turban, 1993). Generally, a data base is managed by software called database management systems (DBMS). An analytical base contains basic computational building blocks, including statistical, mathematical, and other quantitative models. The ability to invoke, run, change, combine, and inspect models is a key capability in decision support systems that differentiates them from traditional information systems (Turban, 1993). The analytical base is managed by software called analytical base management systems (ABMS). A knowledge base is a data base with its content containing human expert knowledge about a specific problem and is generally driven by a software component called an inference engine (this optional sub–system can support any of the other sub–systems or act as an independent component). An user interface provides the facility for the user to communicate with and command the system.

There are six different linkages amongst these four components. The integration demands are beyond the scope of this paper and are listed as: user interface and data base linkage; user interface and analytical base linkage; analytical base and data base linkage; user interface and knowledge base linkage; knowledge base and analytical base linkage; and knowledge base and data base linkage. The problem of how best to develop these components and how to satisfactorily integrate them into a flexible framework is being addressed by our research project. Although the solution proposed in the prototype is specific to the context of the RTA the approach has general applicability to transport agencies.

SYSTEM DEVELOPMENT

System architecture

The key feature in structuring the prototype system (Figure 1) is a loose coupling between different components. This design takes into account existing resources within the RTA (existing databases and analytical bases). The prototype is reduced to a system of four main components: geographical information system (GIS); the database management system; the knowledge-based expert system (KBES); and the analytical base system.

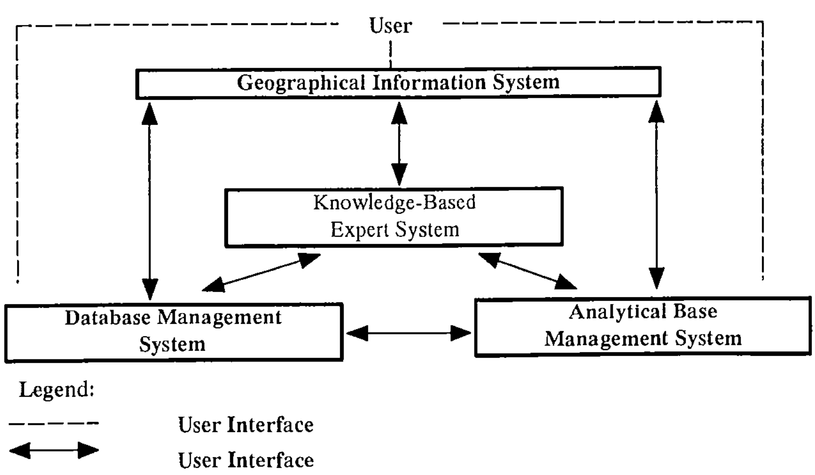

Figure 1 **Structure of spatial decision support system**

The inclusion of GIS represents the spatial aspect of the system and provides a convenient user interface. GIS is a computerised database management system for the capture, storage, retrieval, analysis, and display of spatial data (Cowen, 1990; Dangermond, 1990). The knowledge base component has not yet been integrated into the current system.

System implementation

The following hardware and software were used in system development so that they would be compatible with the strategic directions being taken by the RTA following an external review by consultants in 1993: a SUN SPARC 10 workstation running the UNIX operating system and the ARC–INFO software package developed by ESRI for the GIS component. The research project was predicated on integrating existing RTA databases and analytical models (see Appendices A, B and C) and therefore has not attempted to generate new information.

Although the identification and documentation of this information proved to be a non–trivial exercise the major problem encountered was that the software packages in Appendix C had been developed by different developers and therefore had different input/output formats. This made it difficult to control the linkage between the analytical base component and the GIS component in terms of custom programming. To solve this problem, a software library, written in C++, called TRANSOOP was developed (Ton and Black, 1993) using object–oriented technology. The key feature of this library is its supporting custom programming through software reusability, where a number of basic common abstractions/models and mechanisms are implemented as basic software building blocks. These building blocks form a flexible programming environment to support the development and integration of transport models.

Table 1 shows the general development environment, which provides a library of commonly–used components that are layered from a transport planning perspective. The implementation phase involved the activities that take place on three basic layers: the language specific primitives layer; the TRANSOOP library layer; and the TRANSOOP–based application layer.

Starting at the bottom of Table 1, SUNPRO C++ developed by Sun Microsystems, Inc is employed to provide the facility for using primitive components including char, int, float, double for representing a character, integer number, single and double precision number, respectively. The user–defined constructs are defined by struct and class. The TRANSOOP library layer is in fact an analytical base. It includes generic and specific software components covering the fundamental concepts from the selected domains: land–use, transport, traffic, spatial geometry, environmental impact, statistical, mathematical, and utility. A typical generic software component is the matrix class from the mathematical domain which can be further customised to become a new class, where new specialised functions are developed (eg a function to calculate the mean trip length or to set up trip–length frequency distributions) for use in the transport domain such as trip distribution modelling. An example of a specific software component in the four–step transport model is the gravity model of trip distribution (class "Gravity"). Various models can be reused and combined from generic and or specific components to support the development of a wide range of model applications in the top layer in Table 1.

Table 1 Structure of TRANSOOP modelling environment

Layer	Description	Developers
TRANSOOP–based application layer	Stand–alone or integrated software applications	Research Team
TRANSOOP library layer	Basic software building blocks (classes) from 8 different supporting domains. 1. Land–use classes represent Lowry–based models 2. Transport classes four–step transport models (trip generation, trip distribution, mode choice and traffic assignment) and their variants 3. Traffic classes represent basic traffic intersection (geometry, traffic data and capacity models) and mid–block 4. Spatial geometry classes represent basic spatial geometry (Location, Node, Link, Line Parameter, Polygon) 5. Environmental Impact classes represent the CORTN traffic noise model for single site, multiple sites and network level 6. Mathematical classes represent matrix models, linear algebra, mathematical function and integration. 7. Statistical classes represent histogram, basic statistics, statistical distribution, random number generators, curve fitting processes 8. Utility classes represent a number of utility function including generic look–up mechanism, generic iteration process.	Research Team
Language Specific Primitive Layer	Basic software building types with the support of a C++ runtime library	Third party software developer

SYSTEM APPLICATIONS

Case study 1: Census journey-to-work analysis system

Strategic planning of any major element of the State's road network requires an understanding of the spatial pattern of traffic associated with the proposed corridor. The objective of the first application is to utilise the interactive graphics and mapping capability of GIS to demonstrate the observed behaviour of transport system users. Journey–to–work trip data at the spatial resolution of local government area can be cross–tabulated by gender and industry classification. In addition to the standard GIS mapping output of desire lines, other outputs are origindestination matrices, trip–length frequency distributions and the associated mean trip length. The latter two outputs may be constructed for origin or destination areas.

Three sets of data provide the input to the application program: trip data; travel cost data; and statistical local government area (SLGA) boundary data. The trip and travel cost data were obtained from New South Wales Department of Transport Study Group whereas the SLGA boundary data was obtained from Peripheral Systems. The trip data contain the 1991 journey–to–work census data aggregated to SLGA relating trip frequency between areas by different genders and industrial occupation codes. The trip data file contains 70,848 records (1,558,656 bytes) representing 1,782,092 trips and is structured around the following five fields:

1. SLGA of Origin (64 areas);
2. SLGA of Destination (64 areas);
3. INDP03 — Industry Code (65 industry classifications);
4. SEXP — Male/Female; and
5. Frequency — (Number of trips made).

The travel cost data contains the travel cost between a pair of origin and destination SLGAs. Distance, travel time or generalised cost can be used to represent the travel cost, although, currently, only distance and travel time data are available. The SLGA boundary data contains the SLGA boundaries and centroids. The desired output is an origin–destination table for given zone (SLGA), gender and/or industrial occupation code together with its trip–length frequency distribution. The output format is either in text or graphical display.

Figure 2 shows the system flowchart linking databases, analytical program (TCENSUS) and the GIS component (ARC–INFO).

The methodology is to use the TRANSOOP library to develop TCENSUS and integrate it with ARC–INFO GIS package to support the functionality of the intended system. The role of TCENSUS is to provide the data processing, retrieving, querying, and manipulation support; ARC–INFO supports the user interfaces, database management and graphic displays. The ARC module handles the spatial modelling task. INFO module is a database management system and complements the ARC module in handling aspatial data attributes. ARCEDIT module helps the user to edit any error in representing the map information. ARCVIEW is employed to display a graphical view. ARCVIEW itself is a separate package that can be used to view ARC–INFO coverages and to view attribute data. ARCVIEW can run on both microcomputer and UNIX–based workstation. ARCTOOL and ARCPLOT are two modules to help setup the menu and graphic plotting, respectively. The output can be alternated between the window screen and the plotter.

The user of this system has two simultaneous views of the travel data: static and dynamic. The static view can be seen by communicating with ARCVIEW. These views are displayed by ARCVIEW with the base boundary map of Sydney and different zonal values of selected attributes are presented in different colours. The user can operate the mouse to control the output display by selecting an attribute and a zone to display. For example, a user can perform on the same window screen to display two specific views: a view of the pattern of male and female workers ratio in any SLGA and a view of a particular database table for Randwick LGA (which has been selected because it is the conference venue) shown in Figure 3.

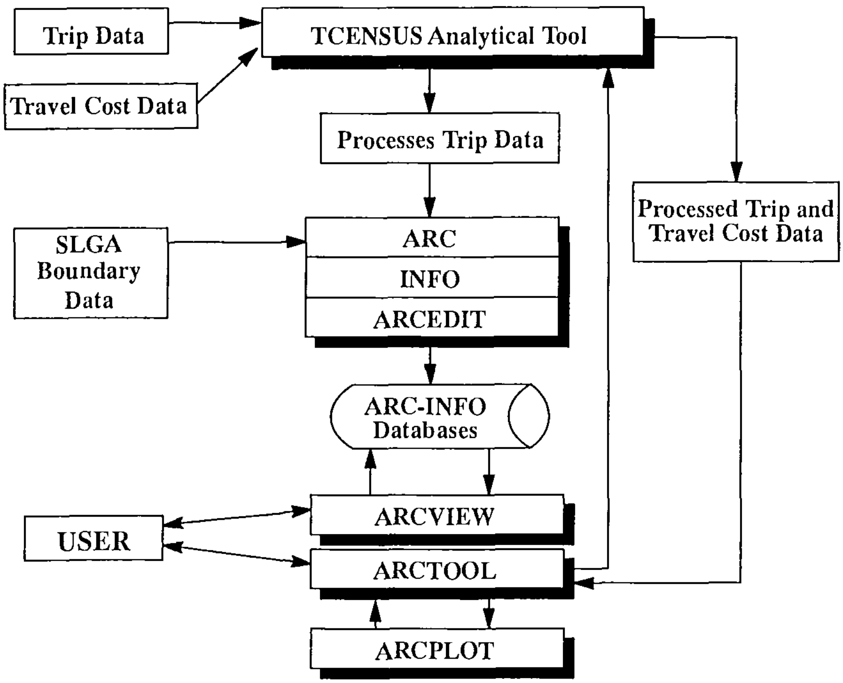

Figure 2 System flowchart for journey–to–work analysis

The dynamic view can be obtained by communicating with ARCTOOL menu system. This menu system can be customised to suite a particular application. Based on the user selection, the dynamic view can be setup at run time involving the use of TCENSUS and ARCPLOT to process and plot the data, respectively. Figure 4 shows the zonal trip length frequency distributions of journey-to-work trip for Sydney region.

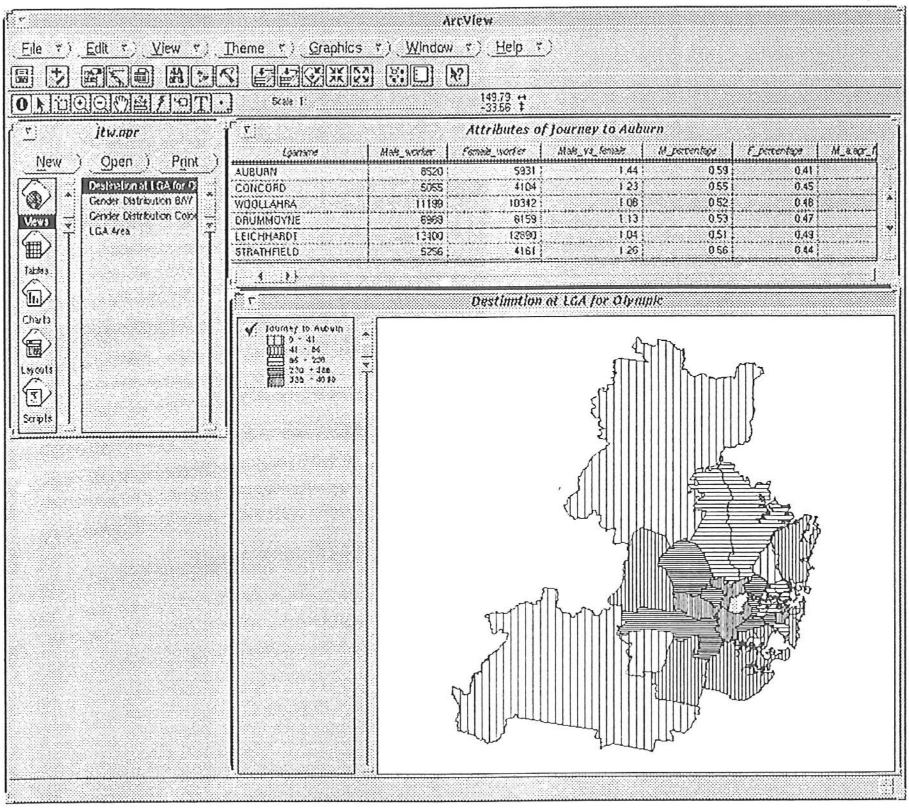

Figure 3 **An example of the system's static view**

Case study 2: The four-step transport planning model

Having successfully implemented the linkage between GIS and TRANSOOP analytical base in the journey–to–work analysis application, the flexibility of the spatial decision support system can be further demonstrated with the TRANSOOP analytical base being expanded to implement the four–step transport model (trip generation, trip distribution, mode choice and traffic assignment).Without getting into the mathematical details of different sub–models, it is obvious that there are numerous combinations of these four sub–models to form an overall model. If, for example, there are three sub–models for trip generation, four sub–models for trip distribution, two for mode choice and three for traffic assignment, then the number of possible combinations to form a complete four–step transport model will be 72. It is unlikely that any one model will satisfy all the needs of a transport planner (Dasgupta, 1991).

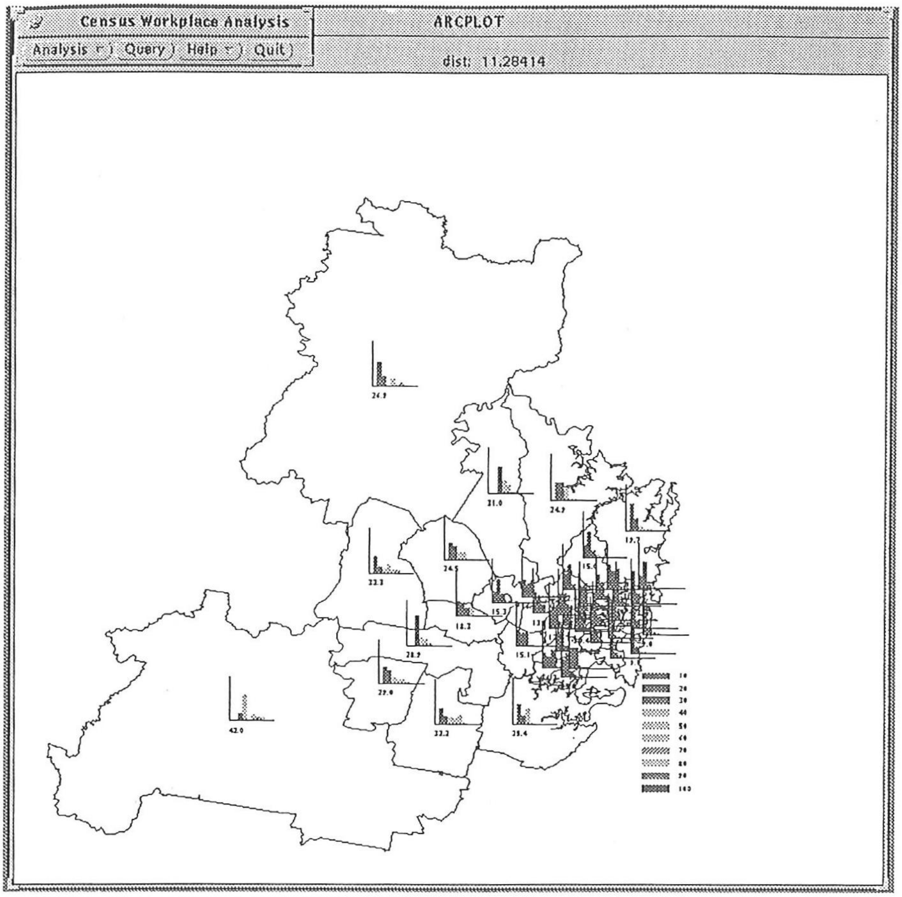

Figure 4 An example of the system's dynamic view

This case study demonstrates that with the object–oriented programming approach, and the support of TRANSOOP analytical base, different variations of the four–step transport models can be flexibly modelled using the same program environment. The key feature is the identification of all common data and the associated functions. They are used as base models and more specific modelling can then be further developed from each base case. As a result, less software is written as the base models are implemented as building blocks and more specialised models are then developed from the basic building blocks. More details on this approach have been reported by Ton and Black (1993b). Additional work is being carried out on the integration with the GIS components based on an educational land–use and transport software package previously developed by Black and Ton (1989). The development of this new system will enhance the interactive graphics and mapping capability for representing the inputs and outputs of the four–step transport models and their variants.

Case study 3: Environmental and traffic impact analysis system

The third case study, when completed, will allow the assessment of alternative land–use/transport plans in terms of the traffic and environmental impact of a proposed road corridor. Figure 5 summarises the network performance information required by the RTA: land–use information; road network information; travel demand information; economic evaluation; travel performance; environmental impact; safety; equity/social factors; and energy consumption.

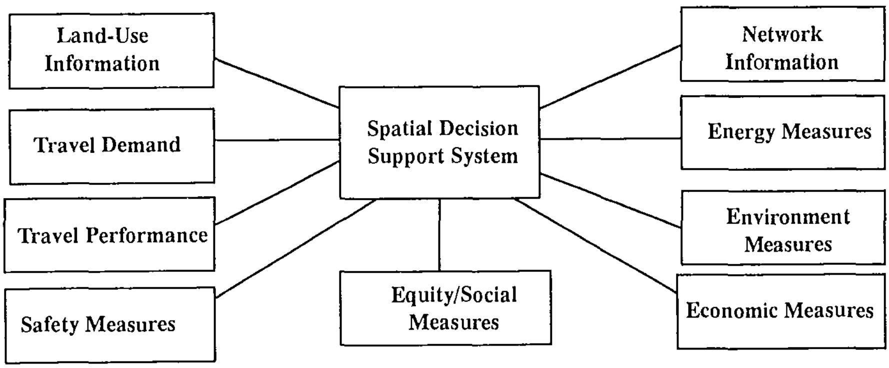

Figure 5 Performance measure modules of the spatial decision support system

As one the most significant challenges in the implementation of this system has been the development of the environmental impact models (such as traffic noise) and their integration with the spatial decision support system, we concentrate on this aspect. The role of GIS is to integrate socio–economic data, land use and transport system facilities (eg the coordinates of road network and associated information such as the geometric standards, history of traffic flows and accidents). For road traffic noise calculations the data required are ground conditions, distance between the edge of nearside carriageway and the facade of buildings. GIS can also be used to in convert data to and from the following three graphic formats for input and output data: linked–based, grid–based and zonal based information.

In Australia, most of the current computer packages for road traffic noise are based on the UK CORTN method which is distance–based approach: the distances and angle relating to the geometrical relationship between the noise source, noise receiver and noise barrier are required by the model. The key issues for our research are: (a) how to implement this model in such a way that it can be flexibly used at a single reception point as well as for the network level; and (b) how to fully integrate it into the spatial decision support system outlined in Figure 5.

Instead of using a distance–based approach, our representation is based on coordinates. Consequently, a noise analyst does not have to go through all details for estimating or measuring the distances and angles: only the coordinates of the five strategic points which relate to the location of the participating objects in any traffic noise problem—namely, noise source, noise receiver and noise barrier—are required. By using TRANSOOP, the traffic noise model was implemented in a flexible and efficient way to handle the traffic noise prediction at both spot level and the network level. Figure 6 describes the system flowchart for environmental impacts—in this case, the generated noise contours for any given land–use/transport/environment configuration.

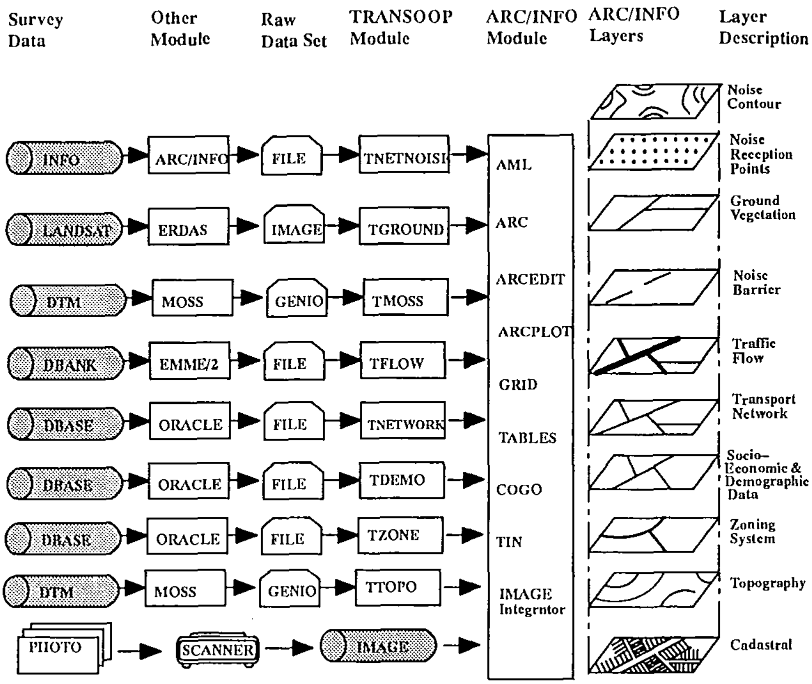

Figure 6 The system flowchart for generating noise contours in case study 3

The flowchart starts from the input of surveyed data to the external software packages including database management system (eg ORACLE), remote sensing system (eg ERDAS is an image processing software system used for analysing LANDSAT satellite images for detecting the ground surface for inputting to the detail noise calculation as a ground correction factor) and transport/highway software (eg MOSS is a highway design package; EMME/2 and SATURN are transport packages). The data flow then comes to TRANSOOP analytical base for custom programming tools to process a suitable dataset in a format that can be understood by the GIS software package. The final output is a set of ARC/INFO layers consisting of cadastral, topology, zoning system, socio-demographic data, transport network, traffic flow, noise barrier, ground condition, noise reception points and the noise contour.

The M5 East corridor between Fairford Road, Padstow, to General Holmes Drive, south of Sydney Kingsford Smith Airport, is selected as a case study to demonstrate the detailed assessment of traffic noise impact (eg number of people affected by a certain noise levels over the whole case study area). The proposed motorway is a 13.5 kilometre tolled road with four lanes for general traffic, and a combined bicycle and breakdown lane on the outer shoulders. Most of the input data to test the system comes from the Roads and Traffic Authority and Environment Impact Statement of the Proposed M5 East Motorway (Manidis Roberts Consultants, 1994). The system being developed can be used as an useful tool for assessing traffic noise impact. Figure 7 shows a one kilometre square: noise contours are expressed in units of Leq(24 hours) dBA superimposed over roads and property boundaries.

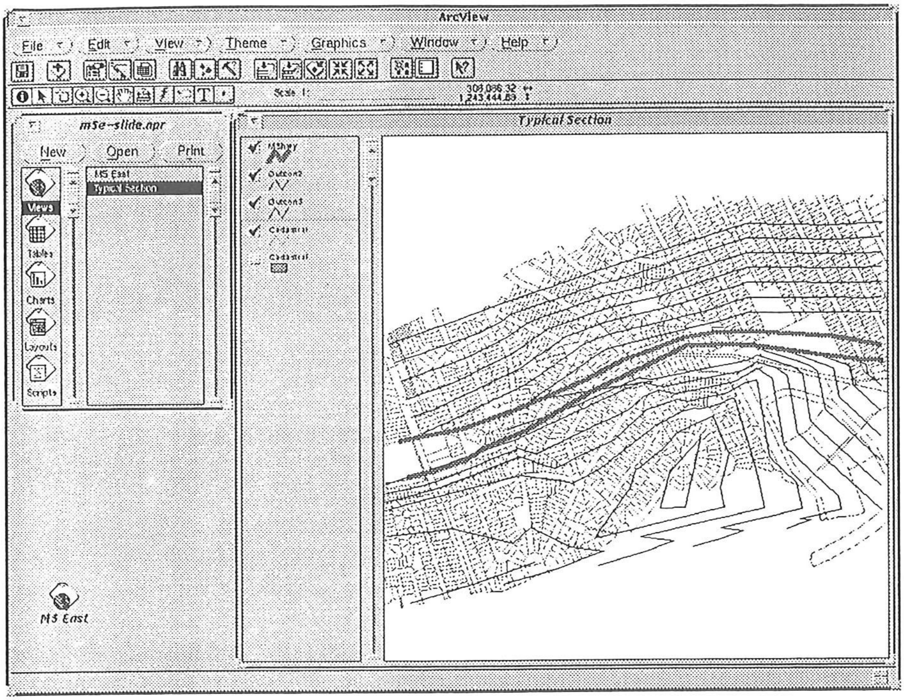

Figure 7 Typical noise contours in dba (leq over 24 hours) superimposed on road and property boundaries at a selected section of the M5 East corridor

CONCLUSION

This collaborative project between the New South Wales Roads and Traffic Authority (RTA) and the University of New South Wales has developed a computer–based spatial information system encoded for traffic impact analysis that allows transport planners to explore the economic, social and environmental implications of alternative land–use/transport strategies. It is being built on existing technologies of land information systems, database management systems, land–use/transport modelling, environmental impact modelling and GIS. This paper has outlined the system architecture and has reported on progress with system implementation (the language specific primitive layer, the TRANSOOP library layer and the TRANSOOP–based application layer). Examples of system applications (journey–to–work analysis; flexibility in using different components of four–step land–use/transport modelling; and road traffic noise prediction) have been presented. Once the prototype has been completed then an evaluation of the value of the system to the RTA will be conducted.

There remains unfinished work. Currently in progress is the production of the final prototype decision support system and the documentation of problems arising. However, there are two directions for research not reported: integrating the current system with a knowledge–based expert system (KBES); and further development of the TRANSOOP library. The main limitation of expert systems in the context of transport planning is that problems are usually complex and there are seldom "expert" solutions that every transport planner/engineer can agree. Notwithstanding, there are some areas in transport planning where an expert system can make an important contribution: to advise the user on the relationship between different transport models available and the associated transport data requirements. A knowledge-based expert system, named EXTRAN, has been developed in a parallel research project (Ngo, 1994) and the challenge is how to integrate this KBES with the spatial decision support system (Figure 1). In the longer term, TRANSOOP can be further enhanced to an "intelligent" analytical base environment to generate transport models for various demands in transport planning through a two-stage procedure: customisation and source code generation. This will necessitate the linking of TRANSOOP with the EXTRAN expert system. This developed environment could then offer users (end-users as well as software developers) the ability to generate a suitable transport model with a minimum programming effort to suit a prescribed purpose.

ACKNOWLEDGMENTS

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REFERENCES

Black, J.A. and T.T. Ton (1989) Developments in computer–aided teaching of land–use and transport planning techniques, *Proceedings of International Conference on Computers in Urban Planning and Urban Management*, Hong Kong, Centre of Urban Studies and Urban Planning, 22–25, August, 51–64.

Cowen, D.J. (1990) GIS versus CAD versus DBMS: What are the differences?, In: *Introductory Readings in Geographic Information Systems* (D.J. Peuquet and D.F. Marble, ed.), Taylor & Francis, London, 52–62.

Dangermond, J. (1990) A classification of software components commonly used in Geographic Information Systems, In: *Introductory Readings in Geographic Information Systems* (D.J. Peuquet and D.F. Marble, ed.), Taylor & Francis, London, 30–51.

Dasgupta, M. (1991) Modelling urban travel demand, in J.H. Rickard and J. Larkinson (eds), *Long Term Issues in Transport*, Avebury, Sydney, 470–508.

Ngo, C.C. (1994) *A Expert System Approach for Decision Support System in Local Area Traffic Management and Urban Transport Planning*, Unpublished PhD Thesis, The University of New South Wales, Sydney.

Roads and Traffic Authority and Manidis Roberts Consultants (1994) *Proposed M5 East Motorway Fairford Road to General Holmes Drive* Environmental Impact Statement, Roads and Traffic Authority New South Wales, Sydney.

Ton, T.T. and J.A. Black (1993a) An object–oriented approach for implementing an integrated four–step transport planning model, In: *Proceedings of Third International Conference on Computers in Urban Planning and Urban Management* (R.E. Klosterman and S.P. French, ed.), Atlanta, Georgia, 23–25, July, Vol. 2, 471–491.

Ton, T.T. and J.A. Black (1993b) Geographical information systems and land–use/transport interaction models: towards system integration, In: *Proceedings of Conference on Land Information Management and Geographical Information Systems and Advanced Remote Sensing*

(E.W. Masters and J.R. Pollard, ed.), The University of New South Wales, Kensington, 19–23, July, Vol. 1, 263–276.

Turban, E. (1993) *Decision Support and Expert Systems: Management Suport Systems,* Macmillan Publishing Company, New York, Third Edition.

APPENDICES

Appendix a: Spatial databases in RTA

Source	Databases
Peripheral Systems	1. All New South Wales road centrelines, waterways and railways 2. Census Collector District (CCD) boundaries 3. Local Government Area boundaries 4. State and Federal Electoral District (SED, FED) boundaries. Some suburb boundaries for Sydney, Wollongong, Gosford and Newcastle 5. Postcode boundaries
Geographical Names Board	6. All suburb/locality boundaries for New South Wales are included
Land Information Centre	7. Cadastral data cover most of the North Coast and Eurobodalla Shire and parts of Sydney.

Appendix b: Aspatial databases in RTA

Source	Databases
1. ROADLOC	A road location methodology for the Authority's classified roads. It provides the basic spatial entry point between graphics information and other RTA programs and databases. It is based on linear distance from pre-defined control points. Every road has a road number and a prescribed direction. Each road is divided into links with a link number which ascends along the road in the prescribed direction.
2. SCATS	SCATS stands for Signalised Coordinated Adaptive Traffic System. SCATS records 1800 coordinated traffic intersections in New South Wales which cover most of Sydney Metropolitan Area as well as Wollongong, Gosford and Newcastle.
3. Home Interview Survey	It contains the result of a survey of 20000 households in the Sydney over a 12 month period (1991-1992). The CCDs were used as the primary sampling unit (Source: DOT Study Group).
4. Journey- to-work Census	It contains 1991 Journey-to-work census data. It was processed by New South Wales Department of Transport Study Group (DOT Study Group) into 25 different cross-tabulations.
5. CVS	CVS stands for Commercial Vehicle Survey. It contains the result of a survey of 30000 commercial vehicles over a 12 month period (1991- 1992). It provides detailed information about the current usage of the urban road network for freight transport and other commercial operations. (Source: DOT Study Group)
6. CRASH	CRASH is an accident data acquisition scheme. It records all accident data collected from the police accident form. It runs on the IBM mainframe database with three categories of data collected: accident, traffic, casualty (Source: Road Safety Bureau).

Appendix c: Analytical model base in RTA

Category	Typical Packages
1. Transport Planning	TRANPLAN, EMME/2, SATURN.
2. Highway Design	MOSS.
3. Traffic Engineering	INSECT, SIMSET, INTANAL, SCATES.

Note: this appendix only compiles the typical traffic/transport models used in RTA)