APPLICATION OF A DECISION SUPPORT TOOL FOR THE MULTICRITERIA ENVIRONMENTAL SENSITIVITY EVALUATION OF THE URBAN ROAD NETWORK: THE CITY OF UNLEY CASE STUDY

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ABSTRACT

Road traffic is a major contributor to degradation of amenity and environment in urban areas. Such degradation varies, ranging from direct health hazards to annoyance effects, and includes both qualitative and quantitative aspects. The measurement and assessment of degradation is difficult and complex. A decision support tool has been developed to evaluate the multicriteria environmental sensitivity of urban road networks. It involves an integration of management science and knowledge-based expert systems (KBES) technology. This paper discusses the theoretical foundations and an application to the City of Unley road network in Adelaide Australia. The results indicate the potential utility of this tool to assess the combined environmental impacts of road traffic at the local level, identify problem locations, and suggest the possible causes and the factors contributing to such problems.

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1 Introduction

Road traffic is a major cause of the degradation of safety, environment and amenity in urban areas. This degradation includes air pollution, difficulty of access, noise and vibration, pedestrian crossing delays, pedestrian safety, severance, visual intrusion, fear and intimidation (Singleton and Twiney (1985); May (1988)). Local governments and other agencies attempt to control such problems by implementing different scales of traffic management schemes. The understanding of road traffic impacts on the adjacent environment is a prerequisite for such implementation. The estimation and assessment of these impacts is difficult and complicated. This is because while some impacts can possibly be quantified (eg air pollution and noise level etc), others can only be qualitatively measured (eg difficulty of access, fear and intimidation etc). In addition, both qualitative and quantitative impacts vary, ranging from direct health hazards to annoyance effects. The environmental sensitivity method (ESM) introduced by Singleton and Twiney (1985) can be used to accomplish such difficulties. The knowledge-based expert system (KBES) is a computer program containing judgmental and other heuristic expertise that emulates some aspects of the human behaviour in solving problems of various types (Maher (1987)). The ESM concept is well-suited to a KBES approach. In practice, both qualitative and quantitative impacts need to be measured and compared. This is because the trade-offs of relative importance between them and the combined impacts are fundamental in the identification of problem locations, determination of the problems and their possible causes and recommendation of appropriate remedial treatments. The multicriteria decision making (MCDM) approach can be used to handle this task.

This paper discusses the application of a decision support tool for the multicriteria ES evaluation of urban road networks. This tool has been developed from the integration of concepts from management sciences (MCDM) and the KBES technology and primarily based on the ESM concept. The utility-based method, called weighted summation, was adopted for MCDM process and the analytic hierarchy process (AHP) was employed to estimated the relative weights of various environmental criteria. An expert system shell, KnowledgePro for Windows, is being used to develop the prototype KBES for evaluating the multicriteria ES of urban road networks.

2 Methods for Assessing Traffic Environmental Impacts

Several methods have been developed to assess the safety, amenity and environmental consequences of road traffic in an urban road network. In Australia, Amenity Sensitivity (AS) (Loder & Bayley (1980)) was developed to specify the environmental and amenity impacts of road traffic on its adjacent environment. The method assigns a subjective score ranging from 1 (less sensitive) to 5 (highly sensitive) for each of the selected criteria and then sums the scores up to obtain a 'Composite Sensitivity Index' for a specific road section. This index is mainly relied on the experiences and judgement of traffic engineers or urban planners and may not lead to the comprehension of the actual interaction of road traffic and adjacent environment (Singleton and Twiney (1985)).

A more rigorous method introduced by Buchanan (1963) was Environmental Capacity (EC). Holdsworth and Singleton (1979) defined EC of a road as '*the maximum number of vehicles that should be permitted to pass along that road during a certain period of time and under fixed physical conditions without causing environmental detriment*'. Initially, the environmental standard for a given criterion is specified and then the numerical equation available for the criterion will be solved to yield the maximum traffic flow complying to the specified standard. Holdsworth and Singleton (1979) applied the EC in terms of noise pollution and pedestrian crossing delay to traffic management planning. Recently, Song *et al* (1993) expanded the Holdsworth-Singleton EC concept by including a pedestrian accident risk criterion. They also proposed the use of the geometric mean method to calculate the combined EC of various Ecs estimated for different criteria.

In practice, EC suffers from several limitations including: (i) the EC value can only be estimated for quantifiable criteria from a numerical equation; (ii) the inappropriate use of a single environmental standard as a specific criterion for all road sections regardless of road hierarchy classes and land use types; (iii) derived EC values are sometimes inappropriate or misleading; (iv) the use of only the minimum EC estimated for any single criterion among all others is unrealistic; (v) considerable time, effort and resources are needed for EC data collection and numerical computation (Holdsworth and Singleton (1980); Gilbert (1988); Chadwick (1990)).

3 Environmental Sensitivity Method (ESM)

Singleton and Twiney (1985) proposed the Environmental Sensitivity Method (ESM) as a means to evaluate the Environmental Sensitivity (ES) of road sections caused by road traffic. The ESM assumed that the physical and land use characteristics of a particular road section can be utilised to examine the ES of that road due to road traffic. The methodology falls between the simple and judgmental nature of the AS concept and the robust and objective nature of the EC approach. The ESM concept can be used to overcome some of EC's limitations. For example, ESM can handle both qualitative and quantitative criteria, take the effects of different land use types into consideration, tackle the high degree of numerical accuracy of estimated EC values, and reduce time, effort and resources required in EC estimation. The methodology is shown in Figure 1 and described below.

The Singleton-Twiney method was adapted as follows. A number of appropriate environmental criteria were selected and key factors contributing to each criteria were identified. Experiences with the EC concept were used to choose appropriate criteria, identify major contributing factors and establish the scales of measurement for various factors for each criterion. Table 1 shows the different measuring scales of several factors contributing to the noise level criterion. The road network in the study area was divided into a number of homogenous links according to the uniformity of physical characteristics; homogeneity of abutting land uses; spacing and complexity of road junctions, and derived link lengths. Then the road physical and land use data relevant to the contributing factors for each criterion of each side of each link were collected.

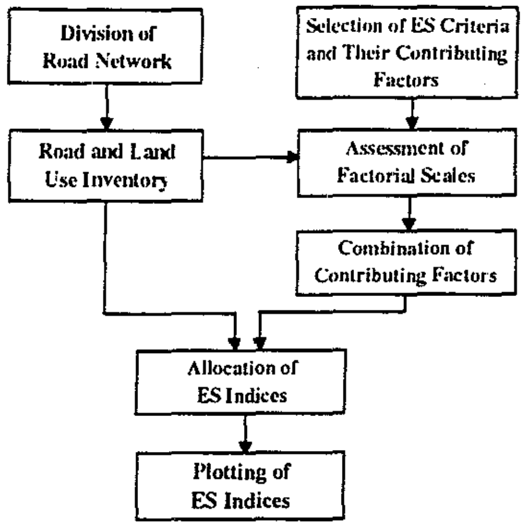

Figure 1 Environmental Sensitivity Method

Source: (Adapted from Singleton and Twiney (1985) p 179)

The measured value of each contributing factor for each criterion can then be compared with the corresponding measuring scales (see Table 1) and a score of each factor assigned accordingly. For each criterion, all derived scores of each factor were used to determine the ES index by using an established system for combination. Table 2 presents the decision table containing the knowledge extracted from the combination system for all contributing factors for the noise level criterion presented in Singleton and Twiney (1985). All decision rules given in Table 2 were encoded and stored in the noise level knowledge-based (KB) file of the prototype KBES, which is discussed later. Finally, the ES indices of different links for each criterion were then plotted separately.

Table 1 The Measuring Scales of Contributing Factors for Noise Level

Contributing Factors	Measuring Scales	Descriptions
Opposite facade	Yes	Existence of opposite facade generally assumed
	No	If park or open space opposite etc.
Road gradient	Low	Slight or flat (road gradient less than 5 %)
	High	Medium or steep (road gradient equal to or greater than 5%)
Building setback	Small	building setback less than 2 m.
	Medium	building setback equal to or greater than 2 m and less than 6 m.
	Large	building setback equal to or greater than 6 m.
Land use type	1	Residential/School/Hospital
	2	Retail/Commercial/Office/Park
	3	Industrial (light or heavy)/Railway

Source: (Adapted from Singleton and Twiney (1985), pp 174)

Table 2 Decision Table for Combining the Factorial Scores of Noise Level

Rule Number	Opposite Facade	Land Use Type	Road Gradient	Building Setback	Sensitivity Rates
1	-	1	Low	Large	Medium
2	-	1	-	-	High
3	Yes	2	-	Large	Medium
4	Yes	2	Low	Medium	Medium
5	Yes	2	-	-	High
6	Yes	3	-	Small	Medium
7	Yes	3	-	-	Low
8	No	2	-	Small	High
9	No	2	Low	Large	Low
10	No	2	-	-	Medium
11	No	3	-	-	Low

Remark: '-' sign means that, the factorial scores in that cell can be any defined ones, except the one which will produce the identical rule previously established.

The obtained ES indices of all links for each criterion can be used to indicate the locations of links which need special attention or remedial treatments for each particular criterion. In practice, it is essential to combine the separate ES indices estimated for different criteria of a given link in order to assess and compare the combined ES indices of all different links in a road network. Such indices can be utilised to uncover the ranking order among different road links according to the degree of the combined ES of each link. The resultant ranking order is of particular importance in prioritising the special investigation and allocating the government budget for implementation of traffic management schemes on different links in a road network. The multicriteria decision making (MCDM) approach can be used to combine both tangible and intangible criteria and to recognise differences in the relative importance of these criteria.

4 Multicriteria Decision Making (MCDM) Process

A number of techniques were established to deal with MCDM problems. These techniques include weighted summation, concordance analysis, ideal point analysis and analytic hierarchy process (Voogd (1983)). The most widely used and simplest one is weighted summation. In this paper, the weighted summation method is used to integrate all separate ES indices for different criteria to achieve the Composite Environmental Sensitivity Index (CESI) for each link of the road network as shown in equation 1 (Nijkamp *et al* (1990)). Then

$$CESI_i = \sum_{j=1}^{m} w_{jk} r_{ijk} \qquad (1)$$

$$\sum_{j=1}^{m} w_{jk} = 1, \; w_{jk} > 0$$

where: $CESI_i$ is the Composite Environmental Sensitivity Index of link i, (i = 1, 2,...., l); w_{jk} is the relative weight of criterion j in land use k, (j = 1, 2,....,m) and (k = 1, 2,...., n); and r_{ijk} is the ES index of link i for criterion j in land use k.

The identical ES scoring system to that used in Singleton and Twiney (1985) is applied to all selected criteria. An ordinal scale of 1, 2 and 3 is assigned to the ES indices (r_{ijk}) of 'low', 'medium' and 'high' respectively, based on the assumption that the ES indices have a linear relationship. The Analytic Hierarchy Process (AHP) is utilised to estimate the relative weights (w_{jk}) for each criteria in different land use types as described below.

5 Analytic Hierarchy Process (AHP)

Several mathematical techniques such as the trade-off method, rating method, ranking method and pairwise comparisons (Nijkamp *et al* (1990)) were developed to compute the relative weights among various decision elements. Pairwise comparison, known as the Analytic Hierarchy Process (AHP) have gradually become more popular than the other methods because of its simplicity, its theoretical robustness, its ability to handle both intangible and tangible criteria and its capability to directly determine the judgment consistency (Saaty (1994); Vargas (1990)). Therefore, AHP was used to estimate the relative weights of each criterion for each land use type.

AHP comprises a three-step process: (i) identifying and organising the decision elements into a hierarchical structure; (ii) estimating the relative importance of each decision element at each hierarchy level and determining the consistency of judgment; and (iii) synthesising the results of the pairwise comparisons over all the levels. The procedural steps of the AHP are illustrated in Figure 2 and briefly discussed as follows.

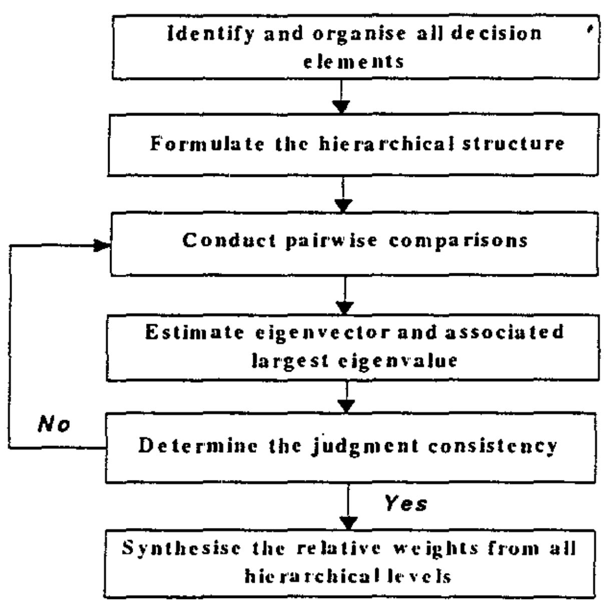

Figure 2 The AHP Flowchart Diagram

Each decision element of the problem is identified and the relationship among these elements is formed as the hierarchical structure. Then, pairwise comparisons of the decision elements at the same hierarchical level are conducted corresponding to the scale of relative importance ranging from 1 (equal importance of both elements) to 9 (extreme importance of one element over another) (Saaty (1980)). The derived pairwise comparisons of relative importance, $a_{ij} = w_i/w_j$, for all decision elements and their reciprocals, $a_{ji} = 1/a_{ij}$, are inserted into a square matrix $A = \{a_{ij}\}$ as shown in equation 2. The analytical solution of equation 3 then provides the relative weights for each element. According to the eigenvalue method (Saaty (1980)), the normalised eigenvector $(W = (w_1, w_2, ..., w_n)^T)$ associated with the largest eigenvalue (λ_{max}) of the square matrix A provides the weighting values for all elements.

$$A = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \quad (2)$$

$$AW = \lambda_{max} W \quad (3)$$

A Consistency Index (CI) is used to measure the degree of inconsistency in the matrix A (where, $CI = (\lambda_{max} - n)/(n - 1)$). Saaty (1994) compared the estimated CI with the same index derived from a randomly generated square matrix, called the Random Index (RI) as shown in Table 3. The ratio of CI to RI for the same order matrix is called the Consistency Ratio (CR). Generally, CR of 0.10 or less is considered acceptable, otherwise the matrix A should be revised to improve the judgmental consistency.

Table 3 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	1.40	1.45

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

The global relative weights for each decision element in the lowest hierarchical level can be obtained by multiplying its local weight by each of the global weights of their parent elements in the immediate higher level. Then the obtained results are summed over all parent elements. Saaty (1989) also introduced the use of the geometric mean method (GMM), as shown in equation 4, to aggregate different judgments from different decision makers. In GMM, the geometric means (a_{ij}^{gp}) of the paired comparisons conducted by each decision maker (a_{ij}^{k}) are inserted into the group pairwise comparison matrix and the eigenvalue method is used to estimate the group relative weights of all decision makers.

$$a_{ij}^{gp} = (a_{ij}^{1} \cdot a_{ij}^{2} \cdot a_{ij}^{3} \cdots a_{ij}^{k})^{1/n} = (\prod_{k=1}^{n} a_{ij}^{k})^{1/n} \quad (4)$$

where, $a_{ij}^{k} = (w_i / w_j)$ is an element of the square matrix A of a decision maker k.

6 Development of A Knowledge-Based Expert System (KBES)

Knowledge-based expert system (KBES) have evolved as a branch of artificial intelligence and have been successfully applied mostly in the field of medicine, chemistry, engineering and the military (Han and Kim (1990)). The KBES is defined as *"a computer program that emulates human behaviour in solving problems. It includes a separate reasoning mechanism that performs the same function as a human expert's brain"* (Cohn and Harris (1992)). The ESM approach involves and contains the judgment, experience and other heuristic expertise of human experts and is consequently well-matched to the KBES concept. In addition, a KBES can provide several other merits including: (i) reduction of time, costs and resources for solving a specific problem; (ii) increase of judgmental reliability; (iii) offering steady, unemotional and complete response at all time; (iv) dealing with real problems involving human behaviour, social and political considerations and multiobjective decision making process; and so on (Giarratano and Riley (1989); Cohn and Harris (1992); Yeh *et al* (1986)). Hence a prototype KBES was developed for the evaluation of the multicriteria ES of urban road networks (Klungboonkrong and Taylor (1995)).

In this study, the expert system shell KnowledgePro for Windows (KPWin) is used to develop the prototype KBES for the multicriteria ES evaluation of urban road networks. The structure of the KBES is illustrated in Figure 3 and briefly described below.

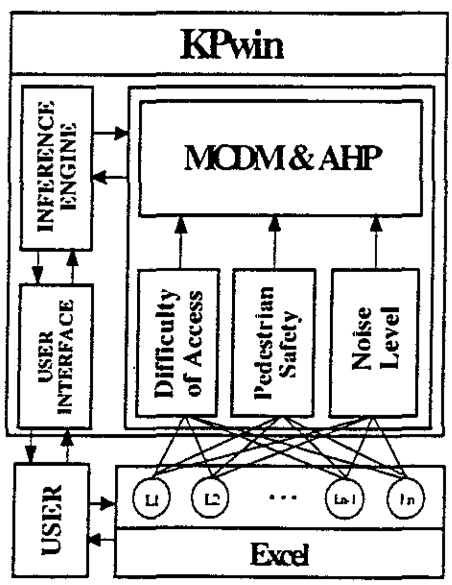

Figure 3 The Basic Structure of the Prototype KBES

Knowledge base: the knowledge base contains the knowledge derived from domain experts (ie people recognised as having special expertise and knowledge in the particular field). This knowledge includes judgments, facts or belief, rules of thumb, and other heuristic expertise. The knowledge base is the strength of the KBES (Yeh *et al* (1986)). The current KBES consists of four knowledge-based (KB) files. These are difficulty of access, noise level, pedestrian safety and multicriteria decision making (MCDM). The knowledge contained in the first three KB files was derived from the ESM concept with some refinement. The concept of decision table (Seagle and Duchessi (1995)) was used to extract the relevant knowledge from Singleton-Twiney factorial combination system for each criterion.
The knowledge stored in the last KB file was gleaned from direct interviews with three selected experts. The AHP method was adopted to transfer and aggregate the knowledge concerning the relative importance of various environmental criteria for different land use types from the selected experts to the prototype KBES. A rule-based structure is adopted as a knowledge representation. Therefore, the knowledge base consists of a set of rules and is represented in the form of IF *(conditions)* THEN *(conclusions)*. One example of a set of rules stored in the noise level KB file is given below.

IF *?Opposite_Facade = Yes*
AND *?Landuse_Type = 2*
AND *?Road_Gradient = Low*
AND *?Building_Setback = Medium*
THEN *Noise_Sensitivity = Medium.*

Inference mechanism: the inference mechanism is the control level of the KBES. This component will manipulate the relevant knowledge stored in the knowledge base to resolve the problem (Yeh *et al* (1986)). A control strategy used is backward chaining.
User interface: the user interface efficiently provides interactive two-way communication between user and the KBES.

In this study, the required information for each of difficulty of access, noise level and pedestrian safety KB files can be interactively entered by the user or directly imported from all data files stored in the Excel spreadsheet. The backward chaining strategy is adopted to resolve for ES indices of any link for each criterion. Subsequently, the derived ES indices will then be automatically input to the MCDM KB file which then estimated the CESI of all criteria for each link.

7 The Case Study Area

The City of Unley in Adelaide, Australia was adopted as a case study area. It is an inner suburban area immediately adjacent to the Adelaide Central Business District (CBD). Its road network is basically a grid system as illustrated in Figure 4. The focus of the case study was to assess the traffic environmental impacts on pedestrians and residents in land uses abutting the road network. The main roads which serve both traffic mobility and frontage related activity functions (eg access, shopping, etc) were the main subject of this study. Ten main roads in Unley were selected and these roads were divided into 23 homogeneous links as indicated in Figure 4 according to the suggestion given in Singleton and Twiney (1985).

The physical and land use characteristics along each of these divided links were gathered from existing data and field surveys. These include: (i) physical characteristics of the roads; (ii) pedestrian facilities; (iii) nature of parking restrictions; (iv) type and practicality of land use access; (v) adjacent land use categories; (vi) typical building setback from the property line; and (vii) building facade orientation. These data were refined and verified by using on-road video recordings, aerial photographs and other relevant documents. The database was established within a geographical information system (GIS) environment, namely MapInfo.

Previous research has indicated that residents living along busy roads are most concerned about four aspects, namely air pollution, noise, pedestrian crossing delay and pedestrian safety (Holdsworth and Singleton (1979); May (1988)). The three environmental criteria considered for the City of Unley case study were difficulty of access, noise level and pedestrian safety. The established AHP hierarchical structure is given in Figure 5. Three experts were asked to conduct pairwise comparisons of all selected criteria for each land use category. All land use categories were classified as given in Table 5. An example of the pairwise comparison matrices and the estimated relative weights is shown in Table 4. Because the estimated CR values for all matrices were less than 0.10, the resulting pairwise comparisons were considered consistent.

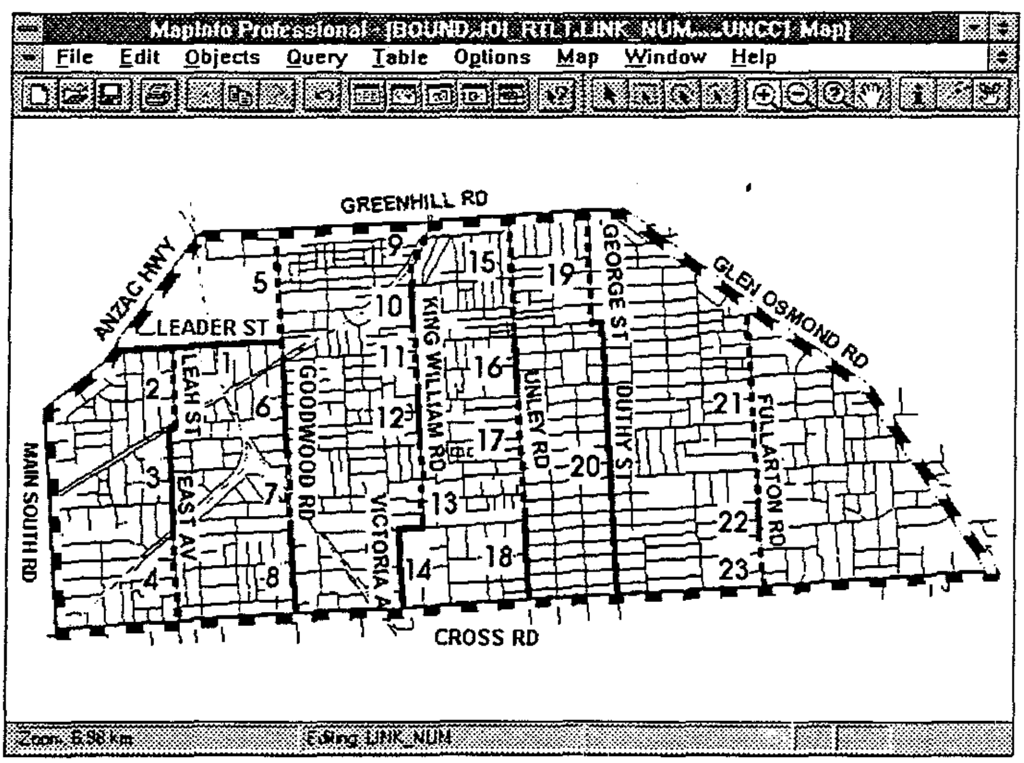

Figure 4 The City of Unley Road Network

The GMM was applied to integrate different judgments of the three experts and the estimated group relative weights were then employed to combine the separate ES indices of all criteria for each link in the MCDM process. The estimated group relative weights of all criteria for each land use type are presented in Table 5. The results of the interviews with three selected experts interestingly showed that the relative weights among the three criteria are relatively constant and barely vary with land use types.

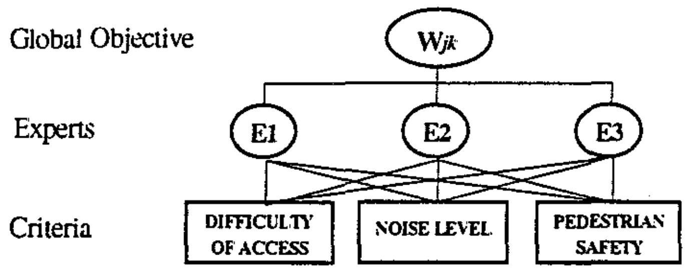

Figure 5 A Hierarchical Structure of Weight Estimation for Each Land Use Type

Table 4 Pairwise Comparisons of all Criteria for Land Use Type II by Expert 1

	(1)	(2)	(3)	Weights
(1) Difficulty of Access	1	1.5	1	0.3695
(2) Noise Level	1/1.5	1	1/2	0.2238
(3) Pedestrian Safety	1	2	1	0.4067

$\lambda_{max} = 3.009$ $CI = 0.005$, and $CR = 0.009$

Table 5 Group Relative Weights of All Criteria by Land Use Types

Land Use Types	Environmental Criteria		
	Difficulty of Access	Noise Level	Pedestrian Safety
(I) Residential/School/Hospital	0.3356	0.1604	0.5040
(II) Retail/Commercial/Office/Park	0.3535	0.1535	0.4931
(III) Industrial/Railway	0.4208	0.1172	0.4620

All information for each criterion of a specific link were interactively input to the KBES which then identified the resultant ES indices. Finally, the KBES estimated the CESI of all criteria for that link. The derived ES indices for the difficulty of access, noise level and pedestrian safety criteria of all links in the City of Unley are shown in Figure 6, 7 and 8, respectively. The estimated CESI values of all links are indicated in Figure 9.

8 Interpretation

As geographically identified in Figures 6, 7 and 8, all links with high ES indices are likely to lie on the busy roads. These links indicate the needs for special attention or remedial treatment regarding the difficulty of access, noise level and pedestrian safety criteria, respectively. The possible contributing factors for each criterion to such problems can be

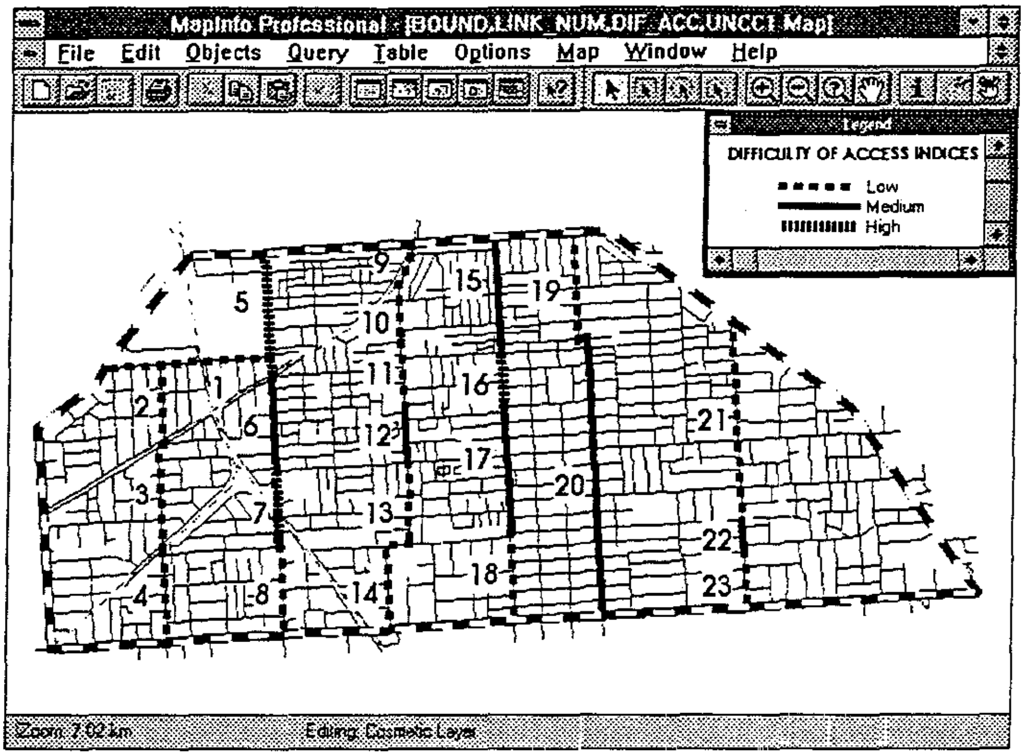

Figure 6 The Separate ES Indices for Difficulty of Access

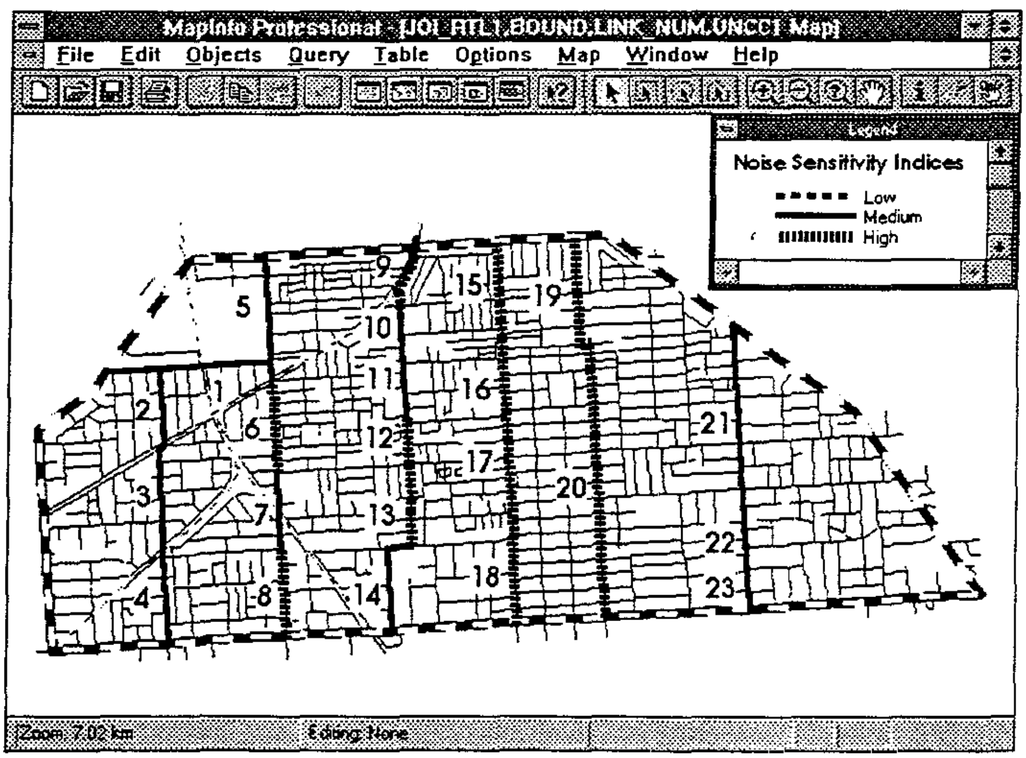

Figure 7 The Separate ES Indices for Noise Level

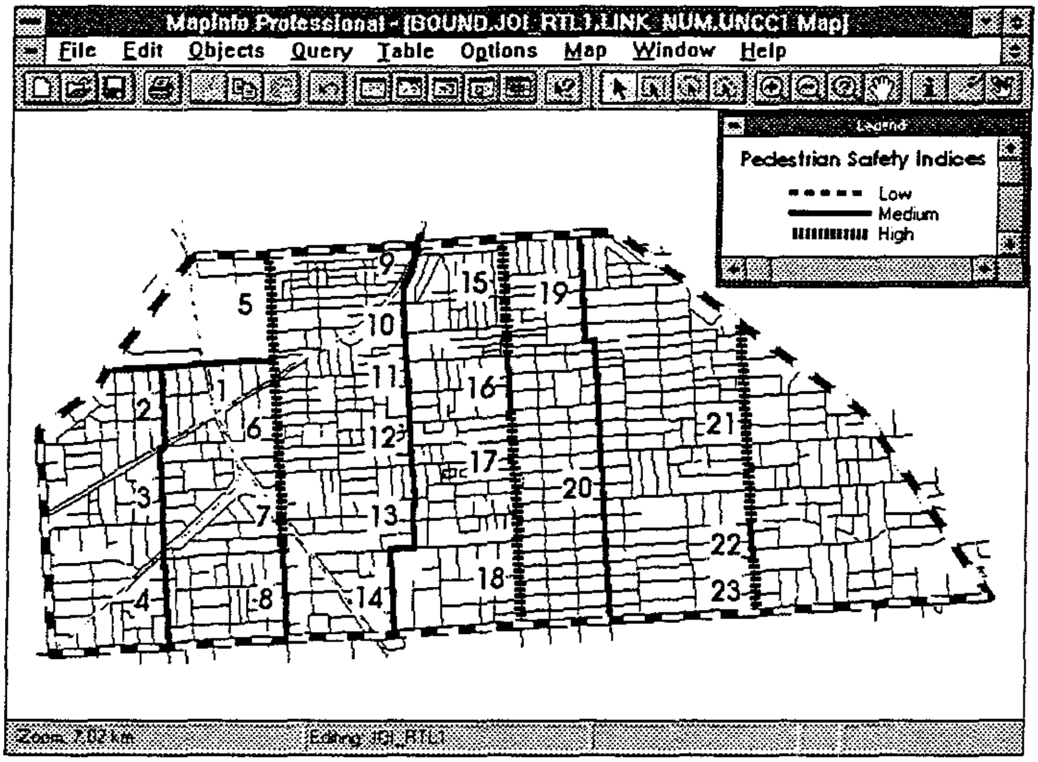

Figure 8 The Separate ES Indices for Pedestrian Safety

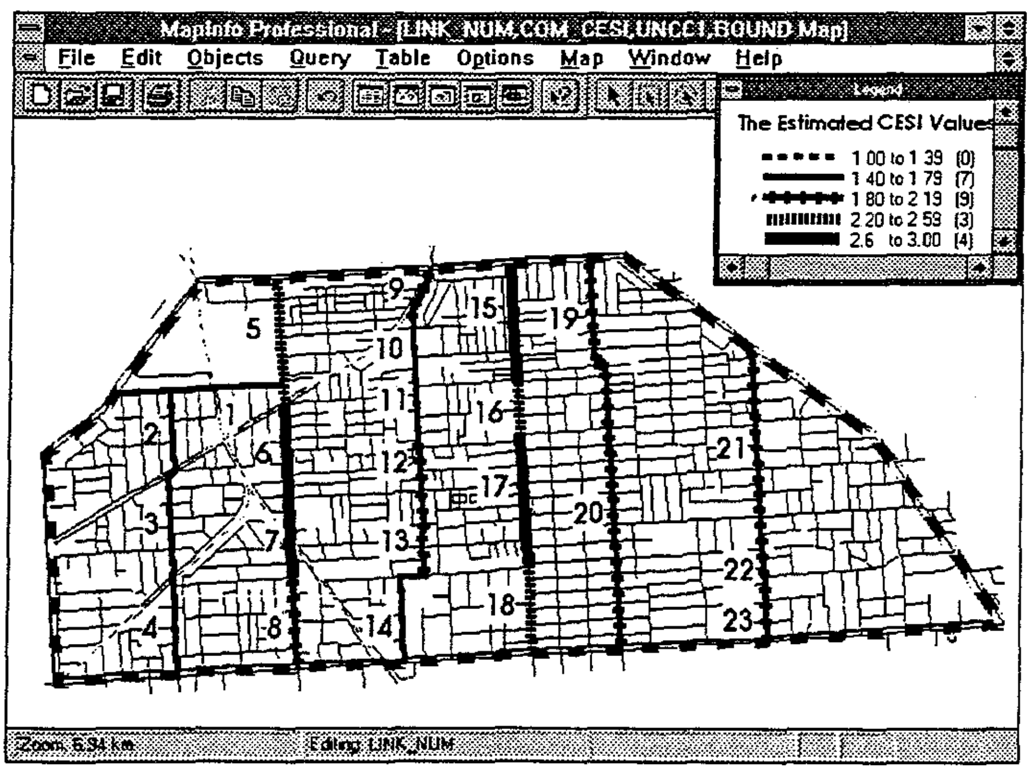

Figure 9 The Estimated CESI Values of All Links

identified from information of each link's road physical and land use characteristics contained in the KBES.

CESIs were used to assess the combined ES effects of different criteria for each link. Such indices can be utilised to identify problem locations and reveal the ranking order corresponding to the degree of the combined environmental impacts of each link. The direct comparisons of the resultant CESI values are valid, because the influences of land use types on the separate ES indices have already been taken into account in the KBES. As illustrated in Figure 9, seven links with high CESI values (CESI greater than 2.20) lie along the busy roads. The rank for those links according to the magnitudes of their CESI values in descending order are: link 7 ($CESI_7$ = 2.840); links 6, 15 and 17 (2.647); link 16 (2.507); link 5 (2.354); and link 18 (2.329).

In addition, the numerical composition of CESI values can also be used to indicate the possible causes of the problem for each link. For example, link 17 lying in land use type II along Unley Road has an estimated $CESI_{17}$ value of 2.647. The descending rank of likely causes (criteria) of the environmental problem on this link are: pedestrian safety (1.4793 = (0.4931 x 3)); difficulty of access (0.7070 = (0.3535 x 2)); and noise level (0.4605 = (0.1535 x 3)). It should be noted that although noise level scored a high degree of ES, it is considered to have less problem-generating potential than difficulty of access. This is because the relative importance of difficulty of access is much greater than noise level for the predominant land use type II and this condition can override the influence of a high degree of ES for the noise level criterion.

9 Limitations

The separate ES indices derived from the KBES has been based solely on the physical and land use characteristics of road concerned, but neglected other important factors such as the influences of traffic conditions (eg volumes, speed, heavy vehicle composition, etc), number of affected people (eg number of pedestrians and residents in abutting land uses) and others. This may lead to the misinterpretation of the obtained results. Further research is required to account for these effects in the KBES.

The relative weights used in the weighted summation method are based on a linear utility function, which has been applied for trade-off interpretation (Nijkamp *et al* (1990)). This implies that the method allows for a high degree of compensatory justification among different criteria. For example, a high ES index for a lower relative weight criterion can possibly be compensated by a low ES index for a higher relative weight criterion. Therefore, the results derived from this method must be carefully interpreted. The influences of all estimated relative weights for each criterion on the CESIs and their ranking order can be determined by using the sensitivity analysis. In addition, the relationship of different ES scores for all criteria was simply assumed to be a linear function. This assumption may not necessarily be correct for each or all criteria. The AHP method can be used reveal the actual relationship of these ES scores. Again, further research is needed to study the influences of compensatory justification.

10 Conclusion and Further Research Directions

This paper has presented the application of a decision support tool for assessing the multicriteria ES of urban road network. The decision support tool was developed as an integration of management sciences (MCDM and AHP) and a KBES. The results of the case study indicate the potential utility of the tool for assessing the combined environmental impacts of road traffic at a local level, identify problem locations, and specify the possible causes and the factors contributing to such problems. In addition, the tool can also be applied in prioritisation of links which require special investigation or budget allocation for remedial treatment implementation. Ongoing research with the tool is intended to explicitly incorporate other related parameters such as road traffic conditions (e.g. volume, speed etc.), frontage land use activities (e.g. number of residents, pedestrians and visitors etc.) and so on. The current state of the decision support tool will be expanded and refined. It will be integrated with a GIS (MapInfo), to develop a Spatial Expert System (SES). The end result of this SES should be a comprehensive and powerful decision support tool for traffic engineers and urban planners.

References

Buchanan, C. (1963). *Traffic in Towns*. (HMSO: London).

Chadwick, N. (1990). "Computer aided environmental traffic design." *Proceedings of Seminar G, P 334. The 16th PTRC Summer Annual Meeting on Traffic Management and Road Safety*. pp 95-106.

Cohn, L.F. and Harris, R.A. (1992). *Synthesis of Highway Practice 183: Knowledge Based Expert Systems in Transportation: A Synthesis of Highway Practice, NCHRP Synthesis 183*. (Transportation Research Board: Washington DC).

Giarratano, J. and Riley, G. (1989). *Expert Systems: Principles and Programming*. (PWS-KENT: Boston).

Gilbert, D. (1988). "The environmental capacity approach to the generation of urban traffic schemes." *Proceedings of Seminar M, P 314. The 16th PTRC Summer Annual Meeting on Environmental Issues*. pp 86-101.

Han, S.Y. and Kim, T.J. (1990). "Intelligent urban information systems: review and prospects." In T.J. KIM, L.L. WIGGINS, and J.R. WRIGHT (Eds), *Expert Systems: Applications to Urban Planning, Chapter 15*, pp 241-64 (Springer-Verlag).

Holdsworth, J. and Singleton, D.J. (1979). "Environmental traffic capacity of roads." *Papers of the Australasian Transport Research Forum*, 5, pp 219-38.

Holdsworth, J. and Singleton, D.J. (1980). "Environmental capacity as a basis for traffic management at local government level." *Proceedings 10th ARRB Conference*, 10 (5), pp 165-74.

Klungboonkrong, P. and Taylor, M.A.P. (1995). "Application of an expert system in the multicriteria environmental sensitivity evaluation of urban road network." *Journal of the Eastern Asia Society for Transportation Studies*, 1 (2), pp 469-486.

Loder and Bayley (1980). *Road/Amenity Classification - A Practical Tool for Traffic Management.* Road Safety and Traffic Authority, Hawthorn, Victoria.

May, A.D. (1988). "Transport and the environment in major cities." *Proceedings of Seminar M, P 314. The 16th PTRC Summer Annual Meeting on Environmental Issues.* pp 33-42.

Maher, M.L. (1987). *Expert System for Civil Engineers: Technology and Application.* (American Society for Civil Engineering (ASCE)).

Nijkamp, P., Rietveld, P. and Voogd, H. (1990). *Multicriteria Evaluation in Physical Planning.* (North-Holland: Amsterdam).

Saaty, T.L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation.* (McGraw-Hill International Book Company).

Saaty, T.L. (1989). "Group decision making and the AHP." In B.L. GOLDEN, E.A. WASIL and P.T. HARKER (Eds), *The Analytic Hierarchy Process: Applications and Studies*, pp 59-67 (Springer-Verlag).

Saaty, T.L. (1994). "How to make a decision: the analytic hierarchy process." *Interfaces* , 24 (6), pp 19-43.

Seagle, J.P. and Duchessi, P. (1995). "Acquiring expert rules with the aid of decision tables." *European Journal of Operational Research*, 84, pp 150-162.

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

Song, L., Black, J. and Dunne, M. (1993). "Environmental capacity based on pedestrian delay and accident risk." *Road & Transport Research*, 2 (3), pp 40-49.

Vargas, L.G. (1990). "An overview of the analytic hierarchy process and its applications." *European Journal of Operational Research*, 48, pp 2-8.

Voogd, H. (1983). *Multicriteria Evaluation for Urban and regional Planning.* (Pion Ltd: London).

Yeh, C., Ritchie, S.G. and Schneider, J.B. (1986). "Potential applications of knowledge-based expert systems in transportation planning and engineering." *Transportation Research Record (TRR) 1076*, pp 59-65.