

## COMMUNITY NOISE IMPACTS USING A NETWORK NOISE MODEL AND DECISION SUPPORT TOOLS

J E WOOLLEY  
Research Fellow  
Transport Systems Centre,  
University of South Australia,  
Adelaide SA 5000  
Australia  
Tel: +61 8 8302 1771  
E-mail: jeremy.woolley@unisa.edu.au

Pongrid KLUNGBOONKRONG  
Ph D research student  
Transport Systems Centre  
University of South Australia  
City East Campus, SA 5000  
Australia  
Fax: +61 8 8302 1880  
E-mail: 9412162m@unisa.edu.au

**abstract:** In recent years the traditional operation of transport systems in urban areas has come under increasing scrutiny. Physical characteristics of urban networks have been altered to induce *traffic calming* and hence modify the functionality of the network. The ability to plan and access such alterations has been limited to the first order effects of traffic flow and speeds. Few tools are currently in existence which can quantify second order effects including environmental impacts and safety at the network scale. The authors are developing a planning tool capable of assessing changes to the operation of urban road networks in terms of environmental effects and safety. This paper considers the development and application of such a tool with regards to traffic noise. A set of decision rules are integrated with a network noise prediction model, NetNoise, and a Geographic Information System (GIS), MapInfo.

### 1. INTRODUCTION

The issue of traffic noise in urban areas has now been around for many years. The Organisation for Economic Cooperation and Development (OECD) has estimated that in the early eighties 130 million people in its member countries were exposed to noise levels of 65 dB(A) and above and 300 million living in *acoustic discomfort* being exposed to levels of 55 to 65 dB(A) (OECD, 1986). Recent studies have indicated that noise is still a major environmental issue in the urban environment and only slight improvement has been made over the last 10 to 15 years (OECD, 1995). In Australia, Brown (1994) has estimated that 19 percent of the population is exposed to noise levels of 63 dB(A)  $L_{A10}$  (18 hour) and above. This is somewhat lower than other OECD countries due to the low density urban form that is prevalent in Australia. Nevertheless, noise *black spots* near major freeways and arterial roads do pose problems to the exposed population. Residents living along main roads has been becoming more sensitive to traffic noise effects. Local government and other agencies have tried to include traffic noise effects in the early planning stages. However, noise management in Australia has tended to be reactive rather than pro-active but this trend is slowly changing with new planning approaches and the introduction of Environmental Impact Statements (EIS). Timing of the noise assessment is also crucial as noise tended to be considered *after* draft transport plans had been fixed.

An efficient and comprehensive noise predicting tool to support decision making is therefore indispensable. However, at present there are very few tools available to practicing engineers and planners which quantify the effects of noise on a community over an area

based coverage. Most models are highly site specific and do not integrate well with other traffic and environmental models and data structures. Furthermore, there are very few tools in existence which can be tailored to suit the country or region in which they are being used. The development and application of an integrated decision support tool, including a road traffic model, a network-based noise prediction model, decision rules, and a geographical information system (GIS) constitutes the topic of this paper.

## 2. THE NETNOISE MODEL

The NetNoise model was developed by the authors to provide an area wide estimation of noise levels from a road traffic network. NetNoise forms a module in the IMPAECT supermodel as outlined in Taylor *et al* (1995). IMPAECT consists of a suite of traffic, pollution and land use models combined through a common database structure (TNRDB) which allows the user to assess the impacts of transportation systems on the urban environment. IMPAECT will be discussed in greater detail in section 4 of this paper.

The basic algorithm in the NetNoise model adheres closely to the Calculation of Road Traffic Noise (CoRTN) procedure developed by the United Kingdom's Department of Environment in 1977 (UK DoE, 1977) and consequently revised in 1988 (UK DoE, 1988). CoRTN has been used as a noise prediction procedure by authorities in many countries including the UK, Canada, Hong Kong, Singapore, New Zealand, South Africa and Australia. This in itself is a testimony to the robustness and adaptability of the CoRTN prediction algorithm. The performance of CoRTN under Australian conditions was investigated by Saunders *et al* (1983) and was found to be suitable for Australian conditions. The procedure was found to have a standard deviation of  $\pm 2.5$  dB(A) and correction factors of -0.7 dB(A) and -1.7 dB(A) recommended for receivers located in the free field and 1 m in front of a facade respectively. Research into road surfaces prevalent in Australia has also led to another set of corrections (RTA, 1992). This data may be used in preference to the CoRTN corrections and incorporates chip seal, densely and open graded asphaltic concrete surfaces (non-rigid pavements) and Portland Cement concrete surfaces (rigid pavements).

Several programs have been developed in Australia using the CoRTN procedure. The most prominent of these include NOISE 3 (Fawcett and Samuels, 1985) and T-NOISE (RTA, 1992). Both of these programs require detailed site and traffic information and are therefore labour intensive and only intended for site specific investigations.

The NetNoise program was designed to be simple to use and run on a personal computer (PC) and is described in detail in Woolley (1994). The program was written for the MS Windows environment with a user friendly graphical user interface as shown in Figure 1. Once NetNoise is running the user is provided with guidance for data input and stepped through sequentially to set up a calculation run. The user has been given as much control as possible over the input variables without compromising the integrity of a calculation run. NetNoise allows for several sources of input and output. At present input is in the form of delimited text files or ACCESS database files (TNRDB format). Output can be made to text files, spreadsheets, ACCESS databases and the MapInfo and ARC/INFO GIS. Both input and output may be viewed in NetNoise and summary information such as corrections applied and contour plots are available.



In modelling at the network scale several assumptions and features are added to the basic CoRTN procedure:

- corrections such as facade effect and ground absorbency are applied globally (ie to all links in the network)
- the study area was assumed to be relatively flat with ideal meteorological conditions
- a road hierarchy and scenario planning feature was included into the program to allow the comparison of *what if* scenarios
- a radius of influence feature allows the user to place a limit on how far noise propagates in the urban environment (which may be used as a substitute for shielding provided by buildings)
- a background noise level exists for areas of the network distant from roads

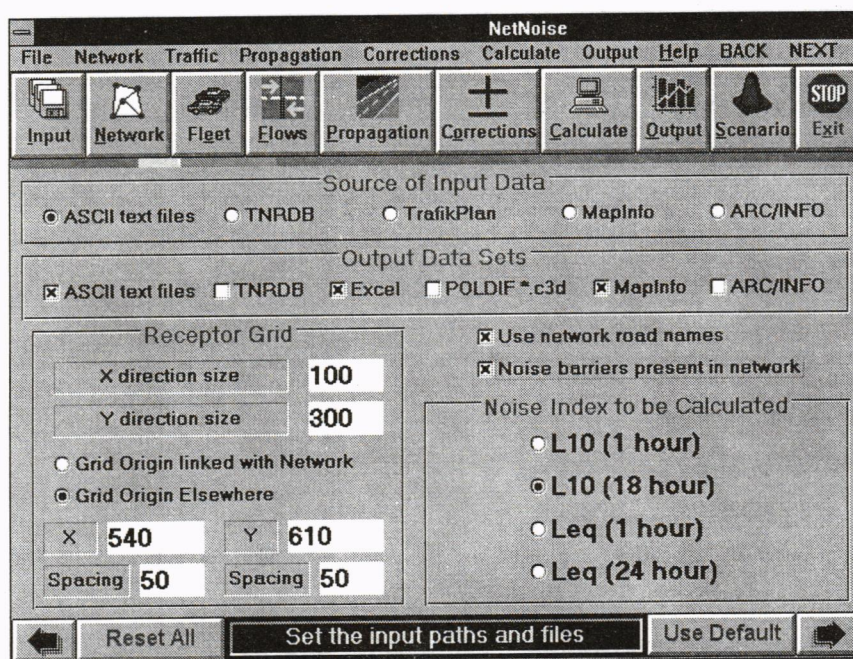


Figure 1: The NetNoise graphical user interface

Area wide coverage is achieved by placing a grid of receivers over the study area in question. The user has total control over the coarseness of the grid and its size and location. Traffic volumes can be in any units provided a conversion factor is approved by the user. Vehicle composition on the network roads can consist of a combination of light and heavy vehicles, or can be fine tuned according to AUSTROADS classification data or Australian Bureau of Statistics data. Although originating in Australia, these classifications only serve to provide a structural shell for the data and vehicle classifications from other countries may be substituted into the shell. Up to 13 vehicle classes can be accommodated. The user has the option of choosing which corrections to apply and information regarding



the derivation of the final noise level can be obtained on a link by link basis. Uncomplicated noise barrier configurations can also be incorporated into the network.

The Scenario Manager interface is shown in Figure 2. This allows the user to investigate *what if* scenarios and compare alternative traffic schemes. For example, the scenario manager could be used to determine the effect of banning heavy vehicles on local roads or altering speed limits by certain amounts. Another advantage of the hierarchy system is its ability to incorporate tunnels, elevated roadways and other link based modes of transport (such as trains and trams) into the network. This feature can be used as a powerful tool for urban planners and traffic engineers to compare and investigate the suitability of several proposed traffic noise management schemes.

**Prediction Model to be Used**

**CoRTN 1988**

Traffic noise prediction model to be used to calculate L10 basic noise levels

**User Defined Adjustment**

Overall Network Adjustment dB(A) **0.0**

This adjustment, based on the users knowledge of local conditions for the network, will be applied to EVERY link in the network.

**Sound Barrier Corrections**

☒ Apply sound barrier corrections

This feature is useful for toggling the sound barriers on and off for "before and after" comparisons.

**Add or Modify a Sound Barrier**

**Variables to Alter**

☒ **Traffic Volumes**

<input checked="" type="checkbox"/> Freeways	±	50	%
<input checked="" type="checkbox"/> Arterials	±	-50	%
<input type="checkbox"/> Sub-Arterials	±	0	%
<input type="checkbox"/> Collectors	±	0	%
<input type="checkbox"/> Local Roads	±	0	%

☒ **Heavy Vehicles**

<input type="checkbox"/> Freeways	±	0	%
<input type="checkbox"/> Arterials	±	0	%
<input type="checkbox"/> Sub-Arterials	±	0	%
<input type="checkbox"/> Collectors	±	0	%
<input checked="" type="checkbox"/> Local Roads	±	-100	%

☒ **Mean Speeds**

<input type="checkbox"/> Freeways	±	0	%
<input checked="" type="checkbox"/> Arterials	±	10	%
<input checked="" type="checkbox"/> Sub-Arterials	±	10	%
<input type="checkbox"/> Collectors	±	0	%
<input checked="" type="checkbox"/> Local Roads	±	-10	%

Figure 2: The NetNoise Scenario Manager interface

Whilst the NetNoise model can predict noise levels for individual points in the network its use is not intended to provide absolute values of noise. Noise can be a very localised phenomenon and accurate prediction requires detailed representation of the urban form, which may be viewed as unnecessary for planning purposes and not feasible for use on a PC at the network scale. A further point to note is the source and accuracy of the input variables. Most traffic network coordinates can now be obtained easily from GIS databases and are generally speaking more than adequate for noise modelling. Traffic variables such as flows, speeds and composition of heavy vehicles will always have varying degrees of accuracy.



Although CoRTN is the default noise prediction model within NetNoise, a capability has been added in which the user can use a different noise prediction model. This feature is similar to the proposed methodology as outlined by Wigan (1976) and is primarily restricted to regression models of similar form (see Figure 3). Unless the customised model has its own attenuation terms the CoRTN attenuation algorithms are applied. The feature allows NetNoise to be customised by a user to suit the region in which the model is being used and also enables the assessment of one model over another for a given scenario or set of noise measurements. For Example, Pamanikabud (1991) modified the Gilbert et al (1980) interrupted flow noise prediction model based on work carried out in the Singapore Central Business District (CBD). When using NetNoise, the user has the opportunity to input the Pamanikabud model coefficients according to the format shown in Figure 3. In this way, noise predictions from NetNoise will reflect the nuances of that particular situation in Singapore. A number of built in models are also included for the convenience of the user. This feature will be expanded and refined by including a knowledge-based expert system developed for providing the recommendation and guidance concerning the suitability, limitations, merits and demerits of noise models to be used for different modelling circumstances.

**Noise Prediction Models**

Clear All Apply Default Accept Help Cancel

☒ Use the CoRTN (1988) attenuation, propagation and barrier algorithms

Most models just provide the noise level at a reference distance from the road. You can opt to include the CoRTN algorithms for deriving noise levels at other locations if there is no distance term in the equation.

☐ CoRTN 1988 (Default NetNoise Model)
 ☐ NCHRP 311 Model (USA)

☐ CoRTN 1975 Model
 ☐ Gilbert et al (Interrupted Flow 1980)

☐ Stafford (Adelaide 1975)
 ☐ Jraiw (Interrupted Flow 1990)

☐ Burgess (Sydney 1977)
 ☒ Custom Model (specify below)

Enter the coefficients for a model of form:  $L_{10} = A + B \log Q + C \log V + D.P + E.w + F.d + G \log O_1 + H.O_2$

☒ Constant A 42.2

☒ Flow,  $Q = x.L + y.M + z.H$  B 10

x 1 y 0 z 1

☒ speed, V C 11.1

☐ composition, P D 0

☐ road width, w E 0

☒ distance to source, d F -12

☐ other variable, O1 H 0

☐ other variable, O2 G 0

veh/time period - can be refined (L M H)

Light, Medium or Heavy (L M H) vehicles

Usually km/h (sometimes mph)

Usually Source to Receiver (m)

Figure 3: NetNoise prediction model customisation screen

The NetNoise model must also be used with caution in environments where traffic flow is heavily congested or where interrupted flow conditions exist. The development of interrupted flow prediction models in Australia has been slow and only the ITFNS model (Samuels and Shepherd, 1991) exists for simple signalised intersections. ITFNS is a simulation model and its incorporation into a PC based network model is not considered

feasible at this point in time. Other interrupted flow regression models (such as Gilbert et al, 1980) have been included with NetNoise but should be used with care as they are intended for use for areas in close proximity to intersections.

### 3. THE NOISE DECISION RULES

The NetNoise model provides the user with the capability to investigate the area wide distribution of noise from a road network. What is also needed is the ability to provide guidance as to where problem areas may be and what remedial action can be used. A knowledge-based expert system (KBES) is being developed by the authors to provide such a capability. As similar to the development procedures of a traffic noise screening (TNS) approach introduced by Barboza et al (1995), a modelling approach was adopted to analyse and extract the relevant knowledge in the knowledge acquisition stage. However, while the TNS method is primarily based on the US STAMINA 2.0 prediction model, for traffic noise decision rules, the NetNoise model was used to estimate traffic noise levels for various scenarios. These scenarios were set up corresponding to the guidance derived from various research papers and other publications including Brown and Patterson (1990) and the Department of Planning (1988). The decision rules take into account various important factors such as traffic characteristics (eg traffic volumes, speeds, etc), road physical and land use characteristics (eg effective road width, building setback distances, land use types, etc) and others. The following assumptions were made when estimating traffic noise:

- i. noise levels ( $L_{10}$  (18 hour)) at different distances perpendicularly from the centre line of a 400 m road length are assumed to be representative of critical noise levels for any road section;
- ii. noise source height is 0.5 m above the road surface and receivers 1.2 m high and 1.0 m in front of a building facade;
- iii. road surface type is a dense grade asphaltic concrete (DGAC);
- iv. the effects of road gradient, absorbent ground coverage, presence of screening and the existence of an opposite facade were not taken into account. In addition, it is also assumed that all road sections are physically homogeneous along their lengths and symmetrical about their centre line. Traffic was assumed to be free flowing in typical off-peak conditions. The corrections for Australian conditions were applied in this study.

The decision rules are intended to be used to assess the traffic noise impacts on pedestrians and residents in land uses immediately adjacent to the road in question. As suggested by Brown and Patterson (1990), the main focus of the traffic noise impact is geographically bounded within the areas between the first row of buildings located on both sides of roads in urban road networks. It should be noted that the end results derived from the TNS method were sets of graphs which can be used to indicate the numerical noise levels according to the given road physical characteristics and traffic conditions. However, the outcomes obtained from the decision rules were traffic noise rating scores in terms of very low, low, medium, high, and very high.



Based on important research findings concerning the general noise effects in several OECD member countries (OECD, 1986), the following noise impact ratings were defined accordingly:

1. Very Low (VL): 58 dB(A)  $L_{10}$  (18 hour) and below;
2. Low (L): between 58 and 63 dB(A)  $L_{10}$  (18 hour);
3. Medium (M): between 63 and 68 dB(A)  $L_{10}$  (18 hour);
4. High (H): between 68 and 73 dB(A)  $L_{10}$  (18 hour);
5. Very High (VH): 73 dB(A)  $L_{10}$  (18 hour) and above.

This scoring system can be used to evaluate not only desirable or acceptable noise levels but also annoyance. An example of the resultant rules is given below:

**IF** Average Daily Traffic is between 12500 and 17500 vehicles per day **AND**  
Mean Speed is between 55 and 65 kilometres per hour **AND**  
Percentage of Heavy Vehicle Composition is between 7.5 and 12.5% **AND**  
Distance from Centre Line of the Road is between 12 and 28 metres  
**THEN** Traffic Noise Rating is High (H).

Decision rules are intended to be used as a simple (but objective) traffic noise impact assessment tool to understand traffic noise impact at the local level, identify potential traffic noise problem locations and suggest the possible contributing factors for those locations. Their accuracy lies between subjective approaches such as the amenity sensitivity (AS) method (Loder and Bayley, 1980) and rigorous approaches like the NetNoise model in IMPAECT (Woolley *et al*, 1996). The decision rule approach can take the effects of different land use types into consideration, tackle the misinterpreted meanings of high degree of numerical exactitude of estimated noise levels, and reduce time, effort and resources required in traffic noise estimations. The decision rules method is not intended to replace the more comprehensive traffic noise predicting model, like NetNoise, but it is rather used as a screening or preliminary assessment tool for more detailed investigation to be initiated. Decision rules can be applied to road hierarchy classification and traffic noise management planning.

#### 4. AN INTEGRATED APPROACH - IMPAECT

During the mid seventies Wigan (1976) proposed a methodology for environmental impact assessment. It is surprising to find that the seemingly logical methodology has never been fully implemented to date. The Impact Model for the Prediction and Assessment of the Environmental Consequences of Traffic (IMPAECT) consists of a framework in which many models interact towards a common goal as shown in Figure 4. A Traffic network model generates the proper traffic flow conditions on the concerned road network for various scenarios. Then, noise pollution, air emission and fuel consumption models are used to calculate local intensity levels of pollutant emissions and fuel consumption, given the estimated traffic flow conditions. With this information together with appropriate meteorological information given, the pollution dispersion model is used to produce spatial pollutant distributions. Finally, the land use impact model geographically overlays the derived pollutant distributions with a given population distribution in the concerned area.

This can be done by using the comprehensive spatial modelling capability in a geographical information system (GIS) technology. The clear patterns of likely environmental problem locations and their severity are therefore lastly achieved (Taylor *et al*, 1995). This is one of the fundamental aspects of the IMPAECT Model and distinguishes it from other community impact models. By concentrating on pollutant immissions, rather than link based emissions, the user is better able to gauge who is being affected. Traffic noise does not constitute a problem if adjacent land uses are not sensitive to the noise.

In order to allow models to communicate with each other, a Traffic Network Relational Database (TNRDB) (Thompson-Clement *et al* 1995) is proposed to store many levels of related traffic data and network attributes. Ultimately IMPAECT will be able to provide network optimisation based on environmental criteria and added functionality can be achieved through the use of KBES technology.

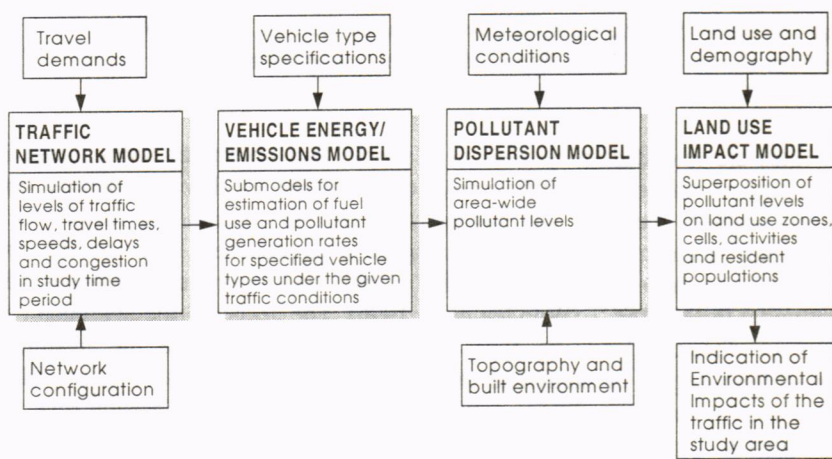


Figure 4: IMPAECT supermodel framework

Perhaps the only other alternative noise model oriented towards planning assessment and an integrated approach is SMIRC\* (Losee and Brown, 1996). SMIRC runs entirely within the MapInfo GIS environment and maps the presence of individual houses in an area. A simplified CoRTN procedure is used for predicting noise at the road link level but data regarding number of houses exposed can be obtained. Losee and Brown put forward a good case for using PC based GIS (namely MapInfo) and highlight the feasibility of the integrated approach given recent advances in PC technology.

## 5. THE CASE STUDY

The City of Unley in Adelaide, South Australia is a well established inner suburban area immediately abutting the southern part of the Adelaide CBD. The road network is based on a traditional grid system common in Adelaide. The central part of the Unley area as

\* System for Modelling the Impacts of Roads on Communities



shown in Figure 5 was used as the case study area due to its relative flatness, mix of land uses and availability of traffic data. The area has formed part of a trial 40 km/h urban speed zone and is surrounded by Greenhill Road (link 11), Unley Road (links 7-10), Cross Road (link 12), Victoria Avenue (link 6) and King William Road (links 1-5). Unley Road and King William Road bears the brunt of traffic travelling to and from the CBD especially during peak periods. Greenhill Road and Cross Road also have high volumes of cross-suburban traffic skirting around the CBD. The main roads in urban areas serving both traffic mobility and frontage related activity functions (access, shopping, etc.) were the primary subject of this study. These roads were divided into twelve homogeneous road sections corresponding to the uniformity of physical conditions, consistency of abutting land uses, configurations of road junctions, and derived road sectional lengths (Singleton and Twiney, 1985) as illustrated in Figure 5.

A database of the area was built up using available data, manual site surveys and equipment including noise loggers, vehicle classifier/counters, radar guns and Global Positioning Systems. The database consisted of:

- i. physical road characteristics (eg surface types, width, number of lanes, etc.);
- ii. adjacent land use types;
- iii. building setbacks;
- iv. building facade orientation;
- v. traffic volumes (daily, annual and peak flows);
- vi. composition of heavy vehicles;
- vii. instantaneous spot speeds;
- viii. measured noise levels;
- ix. in vehicle GPS data.

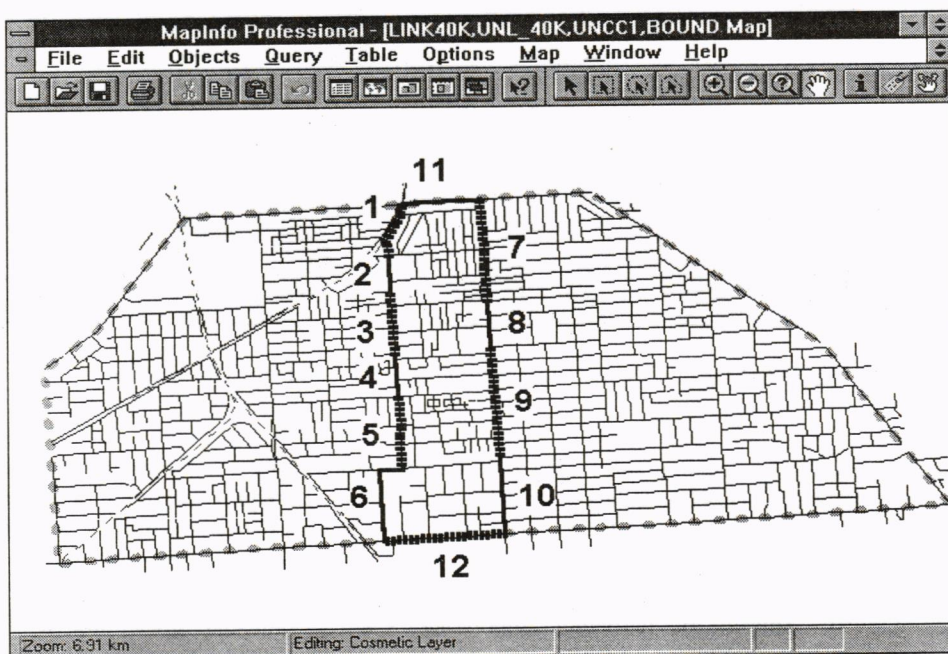


Figure 5: Breakdown of links in the Unley study area

Data was refined and verified by using on-road video recordings, aerial photographs and other relevant documents. Databases were constructed for the MapInfo and TNRDB environments.

### 6.1 Assessment of the Case Study Area

Output from the NetNoise model for the study area is shown in the form of a thematic map in Figure 6. Receivers were placed across the network at 5 by 50 metre intervals. The backdrop to this figure is a low resolution aerial photograph which provides a useful indication of ranges of affected areas and land use types. The bands of noise emanating from the traffic network can be used to calculate regions of exposure based on land use. This can lead to estimations of the number of households exposed to certain noise levels when combined with a demographic land use layer.

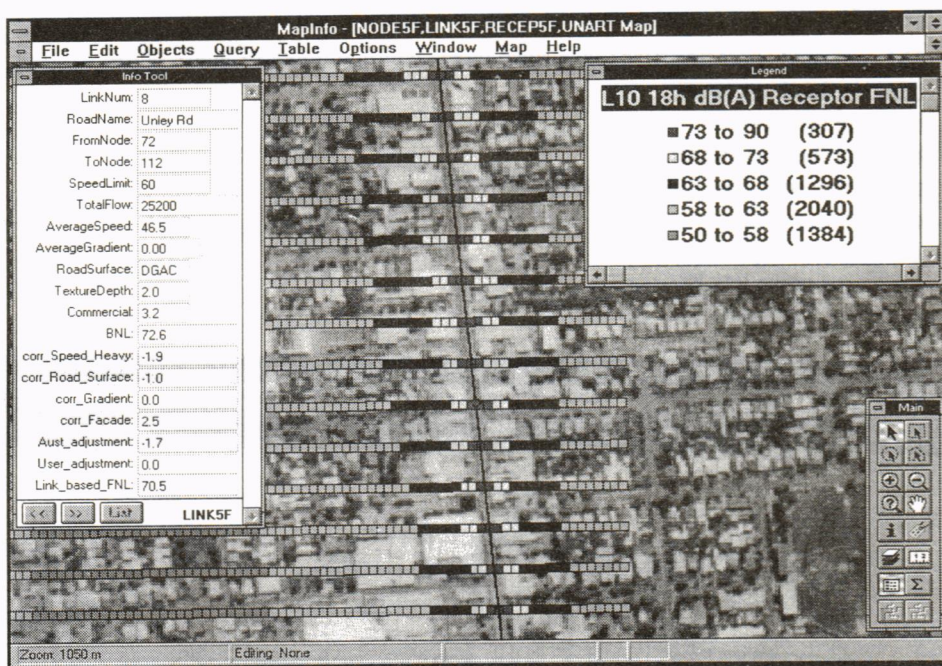


Figure 6: MapInfo thematic map showing noise bands for Unley Road

When applying the decision rules each link was classified with a noise rating score as shown in Figure 7. This immediately identifies the links which require treatment or special attention. Links 7 to 9, 11 and 1 are classified as *very high* and attention must be paid to the land uses adjacent to these links. In the case of the study area, the high rating is brought about by a combination of high traffic flow and the close proximity of buildings to the roadway. This is of particular importance when graphically presenting traffic



environmental impact results to decision makers and effectively communicating with affected residents or public representatives during any public consultation process.

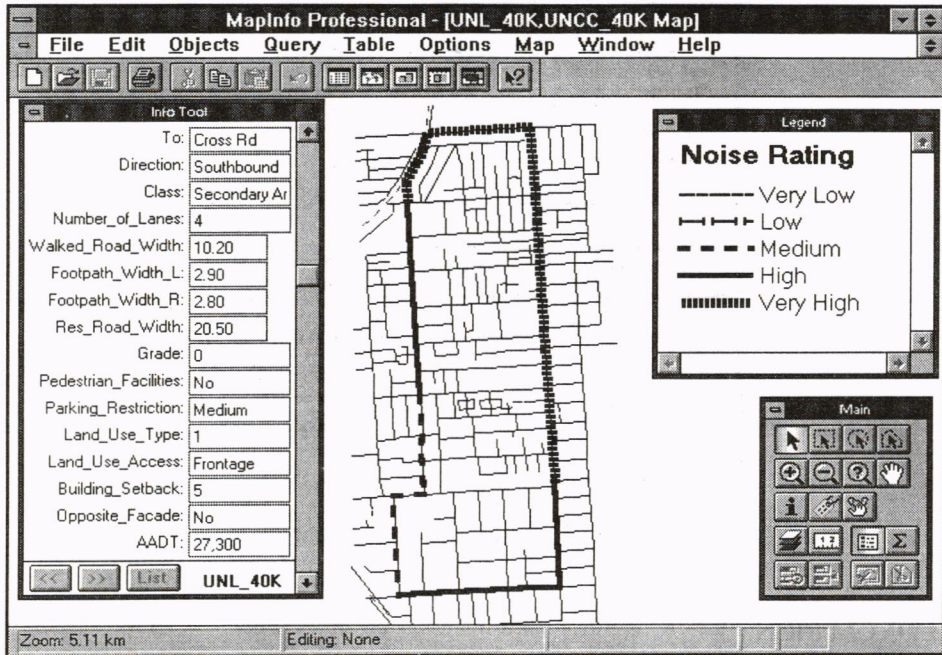


Figure 7: Link based noise ratings for the Unley study area

## 6. FURTHER WORK

Investigations are continuing into the integration of NetNoise with a Knowledge Based Expert System (KBES) (Woolley *et al.*, 1996). Within the context of IMPAECT (as described previously) the KBES can assist in identifying suitable prediction models for various flow conditions, exposing pollution “hot spots”, possible contributing factors and suggested remedial action. In addition, this KBES can also provide intelligent guidance in the modelling process such as recommendation of suitable percentage of absorbent ground for different land use types, different acceptable or desirable noise levels for different land use types, and so on. In addition, the focus is also placed upon the integration with GIS technology to store, manipulate and analyse and present both spatial input data and obtained resultant information. The conceptual framework of this integrated modelling system, called a noise based decision support system (NODSS) is shown in Figure 8.

In addition, Studies using in car Global Positioning Systems (GPS) are underway to determine regions of interrupted flow within a network and hence the appropriate prediction models for specific areas. The NetNoise shell can be used as the basis for an air emissions program with the same degree of flexibility regarding input and output formats. Ultimately, the environmental impacts of traffic such as air emissions, noise and pedestrian safety (or risk) can be estimated, assessed and combined by using the systematic

framework such as the multicriteria decision support tool presented in Klungboonkronk and Taylor (1996).

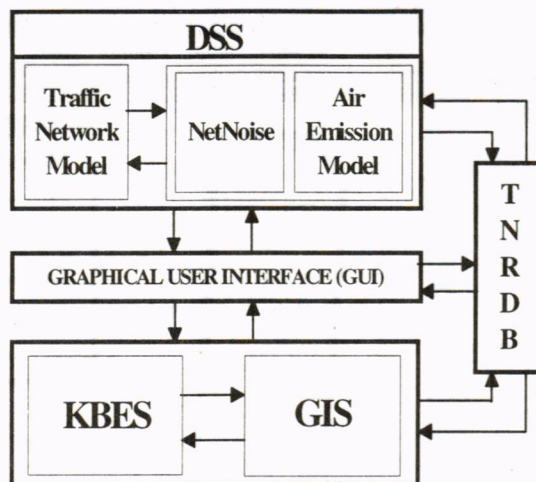


Figure 8: The Conceptual Framework of NODSS system

## 7. CONCLUSION

Noise still forms a major concern in OECD countries and conditions have not improved significantly over the last 10 to 15 years. While there are many noise prediction models in use, these tend to be labour intensive and intended for site specific investigations. The authors have proposed an area based tool using a network noise prediction model (NetNoise) and a set of Decision Rules which, when combined with a GIS, is capable of identifying problem roads and the exposure of land uses to noise levels. The tool is made easy to use through intelligent guidance to the user when setting up calculation scenarios and its graphical user interface. The initial application of the tool to the Unley case study area has already indicated its utility for transport and land use planning.

## ACKNOWLEDGMENTS

The authors would like to thank the Royal Thai Government for the scholarship (Ministry of University Affairs) awarded to the second author for his study at the Transport Systems Centre (TSC), University of South Australia. In addition, the suggestion and guidance provided from the authors' supervisor, Professor M A P Taylor, are also gratefully appreciated.



## REFERENCES

- Barboza, M.J., Carpenter, S.P. and Roche, L.E. (1995) Prediction of Traffic Noise: A Screening technique. **Journal of Air and Waste Management Association**, **45**, 703-708.
- Brown, A.L. (1994) Exposure of The Australian Population To Road Traffic Noise. **Applied Acoustics**, **43** (2), 169-176.
- Brown, A.L. and Patterson, N.S. (1990) Noise assessment when it matters: environmental evaluation integrated with road network planning, **Proceedings of the 15th Australian Road Research Board Conf.**, **15** (7), 61-78.
- Department of Environment and Planning (1988) Traffic Noise from Main Roads (NAASRA Class 6 & 7 Roads in Adelaide), Department of Environment and Planning, Adelaide, Australia.
- Fawcett, G. and Samuels, S.E. (1985) An Interactive Noise Prediction Program. Australian Road Research Board Technical Manual, Melbourne.
- Gilbert, D., Moore, L. and Simpson, S. (1980) Noise from Urban Traffic under Interrupted Flow Conditions, Transport and Road Research Laboratory, Crowthorn, Berks.
- Klungboonkrong, P. and Taylor, M.A.P. (1996) Application of a decision support tool for the multicriteria environmental sensitivity evaluation of the urban road network: the City of Unley case study. **Papers of the Australasian Transport Research Forum**, **20** (2), (unpaged).
- Loder and Bayley (1980) Road/Amenity Classification - A practical tool for Traffic Management, Road Safety and Traffic Authority, Hawthorn, Victoria, Australia.
- Losee, S.P. and Brown, A.L. (1996) Exploiting GIS technology to incorporate environmental modelling in travel forecasting. **Proc. Combined 18th ARRB Transport Research Conference and TransitNZ Land Transport Symposium**, **6**, 297-313.
- Mohammed, S.S. (1995) **Prediction of Road Traffic Noise Under Interrupted Flow Conditions**, PhD Thesis, ITS Leeds, Leeds University, Leeds.
- OECD (1986). Fighting Noise - Strengthening Noise Abatement Policies. Organisation for Economic Cooperation and Development, Paris.
- OECD (1995). Roadside Noise Abatement. Organisation for Economic Cooperation and Development, Paris.
- Pamanikabud, P. (1991) Traffic Noise Model for Assessment of Interrupted Flow Traffic Noise in Central Business District, **Proc. 9th Conference of ASEAN Federation of Engineering Organisations**, Bangkok, 363-373.
- Roads and Traffic Authority (1992) **RTA Environmental Manual - Noise**. Roads and Traffic Authority (RTA and NSW).
- Samuels, S.E. (1990). The Generation and Prediction of Noise at Simple, Signalised Intersections, ARRB Special Report, SR 47, Melbourne, Australia.
- Samuels, S.E. and Shepherd, R.J. (1991) Traffic Noise Prediction at Signalised Intersections, Australian Road Research Board Technical Manual, Melbourne.

Saunders, R.E., Samuels, S.E., Leach, R. and Hall A. (1983) An Evaluation of the UK DoE Traffic Noise Prediction Method. Australian Road Research Board Research Report, Melbourne.

Singleton, D.J. and Twiney, P.J. (1985) Environmental sensitivity of arterial roads. **Papers of the Australasian Transport Research Forum**, 10 (2), 165-82.

Taylor, M.A.P., Woolley, J.E., Young AND T.M., Thompson-Clement, S.J. (1995) **A modelling framework for including environmental impact analysis in transport planning studies: seeking prevention not cure, in Urban Transport and the Environment.** (ed L. Sucharov), Proceedings of the 1st Intl. Conf. on Urban Transport and the Environment, Southampton, England, Computational Mechanics Publications, London, 167-174.

Thompson-Clement, S.J., Woolley J.E. and Taylor, M.A.P. (1995) Applying the Transport Network Relational Database to a Turning Flows Study and a Traffic Noise Model. **Proc. World Congress on Transportation Research (WCTR)**, Sydney.

UK DoE (Welsh Office) (1975) Calculation of Road Traffic Noise [CoRTN]. HMSO (UK DoE Memorandum), London.

UK DoT (Welsh Office) (1988) Calculation of Road Traffic Noise [CoRTN]. HMSO, London.

Wigan, M.R. (1976) The estimation of environmental impacts for transport policy assessment. **Environment and Planning A**, 8, 125-147.

Woolley, J.E. (1994) A Road Traffic Network Noise evaluation Model. **Proc. Australian Acoustical Society Annual Conference**, 158-165.

Woolley, J.E., Klungboonkrong, P. and Taylor, M.A.P. (1996) Some considerations of network traffic noise and a decision support system. **Proc. 2nd International Conference on Urban Transport and the Environment for the 21st Century**, 87-96.