APPLICATION OF AN EXPERT SYSTEM IN THE MULTICRITERIA ENVIRONMENTAL SENSITIVITY EVALUATION OF URBAN ROAD NETWORKS

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Abstract: Road traffic makes a significant contribution to the urban problems of road safety and environmental and amenity degradation. Most local governments and other agencies apply a range of traffic calming strategies to alleviate such impacts of road traffic. The 'Environmental Sensitivity Methodology' (ESM) concept can be used to help traffic engineers and urban planners to relate the ES of a road network to traffic effects at a local level, to specify the likely problem locations, to identify the possible causes of these problems, and to select suitable traffic calming schemes. The ESM concept is well-matched to the expert system approach and the multicriteria evaluation process can be used to combine several criteria used to assess the ES of each link within the road network under scrutiny. The expert system shells VP-Expert and KnowledgePro are therefore being used to develop prototype expert systems for evaluating the multicriteria environmental sensitivity of urban road networks.

1. INTRODUCTION

Road traffic makes a significant contribution to problems of road safety and environmental and amenity degradation in urban areas. Potential impacts of traffic on the surrounding environment include increased traffic noise and induced vibration, increased air pollution, reduced pedestrian safety and crossing opportunities, increased visual intrusion, increased social disruption/severance and reduced accessibility. Such problems are quite complicated and difficult to resolve, often because several and sometimes conflicting objectives have to be reconciled. Most local governments and other agencies apply different types of traffic calming strategies to alleviate these adverse impacts of road traffic. However, the important prerequisite for applying those traffic calming strategies is an agreed functional road hierarchy classification in which the concept of 'Environmental Sensitivity Methodology (ESM)' developed by Singleton and Twiney (1985) can be utilised to accomplish this task. The concept of ESM can help traffic engineers and planners to comprehend the Environmental Sensitivity (ES) of a road network to traffic effects at a local level, to specify the likely problem locations, to identify the possible causes of these problems, and lastly to select suitable traffic calming schemes.

This paper considers the development of an expert system to help in the ESM process. An expert system is a computer program that endeavours to emulate some aspects of human behaviour in solving problems. The ESM concept is well-matched to the expert system approach. In addition, the multicriteria evaluation process can be used to combine several criteria employed to assess the ES of each link within the road network under scrutiny. Two expert system shells, *VP-Expert* and *KnowledgePro*, are being used to develop prototype expert systems for evaluating the multicriteria environmental sensitivity of urban road networks.

2. TRAFFIC CALMING STRATEGIES

It is known that one prerequisite for the planning and implementation of traffic calming strategies is an agreed functional road hierarchy classification. When road classes are defined, the suitable traffic calming strategies can then be adopted to support and reinforce the intended road classification. The responsible local government and road traffic and urban planning agencies normally apply different types of traffic calming strategies to facilitate traffic mobility and at the same time to control the excessive traffic volumes and speeds to an acceptable level in terms of environmental, safety and amenity effects. This means that traffic calming strategies have been utilised as a tool to balance the two controversial components (road traffic and environmental impacts).

Brindle (1991) classified traffic calming into three different levels: Level I: consequences of actions to control traffic speed and mitigate traffic impacts at the local level, where traffic volumes, levels of service and network capacity are not a primary concern (ie Local Area Traffic Management (LATM) and Residential Street Management (RSM) etc); Level II: consequences of actions to control traffic speed and mitigate traffic impacts on traffic routes (district, regional or sub-arterial roads) where traffic volumes, levels of service and network capacity are or may become a primary concern (ie Sub-Arterial Traffic Management (SATM) and Environmental Adaptation Method etc.); and Level III: consequences of actions at the broader scale, to reduce traffic levels and city-wide impacts (ie Travel Demand Management (TDM) and Transport System Management (TSM) etc). This shows that different traffic calming scales are strongly associated with not only differences of geographical scope, but also the differences of relationships between road traffic and adjacent environments. Therefore, distinct measures are needed for different traffic calming levels and the suitable measures for one level may not necessarily be applicable to others.

3. ROAD/ENVIRONMENT INTERACTIONS

The key to achieving the correct functional road classification and therefore suitable traffic calming strategies is the understanding of the relationship between traffic mobility and environmental impacts caused by that traffic: this relationship is usually interpreted as a conflict. The conflict can be defined into two major components: friction and impacts (Westerman, 1990). The 'friction' is the effects of the road environment, land use and frontage related activities (eg vehicle parking, pedestrian crossings, buses stopping etc) on the traffic performance of the road. Conversely, the 'impact' is the effects of traffic on the road environment and the frontage activities along it (eg crossing ability, pedestrian safety, noise and vibration, air pollution, frontage access etc). Westerman (1990) classified road/environment situations according to the relative importance and function of the road and their environments as follows: (i) Type I corridors, where the traffic function is dominant and the frontage function (road environment) must be adapted to this traffic function (eg arterial roads);

(ii) Type II Corridors, where both traffic and frontage functions are important (eg sub-arterial roads in urban areas and the main streets of rural town); and (iii) Type III road/environments, where the environment function is dominant and the traffic function is subservient (eg residential streets etc). He also pointed out that the significance of the interacting situations between friction and impact and the traffic management strategies to be applied to those situations vary dramatically with the types of road/environment situations. It is clear that road hierarchy classification, traffic calming strategies and road traffic and environment interaction are tightly interrelated.

4. AMENITY SENSITIVITY

Amenity Sensitivity is one of the most crucial components of Road/Amenity classification (Loder and Bayly, 1980) which became the most widely accepted functional road classification for existing urban road networks in Australia. Amenity Sensitivity was used to identify the degree of conflicts between road traffic and its adjacent environment and land uses. Such conflicts representing the environmental impacts caused by road traffic will be scored from 1 (less sensitive) to 5 (highly sensitive). The amenity sensitivity was determined for the two aspects (indices) as follows: (i) noise-vibration-pollution sensitivity of frontage land uses; and (ii) crossing expectations and requirements for pedestrians and cyclists along the road. These two indices are considered to have equal importance. The amenity sensitivity index will be refined by adding the two index scores to obtain a 'Composite Sensitivity Index' for each road link. These were defined as follows: Low (2-3); Medium (4-7); and High (8-10). However, Amenity Sensitivity is a fundamentally judgmental approach and will not necessarily lead to a real comprehension of likely environmental and amenity effects of traffic on the study road network.

5. ENVIRONMENTAL CAPACITY (EC)

The concept of 'Environmental Capacity (EC)' has also been adopted to describe the conflicts between road traffic and land use activities. Holdsworth and Singleton (1979) initially introduced the EC concept in Australia with the aim to use this technique in the planning and design of traffic management schemes. Based on a comprehensive literature review they concluded that residents of heavily trafficked streets are most concerned about three aspects: these are noise, pedestrian crossing delay and pedestrian safety. However, they examined only the first two aspects, on the basis that pedestrian safety would be strongly correlated to pedestrian crossing delay. Holdsworth and Singleton (1980) defined the EC of a street as 'the maximum number of vehicles (and associated 50th percentile speed and percentage of trucks) that may pass along the street in the certain time period and under fixed physical conditions without causing environmental detriment'. They applied the EC concept regarding traffic noise and pedestrian crossing delay aspects to the inner metropolitan municipality of South Melbourne. However, they concluded that the real application of the EC concept was questionable, because there were various shortcomings in the use of the gap acceptance based approach to estimating pedestrian delay and several draw backs in noise level computations. In addition, the derived EC values with high scale values were sometimes inappropriate or misleading.

Subsequently Song *et al* (1993) expanded the EC concept presented by Holdsworth and Singleton (1979) with the inclusion of an accident risk criterion. They also proposed the new approach for estimating the EC. The modified EC can be calculated from the weighted geometric average of the three EC values estimated for pedestrian delay, vehicle-pedestrian accident risk, and noise aspects. The weighting parameters for these three aspects corresponding to the specific locations (eg residential streets, school and hospital adjacency etc) are also taken into account in the modified EC estimations. The Environmental Capacity concept is quite rigorous in its applications. However, a considerable commitment of resources is needed to collect the physical and land use characteristics of the concerned road network and to conduct considerable numerical computation.

6. ENVIRONMENTAL SENSITIVITY METHOD (ESM)

Singleton and Twiney (1985) proposed the 'Environmental Sensitivity Method' (ESM) as a means to assess the ES of road links to various traffic-induced environmental effects. The ESM is based mainly on the assumption that the physical and land use characteristics of a particular road can be used to determine the ES of those links to road traffic. The methodology falls between the simple and judgmental nature of the Amenity Sensitivity procedure and the rigorous and objective nature of the EC procedure. The methodology is presented in Figure 1 and explained below.

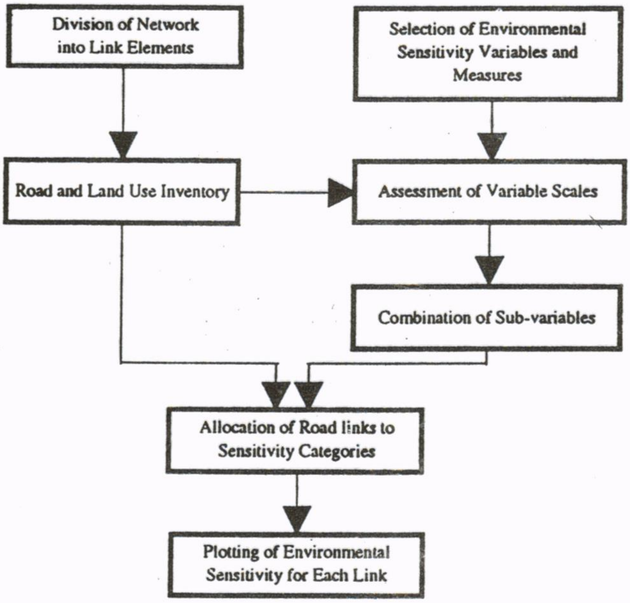

Figure 1 Environmental Sensitivity Method
Source: (Singleton and Twiney, 1985; pp. 179)

The selection of environmental sensitivity variables and sub-variables: three selected variables, namely difficulty of access, pedestrian safety, and noise sensitivity were adopted as ES variables (criteria). For each of these variables, several sub-variables were specified and are presented in Table 1 with their scales of measurement. The previous experiences related to the EC concept helped to identify the ES variables

Table 1 Environmental Sensitivity Sub-variable Scores

Difficulty of Access		
Access	1)	Frontage access generally available
	2)	Rear access available but frontage access restricted
	3)	No immediate access to site.
Parking Restrictions	Low	- limited areas of no-standing, generally no restrictions on on-street parking
	Medium	- some peak hour bans or limited duration parking controls
	High	- no standing or clearway controls at least 4 hrs/day
Land Use	1)	Residential/School/Hospital
	2)	Retail/Commercial/Office
	3)	Industrial- (light or heavy)
Pedestrian Safety		
Pedestrian Facilities	No	- Non-provision generally assumed
	Yes	- Existence of some facilities: medians, islands, crossings, ped. phase at traffic signals etc.
'Walked' Road Width	Narrow	- < two traffic lanes
	Wide	- > two traffic lanes
Footpath Width	Narrow	- < 3 m
	Wide	- ≥ 3 m
Noise Sensitivity		
Opposite Facade	Yes	- Existence of opposite facade generally assumed
	No	- If park/open space opposite etc.
Grade	Low	- slight or flat < 5%
	High	- medium or steep ≥ 5%
Setback (of building from property boundary)	Small	< 2 m
	Medium	2 - 6 m
	Large	≥ 6 m
Land Use	1)	Residential/School/Hospital
	2)	Retail/Commercial/Office/Park
	3)	Industrial (light or heavy)/Railway

Source: (Singleton and Twiney, 1985; pp. 174) and to select the scales of measurement for the various ES measures. **The division of the road network into links:** the road network were divided into a number of links. **Road and land use inventory:** the collections of basic characteristics related to sub-variables and their scales for each side of the road within each link of the network were needed. This was conducted by field staff. **Assessment of variable scales:** from data inventory the values of each sub-variable for each road link was recorded. Then a score of each sub-variable was assigned by using the scaling measurements shown in Table 1. **Combination of sub-variable sensitivity assessments:** the combination of sub-variable scores for each link of the road network was performed corresponding to the system presented in Table 2. It should be noted that the composition of this table was independently reviewed by various members of the study team and the client's planning staff. **Plotting of the sensitivity measures:** the environmental sensitivity results were plotted to illustrate the environmental sensitivity for each link of the road network corresponding to each criterion.

In each link within the road network, the three separate ES scores for difficulty of access, pedestrian safety and noise pollution criteria will be achieved at the end of the ES assessment. In the practical planning process, it is essential to integrate these separate ES scores to specify and compare the total ES indices of different links in the road network. The multicriteria evaluation process is adopted to aggregate these scores. The relative importance of each criteria must be efficiently captured and reflected in the multicriteria evaluation process. This consideration will be discussed in more detail in the next section. In addition the ESM described above is an approach involving and containing judgment, experience and other expertise of human experts and it is consequently well-matched to the expert system concept. Hence an expert system technology is adopted to develop a prototype expert system to evaluate the multicriteria ES of urban road networks. This expert system is potentially applicable to arterial and sub-arterial road categories.

7. MULTICRITERIA EVALUATION PROCESS

Without the accurate algorithm to interrelate these three ES criteria together, the weighted summation method is therefore well-suited to combine separate ES scores in multicriteria evaluation task. The weighting values interpreted in the context of a linear additive function are presented in equation 1 (Nijkamp *et al*, 1990). The results derived from this process are called the "Total Environmental Sensitivity Index" (TESI) which represents the integrated ES index of all separate ES scores for different criteria in each road link. In addition the TESI can be used to reveal the ranking order among considered road links corresponding to the degree of severity of combined ES of each link.

$$TESI_i = \sum_{j=1}^{n} W_j R_{ij} \qquad (1)$$

$$\sum_{j=1}^{n} W_j = 1, \quad W_j > 0$$

where:

$TESI_i$ = the Total Environmental Sensitivity Index of link i, (i = 1,2,3,...,m),

W_j = the weighting value for criteria j, (j = 1,2,3,...,n),

Table 2 Combination of Environmental Sensitivity Sub-variable Scores

Difficulty of Access

Access Availability	Parking Restrictions	Land Use		
		1	2	3
Front 1	Low	L	L	L
	Medium	L	M	L
	High	M	H	M
Rear 2	Low	M	M	L
	Med	M	M	M
	High	H	H	M
No Immediate Access 3	Low	M	M	H
	Med	H	H	H
	High	H	H	H

Pedestrian Safety

Walked Road Width	Footpath Width	Pedestrian Facilities	
		Yes	No
Wide	narrow	H	H
	wide	M	H
Narrow	narrow	M	M
	wide	L	M

Noise Sensitivity

		Road Gradient					
		LOW Setback			HIGH Setback		
	Land Use	Small	Med	Large	Small	Med	Large
Opposite Facade	1	H	H	M	H	H	H
	2	H	M	M	H	H	M
	3	M	L	L	M	L	L
No Opposite Facade	1	H	H	M	H	H	H
	2	H	M	L	H	M	M
	3	L	L	L	L	L	L

Legend

Sensitivity:
L = Low
M = Medium
H = High

Land Use
1 Residential/School/Hospital
2 Retail/Commercial/Office/Park
3 Industry/Railway

Source: (Singleton and Twiney, 1985; pp. 176)

R_{ij} = the separate ES score for criteria j of link i,
m = the total number of links within the road network, and
n = the total number of criteria.

In this study the values of each separate ES score for all criteria will be assigned corresponding to the range of scores used in the amenity sensitivity of Road/Amenity Classification. Therefore the values of low, medium and high will be 1, 3 and 5 respectively. It is assumed that the same scoring system is applied to each criterion.

8. ANALYTIC HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP) (Saaty, 1980) is a mathematical method used to estimate the relative importance weight of each individual criterion in the decision-making process. It consists of the three-step processes: (i) identifying and organising the criteria into a hierarchy structure; (ii) estimating relative importance by establishing and evaluating pairwise comparisons between relevant elements at each level of obtained hierarchy structure and determining the consistency of the judgment; and (iii) synthesising the results of the pairwise comparisons over all the levels. When the hierarchy structure of the criteria is completed, the consideration of the weighting values will start by setting up pairwise comparisons for the given criteria at the same hierarchy level corresponding to the scale of relative importance ranging from one (equal importance of both elements) to nine (extremely importance of one element over another) as shown in Table 3. The derived pairwise comparisons of relative importance, $a_{ij} = w_i/w_j$, for all criteria and their reciprocals, $a_{ji} = 1/a_{ij}$, are then inserted into a square matrix $A = (a_{ij})$ as shown in equation 2.

Table 3 Pairwise Comparison Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favour one activity over another.
5	Strong importance	Experience and judgment strongly favour one activity over another.
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its demonstrated in practice.
9	Extremely importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix.
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.

Source: (Saaty, 1994; pp. 26)

$$\mathbf{A} = \begin{bmatrix} 1 & w_1/w_2 & \ldots & w_1/w_n \\ w_2/w_1 & 1 & \ldots & w_2/w_n \\ \vdots & \vdots & ::: & \vdots \\ w_n/w_1 & w_n/w_2 & \ldots & 1 \end{bmatrix}. \qquad (2)$$

The eigenvector with largest eigenvalue associated with matrix **A** provides the weighting values for all criteria. The maximum eigenvalue, λ_{max}, is used to estimate the consistency of the respondent's judgment. The closer λ_{max} is to n, the more consistent is the result. The Consistency Index (CI) can be used to measure the inconsistency of the matrix (where, CI = $(\lambda_{max} - n) / (n - 1)$). The smaller the value of CI, the more consistent matrix **A** becomes. If CI is zero, then matrix **A** is perfectly consistent. Saaty (1994) also proposed to compare CI with a randomly generated reciprocal matrix, derived from a large sample, called the Random Index (RI) as shown in Table 4. The ratio of CI to RI for the same order matrix is called the Consistency Ratio (CR). A CR of 0.10 or less is considered acceptable, otherwise a square matrix **A** is considered to have a high degree of randomness and should therefore be modified to improve the judgmental consistency.

Table 4 The Random Index

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.4	1.45

Source: (Adapted from Saaty, 1994; pp. 42)

The AHP is becoming more popular over other decision making methods, because of its simplicity, its theoretical robustness, its applicability to handle both tangible and intangible criteria through ratio scale and importantly its ability to directly measure the consistency of respondent's judgments (Saaty (1994), Vargus (1990)). A wide variety of applications of the AHP in physical planning processes were discussed in Golden *et al* (1989), Saaty (1994), Vargus (1990) and Zahedi (1986).

9. EXPERT SYSTEMS

Expert systems have evolved as a branch of artificial intelligence and have been successfully applied mostly in the field of medicine, chemistry, engineering, and military (Han and Kim, 1990). An expert system is defined as 'a computer program that emulates human behaviour in solving problem. It includes a separate reasoning mechanism that performs the same function as a human expert's brain' (Cohn and Harris, 1992). The separation of the knowledge base from the inference mechanism provides more flexibility in programming, upgrading and maintaining the expert system. Figure 2 presents the general architecture of an expert system. Each element of an expert system will be briefly described below (Yeh *et al* (1986), Maher (1987)).

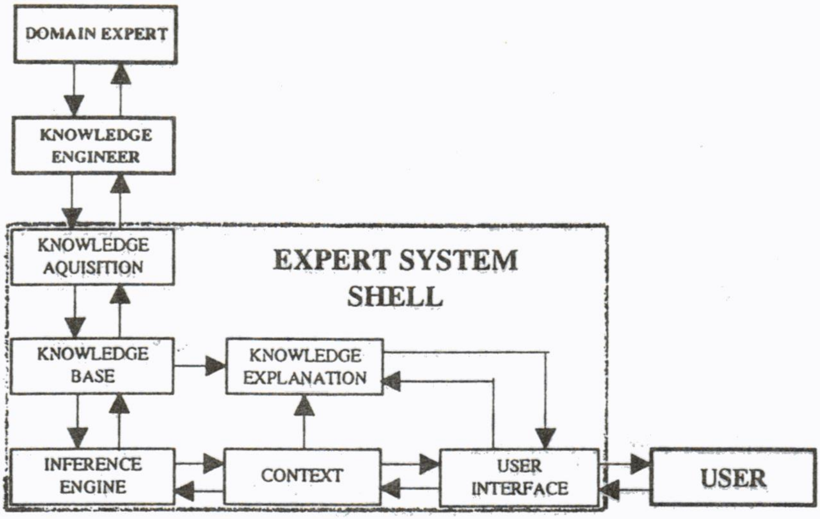

Figure 2 General Architecture of Expert System
source: (Adapted from Maher, 1987; pp.6)

Knowledge base: the knowledge base is the strength of the expert system. It contains the relevant knowledge derived from domain experts including facts or beliefs, rules of thumb (heuristic), and other judgmental factors. The most widely used structure for knowledge representation is the rule-based structure. **Context:** the context contains all data, symbols, and facts about the problem to be solved. At the end of the problem-solving process, the context stores all the intermediate results of the process as well as the solution. **Inference mechanism:** the inference mechanism is the control level of the expert system and contains the computer instructions and procedures of the problem-solving strategies used to conduct the reasoning process by using the relevant information stored in the knowledge base. **Explanation facility:** the explanation facility is used to trace the executing processes and explain its problem-solving strategy to the user. **Knowledge acquisition:** the knowledge acquisition element facilitates entering domain knowledge into the knowledge base. It has been considered as the bottleneck of the entire expert system development process. **User interface:** the user can communicate with the expert system through the user interface.

10. SELECTION OF EXPERT SYSTEM SHELL

Developers might establish their expert system using computer programming languages such as LISP, PROLOG, or C. However, considerable effort is needed to do so and it is not a cost-effective alternative, particularly for non-programmers. In contrast, the expert system shell is capable of providing a standard knowledge acquisition system, knowledge representation structure, inference mechanism, explanation facility, and user interface. Chang *et al* (1994) determined the strength and limitations of more than 30 expert system shells which would be candidates for the signal design project. They adopted four main expert system shell selection criteria: representation, reasoning, communication, and cost. In addition, the technical support provided by the candidate expert system shell suppliers and their credibility are used as

KnowledgePro, Level5, VP-Expert, CxPERT and EXSYS. In this paper VP-Expert was selected as the initial expert system building tool because it is a very powerful and inexpensive tool, easy to learn and use, reasonably easy to integrate with several external application programs, and was immediately available (as an educational version) at the University of South Australia.

11. VP-EXPERT SHELL

VP-Expert is an expert system shell developed by Paperback Software International, running on IBM-PC or compatible computers. A minimum of 512K RAM and at least two double-sided 360K diskette drives (or a hard disk) are required. It will run on DOS v 2.0 or higher. In addition the computer configuration must include an IBM CGA or EGA monitor, a Hercules monochrome graphics adaptor, or a compatible video adaptor (graphic card). The following description is mainly drawn from Bielawski and Lewand (1988), Friederich and Gargano (1989), and Pigford and Baur (1990).

The VP-Expert shell primarily provides a standard rule-based structure as knowledge representation. Backward chaining and limited forward chaining are offered as the control mechanism in the inference engine component. VP-Expert also furnishes a limited induction feature which is capable of creating rules from input data (through the 'editor' approach). This feature is very useful in entering expert knowledge into the knowledge base component. VP-Expert also offers the TRACE facility to keep track of the problem-solving process and display the results in the form of a decision tree, either graphically or in text format. VP-Expert provides a method (eg using the WHAT-IF command) of replaying a consultation when a change of particular input is required. VP-Expert also offers the standard explanation facilities such as HOW and WHY commands. VP-Expert also provides the chaining capability between a number of knowledge base files through the use of the SAVEFACTS, CHAIN, and LOADFACTS statements. VP-Expert is capable of integrating with DOS execution calls and linking with external application programs (eg LOTUS 1-2-3, dBase III etc). For example the WKS and PWKS commands will be employed to read and write to LOTUS 1-2-3 data files, respectively. Bielawski and Lewand (1988) pointed out that because of these special capabilities, VP-Expert is potentially a very powerful expert system development tool at either front ends and back ends for spreadsheet and database programs. In addition VP-Expert contains various sophisticated mathematical functions and facilitates complex confidence factor manipulation efficiently.

12. BUILDING PROCESS OF THE EXPERT SYSTEM

The development process of an expert system for assessing the ES of each link of the road network to traffic effects primarily follows the one presented by Waterman (1986) as illustrated in Figure 3. The development process includes (i) identification; (ii) conceptualisation; (iii) formalisation; (iv) implementation; and (v) testing. These steps are briefly described below.

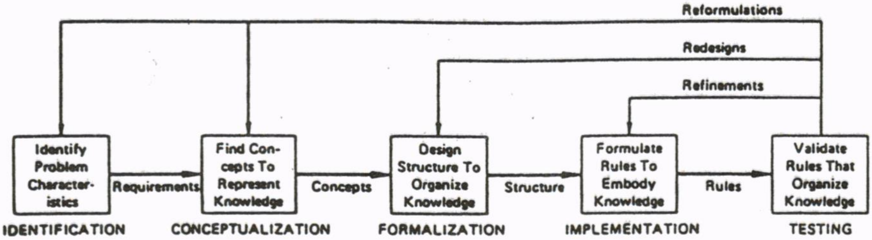

Figure 3 Stages of an Expert System Development
Source: (Waterman, 1986; pp. 139)

Identification: the objective of this study is to develop an expert system to assess both separate ES scores for different criteria and total ES index of each link in the road network The criteria considered are difficulty of access, pedestrian safety, and noise sensitivity. **Conceptualisation:** the current expert knowledge is derived from Singleton and Twiney (1985) as presented in Tables 1 and 2. Additional knowledge bases derived from other relevant sources (reports, research studies, publications etc) and from a series of interviews with human experts will be included as part of the ongoing research project. Multicriteria evaluation processes based on weighted summation method and AHP method were adopted to combine the separate ES scores to achieve the total ES indices. **Formalisation:** the structure of the Environmental Sensitivity Expert System (ES-ES) is illustrated in Figure 4. The VP-Expert shell was used as an expert system building tool and LOTUS 1-2-3 program will be employed to store all needed information.

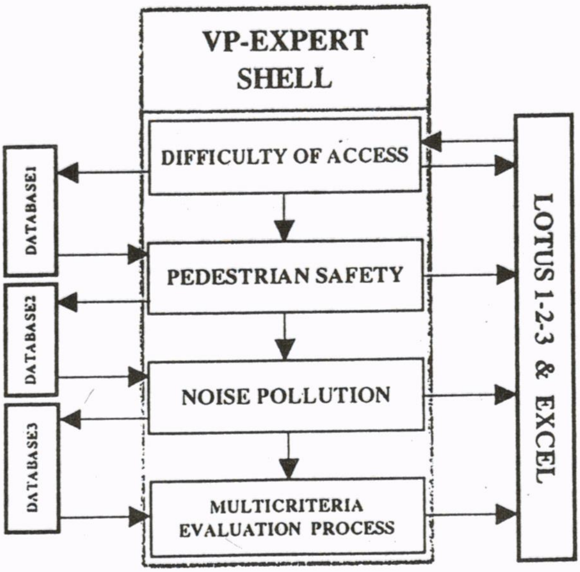

Figure 4 A Structure of the Prototype ES-ES

knowledge representation. Therefore the knowledge consists of a set of rules and is presented in the form of IF ...(premises)... THEN ...(conclusions)... ELSE ...(conclusions) statements. The control strategy used for this study is backward chaining. In addition, other components such as knowledge acquisition, explanation facility, context, and user interface, can be provided by VP-Expert. **Testing:** the last step is to test, evaluate, and modify the prototype expert system. The two testing methods, namely white-box testing and black-box testing, are being used to evaluate the ES-ES (Chau and Yang, 1994). The results of the testing step may lead to reformulating, redesigning, and refining activities as illustrated in Figure 3.

13. OPERATING THE PROTOTYPE ES-ES

The structure of the prototype ES-ES as shown in Figure 4 is composed of four knowledge base files: Difficulty of Access, Pedestrian Safety, Noise Pollution, and Multicriteria Evaluation Process. The operations of each knowledge base file and the whole integrated system are discussed below.

Difficulty of Access knowledge base file: this component was developed to perform the ES assessment for the difficulty of access criteria. Sub-variables required for this task are access availability, parking restrictions, and land-use categories. In this study the knowledge base file was designed to read all relevant information for each road link stored in a LOTUS file and then the backward chaining strategy was used to find the ES score. When all problem-solving processes are completed, the ES results for each link are saved in a database file (Database1) and written back to the same LOTUS file. Then the Difficulty of Access file is chained to the Pedestrian Safety knowledge base file. **Pedestrian Safety and Noise Pollution knowledge base files:** both components were developed to evaluate the ES scores for pedestrian safety and noise pollution criteria of each link in the road network. Identical integrated structures and operating procedures were used in the design of the two files for 'difficulty of access' and 'pedestrian safety'. The noise pollution knowledge base file is then chained to the multicriteria evaluation process file.

Multicriteria Evaluation Process knowledge base file: this component is firstly introduced to aggregate the separate ES scores of any link derived from the three criteria by using the weighted summation method of equation 1. All of the separate ES scores for each criteria of all links can then be loaded from the Database3 file. This information is used to conduct the combined ES assessment. The weighting values representing the relative importance of these three criteria are estimated from the AHP. The simple hierarchy structure of the criteria is illustrated in Figure 5 and the square matrix **A** formulated corresponding to the hierarchy structure and weighting values for each criteria are shown in Table 5. The results reveal that the respondents' judgment reflecting in matrix **A** is consistent (λ_{max} = 3.0183 (close to 3), CI = 0.0092, and CR = 0.0176 (< 0.1)). It should be noted that all these pairwise comparisons are arbitrarily established for the purpose of demonstration. Then the end results obtained from this knowledge base file are written back to the same LOTUS file.

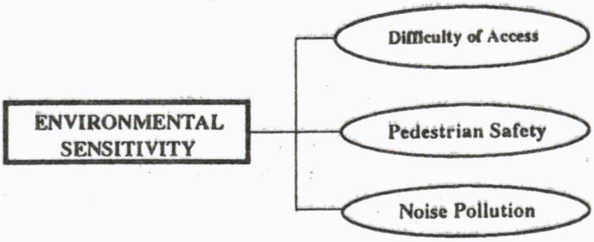

Figure 5 A Simple Hierarchy Structure of All Criteria

Table 5 A Reciprocal Square Metrix A and Weighting Values

CRITERIA	Difficulty of Access	Pedestrian Safety	Noise Level	Weights
Difficulty of Access	1	1/4	1/2	0.1365
Pedestrian Safety	4	1	3	0.6250
Noise Level	2	1/3	1	0.2385
Sum				1.0000

$\lambda_{max} = 3.0184, CI = 0.0092, CR = 0.0176.$

14. TESTING OF THE ES-ES

The testing methods used in this study are white-box testing and black-box testing (Chau and Yang, 1994). White-box (structural) testing is used to validate each module of the knowledge bases. This testing method employs the internal structure of the program, such as the command menu of VP-Expert (eg WHAT-IF, HOW, WHY, TRACE etc) to detect the syntax errors in each knowledge base file. In addition, the black-box (functional) testing is used to evaluate the whole system. This testing method is based on the functional performance of the system, rather than on its own structure. Each individual knowledge base module is tested independently and then the whole system is tested as an integrated unit. Originally, each knowledge base file is developed separately and then tested independently. For the first three files, approximately 30 per cent of all possible cases for each of those files were randomly tested and all the obtained results were positive. The intermodule dependencies and system performance were tested by using test cases. The printed results of the problem-solving process corresponding to the file and modular chaining of the first three knowledge base files are illustrated in Figure 6. The printed output from the Multicriteria Evaluation Process file is shown in Figure 7. All of the obtained results were correct.

15. THE INTERPRETATION

The TESI values derived from Figure 7 can be used to uncovered the ranking order corresponding to the degree of ES among examined road links. Links 3, 5, 1, 7, 4, 2 and 6 are increasingly ranked according to their total ES indices of 1.54, 2.22, 3.20, 3.47, 3.50, 4.25 and 4.52 respectively. Links 2 and 6 are the two highest TESI. The

```
==================================================================================
Link     AD       PR  LU    PF  RW  FPW    OF    G  SB   Access    Safety    Noise
==================================================================================
   1  Front      Low   1   Yes   1    2   Yes    3   2      Low    Medium     High
   2   Rear   Medium   2    No   2    3    No    5   4   Medium      High   Medium
   3     No     High   3   Yes   1    4   Yes    7   6     High       Low      Low
   4  Front      Low   3    No   2    2    No    3   2      Low      High      Low
   5   Rear   Medium   1   Yes   1    3   Yes    5   4   Medium       Low     High
   6     No     High   2    No   2    4    No    7   6     High      High   Medium
   7  Front     High   1   Yes   1    2   Yes    3   2   Medium    Medium     High
==================================================================================

AD = ACCESS DIFFICULTIES:
             Front - frontage access generally available
             Rear  - rear access available but frontage access restricted
             No    - no immediate access to site
                     Press any key to continue
PR = PARKING RESTRICTIONS:
             Low    - limited areas of no-standing, generally no restrictions
                      on on-street parking
             Medium - some park hour bans or limited duration parking controls
             High   - no standing or clearway controls at least 4 hours/day

LU = LAND USE:
             1 - Residential / School / Hospital
             2 - Retail / Commercial / Offices / Park
             3 - Industrial (light or heavy) / Railway

PF = PEDESTRIAN FACILITIES:
             No  - non-provision generally assumed
             Yes - existence of some facilities: medians, islands,
                   crossings, pedestrian phase at traffic signals, etc.

RW = WALKED ROAD WIDTH:
             Narrow - less than 2 traffic lanes
             Wide   - greater than or equal 2 traffic lanes
                   Press any key to continue

FPW = FOOTPATH WIDTH:
             Narrow - less than 3 metres
             Wide   - greater than or equal 3 metres

OF = OPPOSITE FACADE:
             Yes - existence of opposite facade generally assumed
             No  - if park/open space opposite, etc.

G = GRADE:
             Low  - less than 5 percent
             High - greater than or equal 5 percent

SB = BUILDING SETBACK:
             Small  - less than 2 metres
             Medium - greater than or equal 2 and less than 6 metres
             Large  - greater than or equal 6 metres

Access = ACCESS SENSITIVITY
Safety = SAFETY SENSITIVITY
Noise  = NOISE SENSITIVITY
```

Figure 6 A Printed Result of the First-three-file Chaining

```
---------------------------------------------------------
Link    Access    Safety     Noise   Total Sensitivity
---------------------------------------------------------
   1       Low    Medium      High          3.20
   2    Medium      High    Medium          4.25
   3      High       Low       Low          1.54
   4       Low      High       Low          3.50
   5    Medium       Low      High          2.22
   6      High      High    Medium          4.52
   7    Medium    Medium      High          3.47
---------------------------------------------------------
The scaling values assigned to all environmental sensitivity are:
                      Low      =  1
                      Medium   =  3
                      High     =  5

The weighing factors assigned to all environmental aspects are:
                 Access Difficulties =  0.1365
                 Pedestrian Safety   =  0.6250
                 Noise Pollution     =  0.2385
```

Figure 7 A Printed Result of the Muticriteria Evaluation Process File associated with the identified causes (criteria) of the problems within these links can be specified and traced back from the database stored in the LOTUS file. For example the TESI value of 4.52 in link 6 is considered as the highest degree of ES among those seven links. The descending rank of potential causes (criteria) contributing to the ES problems are: pedestrian safety (3.125 = (0.6250*5)); noise level (0.7155 = (0.2385*3)); and difficulty of access (0.6825 = (0.1365*5)). The contributing factors associated with these causes (criteria) can be achieved from the LOTUS file and also shown figure 6. However, it should be noted that although difficulty of access is classified as high degree of ES, it is considered to have less problem-generating potential than noise level. This is because the relative importance of noise level is much greater than difficulty of access and this situation can off set the effect of high degree of ES for difficult of access.

16. CONCLUSION

This paper presents the feasible analytical framework for integrating various environmental sensitivity aspects to assist traffic engineers and urban planners to adopt the suitable road hierarchy classification and traffic management schemes. However, the extension to explicitly incorporate other related aspects such as influences of traffic characteristics (eg volume, speed, composition etc), frontage related activities (eg number of pedestrians on footpath, jaywalkers and jayrunners etc) and pedestrian-vehicle accident aspects should be determined. The impacts on different groups of affected people must also be considered. In addition the appropriate traffic management schemes should be chosen on the grounds of public acceptability. This research is a part of on going research at the Transport Systems Centre (TSC), University of South Australia. The next stage is to integrate the refined Expert System (now using the KnowledgePro win++ package) with a Geographic Information System (GIS) (using either PC ARC/INFO or MapInfo packages), called Spatial Expert System (SES). The GIS is used to store, retrieve, manipulate and analyse the required spatial information and its attributes in the expertise domain contained in expert system module. In addition the GIS is also employed to address safety, amenity and environmental problems, their locations and intensities on any link within the road network. Consequently, merging expert system and GIS technologies is potentially a powerful tool for traffic engineers, urban planners and other decision makers.

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