Application of knowledge-based expert system, Analytic Hierarchy Process and Fuzzy Set Theory in Multicriteria Environmental Sensitivity Evaluation of The Urban Road Network

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Abstract

This paper describes the theoretical foundation and application of a decision support tool for evaluating the multicriteria Environmental Sensitivity (ES) of the Geelong road network, in Victoria, Australia. The tool is an integration of the Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST), and Knowledge-Based Expert System (KBES). In AHP synthesis phase, both principle of hierarchic composition and the fuzzy compositional evaluation methods were applied to synthesize all local priorities to derive global priorities (the Composite Environmental Sensitivity Indices (CESI)) of all road links. The results of the case study indicate the potential utility of the tool for assessing the environmental sensitivity of urban road network at a local level, identify problem locations, and specify the possible causes of those problems. In addition, it is found that the typical AHP expresses more powerful capability in differentiating links according to their combined ES characteristics than the fuzzy compositional AHP.

Introduction

Residents and pedestrians who live or perform their activities adjacent to main roads in urban areas have often suffered from pedestrian danger, amenity degradation and adverse environmental impacts caused by road traffic. These people are gradually becoming more aware of these effects. The adverse impacts includes air pollution, difficulty of access, noise and vibration, pedestrian crossing delays, pedestrian safety, severance, visual intrusion, fear and intimidation. Although some impacts can possibly be quantified (e.g. air pollution and noise level), others can only be qualitatively measured (e.g. difficulty of access and visual intrusion). In addition, both qualitative and quantitative environmental impacts vary, ranging from direct health hazards to annoyance effects. The estimation and assessment of such impacts is therefore difficult and complicated. A decision support tool has been developed to evaluate the multicriteria environmental sensitivity of urban road networks. It is an integration of the Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST), and Knowledge-Based Expert System (KBES). This paper is organized to present the following topics: (i) Environmental Sensitivity Methodology (ESM) concept; (ii) Analytic Hierarchy Process (AHP) methodology; (iii) introduction to Fuzzy Set Theory (FST) and Fuzzy Compositional Evaluation method; (iv) Fundamental Structure of the prototype KBES; (v) the Geelong case study; (vi) the results' interpretation and comparison; and finally (vii) the conclusion.

Environmental Sensitivity Methodology (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 utilized to determine the ES of that road due to road traffic. The methodology is shown in Figure 1 and described below.

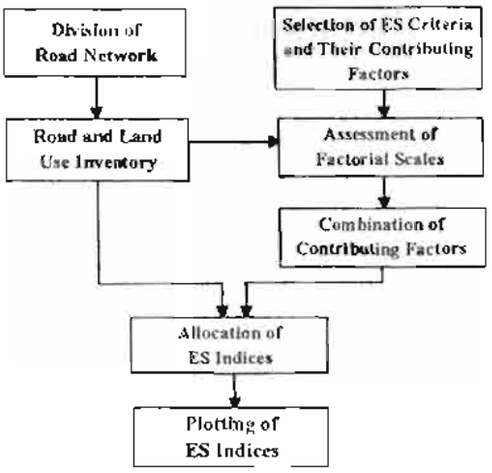

Figure 1: Environmental Sensitivity Method
Source: (Adapted from Singleton and Twiney (1985), p. 179)

The Singleton-Twiney method was adapted as follows. A number of appropriate environmental criteria were selected and key factors contributing to each criterion were identified. For example, Table 1 shows the different measuring scales of several factors contributing to the noise sensitivity criterion. The road network in the study area was divided into a number of homogenous links as suggested by Singleton and Twiney (1985). Then the road physical and land use data relevant to the contributing factors for each criterion of both sides of each link were collected. The measured value of each contributing factor for each criterion will 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. Based on the decision table concept (Seagle and Duchessi, 1995), Table 2 presents several decision rules containing the knowledge extracted from the combination system for all contributing factors for the noise sensitivity criterion presented in Singleton and Twiney (1985). All decision rules given in Table 2 were encoded and stored in the noise sensitivity 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 a 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	*High*	*Medium*	*High*
4	*No*	2	*Low*	*Large*	*Low*
5	-	2	-	*Small*	*High*
6	-	2	-	-	*Medium*
7	*Yes*	3	-	*Small*	*Medium*
8	-	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.

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 combined indices can be utilized 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

prioritizing the special investigation on different links in a road network and functional road hierarchy classification.

Analytic Hierarchy Process (AHP)

AHP is a mathematical method used to determine the priorities of different decision alternatives via pairwise comparisons of decision elements with respect to a common criterion. The pairwise comparison approach coupled with a ratio scaling method has been used to uncover the relative importance among all decision criteria in multiple attribute decision-making environments. The AHP is becoming more popular over other methods employed in the decision making process, because of its simplicity, its promising accuracy, its theoretical robustness, its ability to handle both intangible and tangible criteria and importantly, its capability to directly measure the inconsistency of respondent's judgments (Saaty, 1980 and Vargas, 1990). Therefore, AHP was used in this study. The following discussion is mainly based on the context of the Geelong case study, which will be described in detail later. The AHP is based on three principles as discussed below (Saaty, 1980):

Decomposition: A hierarchical structure is established by decomposing the complex problem into a hierarchy of interrelated decision elements. This structure is the key to interrelate and chain all decision elements of the hierarchy from the top level down to the bottom. The global objective (estimation of CESIs of all road links) is placed at the top of the hierarchical structure. The lowest level of the hierarchy structure consists of more detailed elements (ES indices (e.g. low, medium and high)) which interrelate to the parent elements (environmental criteria) in the next higher level. Typically, the alternatives are contained in the lowest level of the hierarchy. This study used the AHP absolute mode approach. Therefore, all road links (alternatives) was not pairwise-compared directly, but each link was assigned its ES scores for each criterion according to the knowledge contained in the prototype KBES based on the ESM concept. The absolute mode approach is very useful and practical, particularly when dealing with numerous decision alternatives. The hierarchical structure for this study is presented in Figure 2.

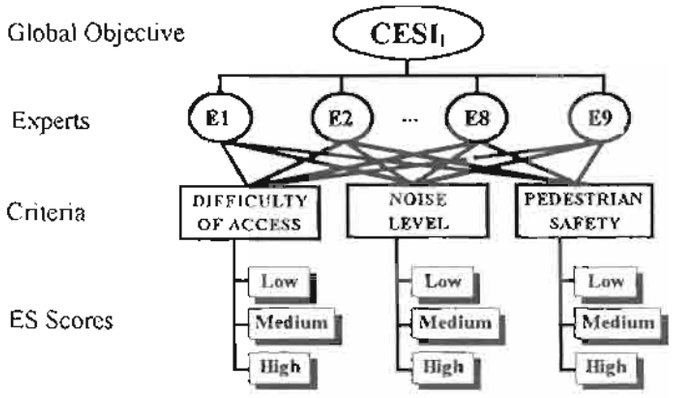

Figure 2: A Hierarchical Structure of the CESI Estimation for Each Land Use Type

Prioritization: Once the hierarchical structure was established, the relative importance (weights) of all decision elements is explicitly captured and revealed through ratio scale approach. Pairwise comparisons of these elements within the same hierarchical level with respect to the parent elements in the next higher level are established. The numerical scales ranging from 1 (equal importance) to 9 (absolute importance) (Saaty, 1980) are used in the pairwise comparisons. The input data can be achieved from individual interviews of several experts. Several sets of pairwise comparison matrices of elements in the same level which attribute to accomplishing the goals of the parent element in the next higher level are finally obtained as shown in equation 1. For each expert, 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 reciprocal square matrix $A = \{a_{ij}\}$ as shown in equation 1.

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

The analytical solution of equation 2 then provides the relative weights for each decision element. According to the eigenvalue method (Saaty (1980)), the normalized right eigenvector $(W = \{w_1, w_2, \ldots, w_n\}^T)$

associated with the largest eigenvalue (λ_{max}) of the square matrix A provides the weighting values for all decision elements.

$$AW = \lambda_{max} W \tag{2}$$

A Consistency Index (CI) is used to measure the degree of inconsistency in the square matrix A (where, $CI = (\lambda_{max} - n)/(n-1)$). Saaty (1980) compared the estimated CI with the same index derived from a randomly generated square matrix, called the Random Consistency Index (RCI) as shown in Table 3. The ratio of CI to RCI for the same order matrix is called the Consistency Ratio (CR). The judgmental consistency of each expert will be determined. Generally, a CR of 0.10 or less is considered acceptable, otherwise the matrix A will be revised to improve the judgmental consistency.

Table 3:
The Random Consistency Index (RCI)

n	1	2	3	4	5	6	7	8	9
RCI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

Source: (Adapted from Saaty (1994), p. 42)

The Geometric Mean Method (GMM) (Saaty, 1989), as shown in equation 3, was employed to aggregate different judgments from several experts. It should be noted that only consistent expert judgments would be included in this step.

$$a_{ij}^{gp} = (a_{ij}^{1} \cdot a_{ij}^{2} \cdot \ldots \cdot a_{ij}^{h} \cdot \ldots \cdot a_{ij}^{H})^{1/H} = (\prod_{h=1}^{H} a_{ij}^{h})^{1/H} \tag{3}$$

where, $a_{ij}^{h} = (w_i / w_j)$ is an element of the square matrix A of a decision maker h; (a_{ij}^{gp}) is the geometric mean of the paired comparisons conducted by each expert; and H is the total number of human experts.

Synthesis: The weighting values for all decision elements at the lowest hierarchical level are derived from the "Principle of Hierarchic Composition" as shown in equation 4.

$$\mu_i = \sum_{j=1}^{n} \mu_j \mu_{ij} \tag{4}$$

where, μ_i is a global weights of an decision element i; μ_j is a local weight of a criterion j; and μ_{ij} is a local weight of an assigned ES index of link i for criterion j. Equation 4 means that the global relative weight of any decision element i can be obtained from the summation of multiplication of the relative weights of criteria and those of the corresponding ES indices of link i across all criteria. This can be considered as a compensatory Multi-Attribute Decision Making (MADM) approach.

The Fuzzy Compositional Method

In this study, the fuzzy compositional AHP (AHP using the fuzzy compositional evaluation method) has also been applied to investigate and compare the obtained results with those of the typical AHP (AHP using the principle of hierarchic composition). Prior to discussing the fuzzy compositional evaluation method, the basic concept of fuzzy set theory is introduced and described.

The Fundamental Basis of Fuzzy Set Theory

Zadeh (1965) introduced the fuzzy set concept as a collection of elements and its degree of belonging, called grade of membership. This can be achieved by adopting the concept of a membership function to assign a number ranging from zero (absolutely not belonging) to unit (fully belonging) according to the degree (grade) of belonging to each element of a universe of discourse. Suppose that $X = \{x\}$ is a universe of discourse. Then a fuzzy set (subset) A in X is defined as a set of ordered pairs $\{(x, \mu_A(x))\}$, where $x \in X$ and $\mu_A : X \rightarrow [0, 1]$ is the membership function of A; $\mu_A(x) \in [0, 1]$ is the grade of membership of x in A (Fedrizzi and Kacprzyk, 1995). The fuzzy subset A of X is expressed in equation 5 for an infinite universe of discourse.

$$A = \int_X \mu_A(x) / x \tag{5}$$

where $\mu_A(x)/x$, called a singleton, is a pair of grade of membership and element of a fuzzy set A and the '∫' signs indicates a union operation in the ordinary set theory.

The Fuzzy Relation and Fuzzy Compositional Evaluation

$X = \{x_1, x_2, \ldots, x_n\}$ is defined as a criterion set containing all selected criteria to be determined. $Y = \{y_1, y_2, \ldots, y_m\}$ is defined as an evaluation set consisting of all decision elements (road links) to be evaluated with respect to each criterion in X. The fuzzy relation, R, from X to Y, called fuzzy evaluation matrix, is a fuzzy set in the Cartesian product of X and Y ($X \times Y = \{(x, y) \mid x \in X, y \in Y\}$. The fuzzy relation, R, is characterized by membership function μ_R (x, y) and is defined as $\boldsymbol{R} = \boldsymbol{X} \times \boldsymbol{Y} = \{\mu_R(x,y)/(x,y) \mid x \in X \text{ and } y \in Y\}$ and shown in equation 6 (Grivas and Shen, 1995). Therefore,

$$\boldsymbol{R} = \begin{bmatrix} \mu_R(x_1, y_1) & \mu_R(x_1, y_2) & \cdots & \mu_R(x_1, y_m) \\ \mu_R(x_2, y_1) & \mu_R(x_2, y_2) & \cdots & \mu_R(x_2, y_m) \\ \cdot & & \vdots & \vdots \\ \mu_R(x_n, y_1) & \mu_R(x_n, y_2) & \cdots & \mu_R(x_n, y_m) \end{bmatrix} \quad (6)$$

where $\mu_R(x_n, y_m)$ is a membership function of a fuzzy relation from a criterion, x_n in a criterion set X to a evaluated element, y_m in a evaluation set Y. A is a fuzzy set in set X and characterized by membership function $\mu_A(x)$ and is denoted as $\boldsymbol{A} = \{\mu_A(x)/x \mid x \in X\}$. A is called weight vector of X.

$\mu_A(x_i)$ is a fuzzy weighting value of criterion x_i in X. Therefore,

$$A = \left\{\mu_A(x_1),\ \mu_A(x_2),\ \cdots,\ \mu_A(x_n)\right\} \quad (7)$$

In this study, the max-min composition is used because it has been well researched and widely used in various applications (Lin and Shieh (1995); Zimmermann (1996)). The fuzzy relational composition, B, of a fuzzy set A and a fuzzy relation R is denoted as $B = A \circ R$. The membership function of B is denoted as

$$\mu_B(y) = \mu_{A \circ R}(y) = \bigvee_{x \in X} \{\mu_A(x) \wedge \mu_R(x,y)\} = \max_{x \in X} \min \left[\mu_A(x),\ \mu_R(x,y)\right] \tag{8}$$

Equation 8 indicates that for each criterion (x), the grade of membership (relative weight) of that specific criterion is compared to the grade of membership of the derived ES index of a link (y) for the same criterion. The minimum of these two values is kept and then compared with the similar values for the remaining criteria. The maximum of all minimum values for every criterion is used to represent the final fuzzy compositional evaluation (CESI value). Therefore, the CESI value of each decision element is solely determined according to the most critical criterion. This method is therefore the non-compensatory approach.

Basic Structure of a Knowledge-Based Expert System

The ESM approach involves and contains the judgments, experiences and other heuristic expertise of human experts and is consequently well matched to the KBES concept. Hence a prototype KBES was developed for the evaluation of the multicriteria ES of urban road networks (Klungboonkrong and Taylor, 1995 and 1996). In this study, the expert system shell KnowledgePro for Windows (KPWin) was used to develop the prototype KBES for the multicriteria ES evaluation of urban road networks. The selection of the expert system shell and the KBES development procedures used in this paper are discussed elsewhere (Klungboonkrong and Taylor, 1995). In addition, the prototype KBES will be linked with the GIS (MapInfo) package to geographically display the analyzed results. The fundamental structure of the KBES is illustrated in Figure 3 and briefly described below.

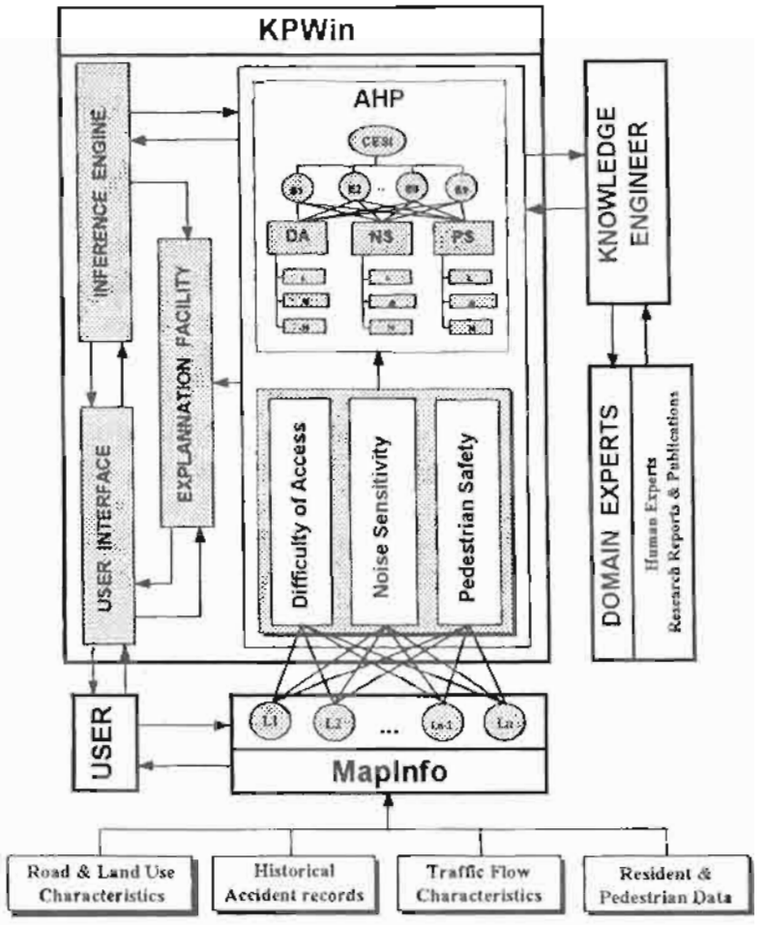

Figure 3: The Basic Structure of the Prototype KBES

Knowledge base: the knowledge base contains the knowledge derived from human experts (ie. people recognized as having special expertise and knowledge in a particular field) and research papers, study reports and other related publications. The current KBES consists of four main knowledge-based (KB) files. These are difficulty of access, noise sensitivity, pedestrian safety and AHP. The knowledge contained in the first three KB files was mainly derived from the ESM concept (Singleton and Twiney, 1985) and the structured interview with the expert who developed the ESM concept. The decision table concept (Seagle and Duchessi, 1995)) was used to extract and reformulate the relevant knowledge from the Singleton-Twiney factorial combination system for each corresponding criterion. In addition, the interview with this expert

provided the important explanation for each derived decision rule. For the AHP file, the knowledge regarding the relative importance (weighting values) of all environmental criteria for each land use type and the relative importance of all ES indices for each criterion was gleaned from structured interviews with nine experts. The AHP approach was used to transfer and aggregate this knowledge from these experts. All of the knowledge described previously was encoded and stored in 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).*

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 concerned problem. The control strategy used is backward chaining. Explanation facility: the explanation facility is used to provide the reasons for each derived conclusion. User interface: the user interface efficiently provides interactive two-way communication with the user, the prototype KBES and other packages. In this study, the required information (the physical and land use characteristics of each link in the road network) for difficulty of access, noise level and pedestrian safety KB files was directly entered into the prototype KBES. The backward chaining strategy is used to resolve for ES indices of any road links for each criterion. Subsequently, the derived ES indices will then be automatically input to the AHP file. Finally, the CESIs based on both the typical AHP and the fuzzy compositional AHP of each link will be achieved.

The Geelong Case Study

The Geelong's Road Network

The City of Geelong, in Victoria, Australia was adopted as a case study area. Its road network is basically a grid system as illustrated in Figure 4. The main roads, which serve both traffic mobility and frontage related activity functions (e.g. access, shopping, etc.) were the main subject of this study. As illustrated in Figure 4, several main roads in Geelong were selected and these roads were divided into 66 homogeneous links according to the criteria suggested by Singleton and Twiney (1985). The physical and land use characteristics along each of these divided links were gathered from available data obtained from Ove

Arup Transportation Planning (1989), a raster image of an aerial photograph of the central Geelong area and other sources. This database was established within a GIS (MapInfo) environment. The analysis results will also be illustrated by using MapInfo. Three criteria selected for the Geelong case study were difficulty of access, noise level and pedestrian safety. Nine selected experts (e.g. local government officers, urban planners, traffic engineers, etc.) were directly interviewed. Based on their experiences and expertise, these experts served the community as the 'measuring instrument' in determining the relative weights of these criteria for each land use type and those of all ES indices for each criterion. All land use types were classified according to Singleton and Twiney (1985) and indicated in Table 6.

The AHP Methodology

The decision problem is formulated as the hierarchical structure and the relationship among these decision elements contained in each hierarchical level is illustrated in Figure 1. Each example of the pairwise comparison matrices and the estimated relative weights of the three selected criteria for each land use type and those of all ES indices for each criterion are shown in Table 4 and 5, respectively. The estimated CR values for these two matrices were less than 0.10, these resultant pairwise comparisons were considered consistent. The GMM was then applied to aggregate different judgments of the nine experts and the estimated group relative weights of three selected criteria for each land use type and all ES indices for each criterion were finally achieved as presented in Tables 6 and 7 respectively. The derived group preferences were tested and found to be consistent

Table 4:
Pairwise Comparisons of all Criteria for Land Use Type II by Expert 3

	(1)	(2)	(3)	Weights
(1) Difficulty of Access	1	1.5	2/3	0.3189
(2) Noise Level	1/1.5	1	1/2	0.2211
(3) Pedestrian Safety	3/2	2	1	0.4600

$\lambda_{max} = 3.002$, $CI = 0.001$, and $CR = 0.001$

Table 5:
Pairwise Comparisons of all ES Indices for Noise Level Criterion by Expert 3

	(1)	(2)	(3)	Weights
(1) Low	1	1/4	1/8	0.0702
(2) Medium	4	1	1/4	0.2227
(3) High	8	4	1	0.7071

$\lambda_{max} = 3.054$, $CI = 0.027$, and $CR = 0.052$

Table 6:
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	0.2755	0.3155	0.4090
(II) Retail/Commercial/Office/Park	0.3477	0.1886	0.4636
(III) Industrial/Railway	0.6067	0.1248	0.2685

Table 7:
Group Relative Weights of All ES Indices by Criteria

Environmental Criteria	ES Indices		
	Low	Medium	High
(1) Difficulty of Access	0.0976	0.2692	0.6332
(2) Noise Level	0.0856	0.2495	0.6649
(3) Pedestrian Safety	0.0853	0.2644	0.6503

It should be noted that as shown in Table 6, the relative weights among those three selected criteria clearly vary with land use types. As indicated in Table 7, the relative weights (numerical values) of all ES indices for the three criteria are almost identical. The relative weights of '*low*' and '*medium*' are significantly lower than that of '*high*'. This implies that the derived relationship among these ES indices is non-linear.

Interpretation

As an illustration, all ES indices of all links for a pedestrian safety criterion are illustrated in Figure 4. All links which have been identified as the '*high*' ES index can be determined as the problem locations for the pedestrian safety criterion. A similar interpretation can be applied to the remaining criteria. For the CESI estimations, by using the typical AHP approach, it should be noted that the estimated weights of all ES indices for each criterion were normalized by dividing by the maximum weight of these estimated ES indices prior to performing the calculations. Link 25 lying in land use type I was assigned the '*medium*', '*high*' and '*high*' ES indices for difficulty of access, noise level and pedestrian safety, respectively. Based on the principle of hierarchic composition, the estimated CESI of link 25 is 0.842 ({0.276×0.425}+{0.316×1.000}+{0.409×1.000}). All CESI values estimated for every link in the Geelong road network were arbitrarily grouped into six intervals as illustrated in Figure 5

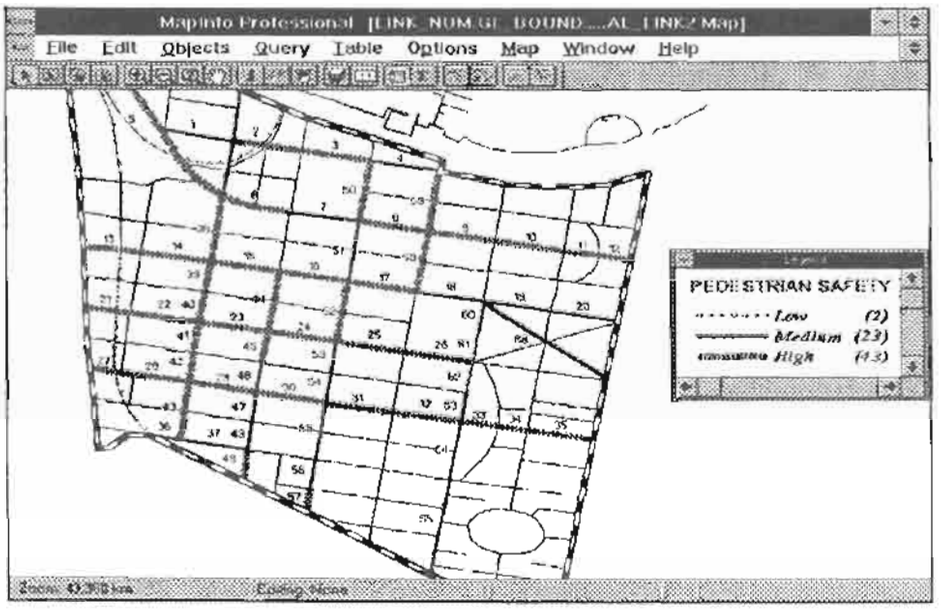

Figure 4: The ES Indices for Pedestrian Safety

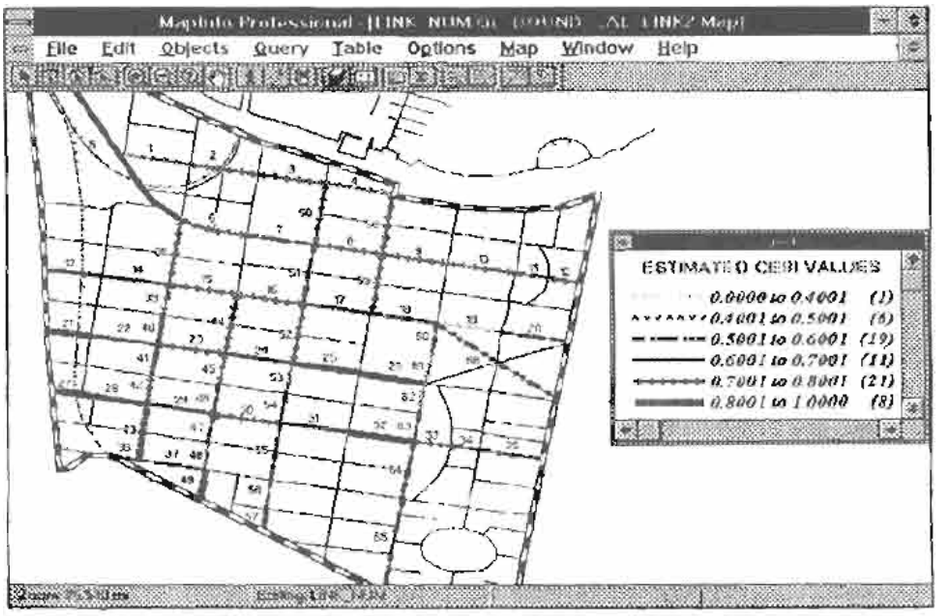

Figure 5: The Estimated CESI Values for All Links

The estimated CESIs can be used to assess the likely composite ES effects of different criteria for each link and identify possible problem locations. As illustrated in Figure 6, eight links (link number: 21, 25, 26, 27, 28, 32, 43, 49) having the same CESI value of 0.842, fall within the highest CESI interval (CESI is greater than 0.800) and therefore, show an indication of environmental problem. 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, for link 25, the descending rank of likely causes (criteria) of the environmental problem on this link are: pedestrian safety (0.409 = (0.409×1.0)); noise level (0.316 = (0.316×1.0)); and difficulty of access (0.117 = (0.276×0.425)), respectively.

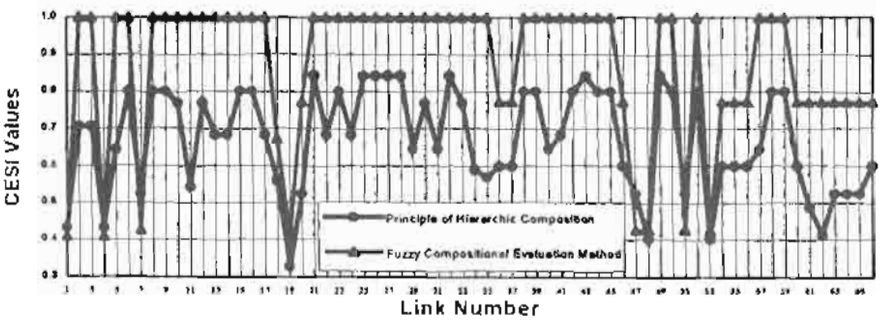

Figure 6: Comparisons of the Estimated CESI Values Using the Typical AHP and the Fuzzy Compositional AHP

For the fuzzy compositional AHP, the CESI values can be estimated from the fuzzy compositional evaluation. Those relative weights of each criterion for each land use type and those of all ES indices for each criterion were normalized by dividing with the maximum weights prior to conducting fuzzy compositional reasoning. For example, as shown in Figure 6, the CESI of link 25 is 1.000 (max {min (0.674, 0.425), min (0.771, 1.000), min (1.000, 1.000)} ≡ max {0.425, 0.771, 1.000}). The CESI value for all eight links mentioned previously are identically equal to 1.000 (the maximum CESI value) and clearly indicate environmental problem. The possible cause of the environmental problem of these links is pedestrian safety. This approach can identify only the most critical cause (criterion) for each link. The similar interpretation for both the typical AHP and the fuzzy compositional AHP approaches can be applied to all of the remaining links.

Comparisons between the Compensatory and Non-compensatory Approaches

The estimated CESI values of all links using the typical AHP (compensatory) method and the fuzzy compositional AHP (non-compensatory) method were illustrated in Figure 6. Figure 6 clearly illustrates that the typical AHP performs better in terms of differentiation capability than the fuzzy compositional AHP. While the typical AHP takes all criteria into account, the fuzzy compositional AHP will take only the most critical criterion into consideration and eliminate other remaining criteria. Therefore, the later can be determined as a

conservative approach. However, as shown in Figure 6, the fuzzy compositional AHP can capture a number of very high and very low CESI values which well match to the CESI values estimated by the typical AHP.

Conclusion

This paper described the theoretical foundation and the application of a decision support tool for evaluating the multicriteria ES of the Geelong road network, Victoria, Australia. The tool is an integration of Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST), and Knowledge-Based Expert System (KBES). In AHP synthesis phase, both principle of hierarchic composition and the fuzzy compositional evaluation methods were applied to synthesize all local priorities to derive global priorities (the CESI values) of all road links. The results of the case study indicate the potential utility of the tool for assessing both the separate and composite environmental sensitivity of urban road network at a local level, identify problem locations, and specify the possible causes of those problems. In addition, it was found that the typical AHP expresses more powerful capability in differentiating links according to their combined ES characteristics than the fuzzy compositional AHP. However, the latter can be used as a conservative decision making tool when considering the most critical environmental criterion. These are of particular importance in understanding environmental problems in urban road networks, establishing suitable functional road hierarchy classification, and prioritizing the special investigation for links having environmental problems. The current state of the tool will be expanded and refined and will be integrated with a GIS (MapInfo), to form a powerful microcomputer-based system, called the "Spatial Intelligent Multicriteria Environmental Sensitivity Evaluation Planning Tool" (SIMESEPT).

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