A MICROCOMPUTER-AIDED SYSTEM FOR THE MULTICRITERIA ENVIRONMENTAL IMPACTS EVALUATION: *THE CITY OF UNLEY CASE STUDY, AUSTRALIA*

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Abstract: The Spatial Intelligent Multicriteria Environmental Sensitivity Evaluation Planning Tool (SIMESEPT) was developed to assess both the separate and the multiple criteria environmental impacts of urban road networks. It is an integration of several important components such as traffic environmental impacts evaluation methods, multiple attributes decision-making methods, Knowledge-Based Expert System (KBES) approach, Graphical Information System (GIS) technology, and others. SIMESEPT were applied to measure and assess the traffic environmental impacts of the City of Unley road network. The Composite Environmental Sensitivity Indices (CESI) of each road link were suitable for gauging the preliminary traffic environmental impacts. On the other hand, the Composite Environmental Consequences Indices (CECI) values of those links were appropriate to measure the more accurate traffic environmental impacts of the urban road network. In addition, SIMESEPT showed its potential utility in identifying problem locations, and suggesting the possible causes and the key factors contributing to those problems.

1. INTRODUCTION

As the economic growth in both developed and developing countries increases, the demand for both freight and personal transportation is also raised because of the additional industrial and manufactured production and income growth. Personal income growth can generate an increase in car ownership and modal shift from public transport to passenger cars (Hayashi, 1996). While the capacity of the transportation infrastructure cannot sufficiently cope with the increased travel demand, unfortunate derived outcomes are increased traffic congestion; adverse environmental impacts; and road safety and amenity degradation. Some of the most pronounced adverse impacts caused by road traffic to the surrounding environment include air pollution, traffic noise and vibration, pedestrian crossing delay, pedestrian safety, social severance, difficulty of access, visual intrusion, fear and intimidation (Buchanan, 1963; Holdsworth and Singleton, 1979 and 1980). The estimation and assessment of safety, amenity, and environmental degradation is difficult and complex. Most local governments and other agencies have applied different types of traffic management (also called traffic calming) strategies to alleviate these safety, amenity and environmental problems caused by road traffic. The important prerequisite for the implementation of these traffic-calming schemes is an agreed functional road hierarchy classification. The appropriate road functional classification is primarily based on the clear understanding of the complex interactions between road traffic and its adjacent environment. Therefore, a practical and rigorous decision support tools are needed to assist traffic and transportation engineers, urban planners, and decision makers to determine the degree of safety, amenity, and environmental impacts generated by road traffic at local (link-based) level during the planning stage, and to assist in the evaluation of multiple environmental impacts of proposed traffic calming alternatives.

This paper is organized to present the following topics: (i) what is the Spatial Intelligent Multicriteria Environmental Sensitivity Evaluation Planning Tool (SIMESEPT); (ii) basic components of SIMESEPT; (iii) the SIMESEPT integrated system; (iv) SIMESEPT's operational procedures; (v) the City of Unley case study; and (vi) conclusion.

2. AN INTEGRATED COMPUTER-AIDED PLANNING TOOL: SIMESEPT

The integration of the traffic environmental impacts evaluation methods (Environmental Sensitivity Method (ESM) (Singleton and Twiney, 1985) and the Mathematical Modeling Method (MMM)), the Multiattribute Decision-Making (MADM) methods (Analytic Hierarchy Process (AHP) (Saaty, 1980) and Fuzzy Multiattribute Decision Making (FMADM) method (Chen and Hwang, 1992)), Fuzzy Set Theory (FST) (Zadeh, 1965), the Knowledge-Based Expert System (KBES) approach, and the Graphical Information System (GIS) technology to form a microcomputer-based decision support system is indispensable. The tool can be utilised to evaluate both separate and multicriteria environmental sensitivity (based on the ESM concept) and environmental impacts (based on MMM) at the local (link-based) level, identify and rank the environmental problem locations in the urban road network, and specify the possible causes (criteria) and key contributing factors to those problems. This tool is named the Spatial Intelligent Multicriteria Environmental Sensitivity Evaluation Planning Tool (SIMESEPT).

3. BASIC STRUCTURE OF SIMESEPT

SIMESEPT is composed of four main components, including the KBES, MMM, MADM, and GIS. The first three components are designed as separate modules by using the KnowledgePro for Windows (KPWin) programming language (Knowledge Garden, 1991). GIS is developed by using the MapInfo package (MapInfo Corporation, 1995). A schematic detailing the basic components of the SIMESEPT structure is illustrated in Figure 1 and each component of SIMESEPT is briefly described below.

3.1 Knowledge-Based Expert System (KBES)

Cohn and Harris (1992) defined KBES 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.*" KBES are basically composed of three fundamental components: knowledge base, inference mechanism, and user interface. Each of these elements is described in the context of SIMESEPT as follows.

3.1.1 Knowledge Base

The knowledge base contains the knowledge derived from human experts (ie people recognised as having special expertise and knowledge in a particular field) and research papers, study reports and other related publications. The current KB component of SIMESEPT consists of seven knowledge-based (KB) files. Three KB files contained a knowledge base for determining the environmental sensitivity of a link for difficulty of access, noise sensitivity, and pedestrian safety, respectively. This knowledge base is mainly based on the ESM concept as will be described below. Two KB files contained the knowledge base regarding the AHP relative-weights of different criteria for each land use type and those of different ES indices (low, medium, and high) for each criterion, derived from the series of interviews with ten Australian experts and four Thai experts. The remaining two KB files containing the knowledge base regarding the crisp (numerical) values of both ES indices (derived from the

ESM method) and rating (subjective) scores (obtained from the MMM method) for each criterion.

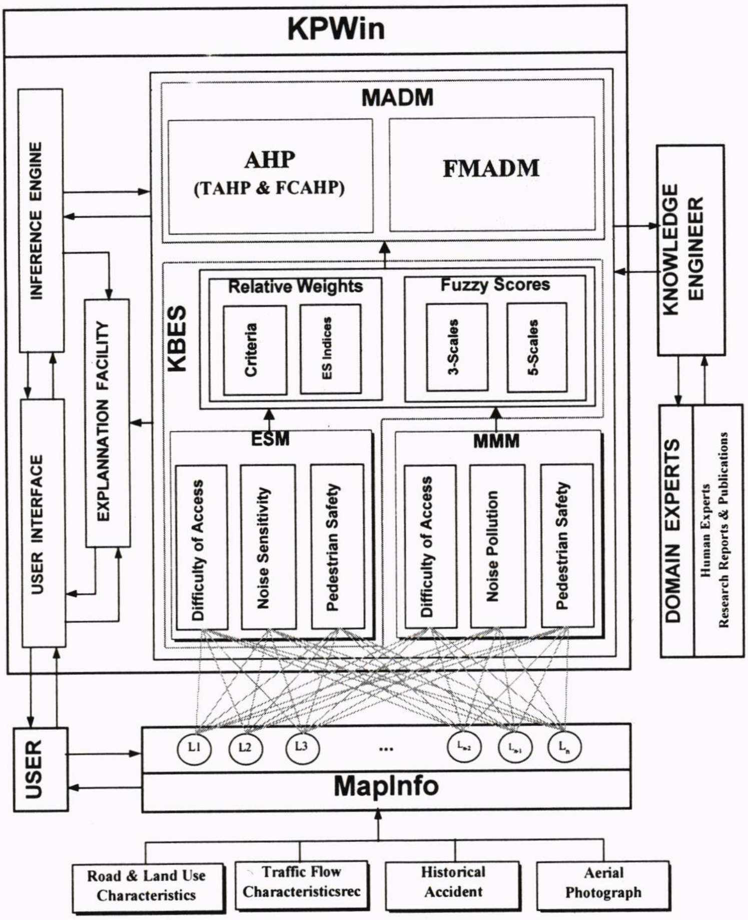

Figure 1 - A basic structure of SIMESEPT

3.1.1.1 Environmental Sensitivity Method (ESM)

ESM was developed to evaluate the environmental sensitivity induced by road traffic in urban road network for the three important criteria, including difficulty of access, noise sensitivity, and pedestrian safety. The ESM assumed that the physical and land use characteristics of a particular road section can be utilised to determine the ES of that road due to vehicular traffic. In the ESM procedures, a number of appropriate environmental criteria were firstly selected and key factors contributing to each criterion were then identified. The road network in the study area was divided into a number of homogenous links. Then the road physical and land use data relevant to the contributing factors for each criterion of each link were collected. These measured values of each contributing factor for each criterion were then compared with the corresponding measuring scales and a score of each factor was assigned accordingly. For each criterion, all derived scores of each factor were used to determine the ES indices (in terms of low, medium, and high) by using an established system for combination. Finally, the ES indices of different links for each criterion were then plotted separately. The ESM knowledge can be easily translated to computer codes by using the appropriate KBES programming languages or shells. This situation coupled with the lack of professional experts in this area has encouraged the development of the KBES component within SIMESEPT. A rule-based structure is adopted as a knowledge representation. These rules are essentially used to evaluate the separate environmental sensitivity caused by road traffic in urban road networks for each criterion. In addition, the direct interview with an expert who developed the ESM concept could provide the important explanation for all derived rules of each criterion. This knowledge was encoded and stored in each of difficulty of access, noise sensitivity, and pedestrian safety KB files in SIMESEPT.

3.1.1.2 The AHP-Relative Weights and Crisp Scores

The domain knowledge regarding the relative weights of all environmental criteria (difficulty of access, noise sensitivity, and pedestrian safety) for each land use type and that of all ES indices for each criterion was gleaned from structured interviews with ten selected Australian experts and four Thai experts. The AHP approach was used to transfer and aggregate this knowledge from these experts. The rule-based structure was adopted as a knowledge representation. The AHP relative weights derived from the ten Australian experts and the four Thai experts were separately developed and encoded into two separate KB files.

In addition, the crisp scores of all linguistic terms (very low, low, medium, high, and very high) used in the FMADM method can also be considered as the domain knowledge. This is because the fuzzy numbers representing each linguistic term have been achieved from the refinement and modifications of a number of experts' judgements regarding the geometric characteristics (eg shape and dimension, etc) of those linguistic terms (Chen and Hwang, 1992). The rule-based structure was used as a knowledge representation. The crisp values of all rating scores for each criterion were separately established and encoded into two separate KB files.

3.1.2. Inference Mechanism and Use Interface

The inference mechanism is the control level of the KBES. This component manipulates the relevant knowledge stored in the knowledge base to resolve the specific problem until the final solution can be reached. The control strategy used in this research is the backward chaining method. The user interface efficiently provides interactive two-way communication between the user and SIMESEPT. In this research, the required information (the physical and land use characteristics of each link in the road network) for difficulty of access, noise sensitivity, and pedestrian safety KB files can be directly entered into SIMESEPT by the user. This information can also be input to SIMESEPT automatically from one of the appropriate file formats. In addition, for ESM, the explanation facility that is capable of informing the user about the executed KB rules and their relevant explanation can be easily developed within the KPWin programming language.

3.2 Mathematical Modelling Method (MMM)

Three mathematical models have been developed to estimate the traffic environmental impacts for difficulty of access, noise pollution, and pedestrian safety. These models were established in SIMESEPT. These mathematical models (based on an algorithmic approach) are employed to estimate the potential environmental impacts generated by road traffic in urban road network. These mathematical models can explicitly incorporate the influences of both the road physical and land use characteristics and traffic conditions. This method can provide some advantages over the ESM concept. The MMM is considered as the refined traffic environmental impacts evaluation methods. Each of these three models is described as follows.

3.2.1 Prediction Model for Difficulty of Access

Little research work has been conducted in this area. However, much research progress has been made in the area of predicting vehicle delays at unsignalised intersections (eg Troutbeck, 1986 and 1993). Vehicle delay when waiting for appropriate gap in the major traffic stream to undertake right turning maneuvers at unsignalised intersections can potentially be used as a measure of difficulty of access. Troutbeck's model involves one random minor traffic stream attempting to cross one major traffic stream having its headway following the Cowan M3 (Cowan, 1975) distribution. The major traffic stream contains both free vehicles and bunches of vehicles. This model has been recognised as more realistic in predicting vehicle delay at unsignalised intersections (AUSTROADS, 1991) and therefore used in this research. The assessment of the impacts of difficulty of access is described in both absolute vehicle right-turning delays (seconds) and their corresponding rating scores (low, medium, and high).

3.2.2 Prediction Model for Traffic Noise

A traffic noise-prediction model was established to predict the traffic noise effects in urban road networks. The model can be used to assess the noise impacts caused by road traffic upon the residents and pedestrians who live, work, or undertake their activities in the abutting land uses along a road segment. The assessment of traffic noise impacts is then described in both absolute noise levels (L_{10} (18 hour) dB(A)) and their corresponding rating scores (very low, low, medium, high, and very high). The model is based on the well-researched and validated Calculation of Road Traffic Noise (CoRTN) methodology (UK DoT, 1988).

3.2.3 Prediction Model for Pedestrian Safety

A probabilistic model developed by Song et al (1993) for predicting vehicle-pedestrian accident risk (at mid-block locations) while crossing a road in urban areas is adopted in SIMESEPT. The model was based on the comprehensive accident records and intensive field observations at various locations on different types of roads such as local streets, sub-arterial roads, and arterial roads in Sydney, Australia. Song's model seems to be the most appropriate pedestrian-risk prediction model developed in Australia. Therefore, it has been adopted in this research. The estimation of pedestrian safety impacts is presented in both absolute vehicle-pedestrian accident risk (probability of occurrence per year) and their corresponding rating scores (low, medium, and high). The development procedures of these three models were described in Klungboonkrong (1998).

3.3 The Multiattribute Decision-Making (MADM) Approach

In practice, it is common to combine several separate environmental impacts estimated for different criteria of a given link to enable assessment and comparison of the combined traffic environmental impacts of separate links in an urban road network. Such combined environmental impacts can be utilised to disclose the ranking order of different links according to the degree of combined environmental impacts. Several Multiattribute Decision-Making (MADM) approaches are capable of aggregating both tangible and intangible criteria and recognizing differences in the relative importance of these criteria in different land use types. Furthermore, the final outputs (presented as low, medium, and high) obtained from the ESM concept and other methods typically contain uncertainty, imprecision, ambiguity, and vague information and meanings. Consequently, the Analytic Hierarchy Process (AHP) (Saaty, 1980), fuzzy compositional evaluation method (Lin and Shieh, 1995), and the Fuzzy Multiattribute Decision-Making (FMADM) methods (Chen and Hwang, 1992) have been developed and utilised to handle this difficulty. Each of these methods was described elasewhere (Klungboonkrong, 1998).

3.3.1 Analytic Hierarchy Process (AHP)

AHP can efficiently be employed to estimate the relative weights of different criteria for each land use type and those of different ES indices for each criterion. AHP can also be used to determine the priority of each link in urban road networks according to the estimated Composite Environmental Sensitivity Indices (CESI) values. The Typical AHP (TAHP) (the AHP using the Principle of Hierarchical Composition), was applied to calculate the CESI values for different road links. TAHP is essentially a compensatory approach. This may lead to some difficulties in interpreting the derived results because the TAHP permits for a high degree of compensatory justification among different criteria. Consequently, a non-compensatory method, the Fuzzy Compositional AHP (FCAHP) (the AHP using the fuzzy compositional evaluation method) was employed to investigate and compare its outcomes with those obtained from TAHP. More details can be found in Klungboonkrong and Taylor (1998). The AHP methodology is capable of dealing with the fuzziness in the MADM environment by establishing the AHP hierarchical structure and estimating the relative importance of different decision elements. The pairwise comparison technique coupled with the ratio scales methods are employed to determine the relative importance of those elements. In addition, AHP provides a systematic way of gauging the consistency of respondents' judgments. This ability is highly significant particularly when dealing with MADM problems. Both TAHP and FCAHP methodologies are established and contained in SIMESEPT.

3.3.2 Fuzzy Multiattribute Decision Making (FMADM) Method

In practice, MADM problems may consist of both qualitative and quantitative information. The traditional MADM methods are capable of dealing with the quantitative data, but most of these methods may encounter some difficulties when dealing with qualitative data. The situations become more complicated when the MADM problems must consider both quantitative and qualitative information. The FMADM method developed by Chen and Hwang (1992) can be applied to resolve this problem. The details of this method will be described in Klungboonkrong (1997 and 1998). In this research, all linguistic terms (very low, low, medium, high, and very high) will initially be transformed to their appropriate scores using the fuzzy scoring method (Chen and Hwang, 1992). Then, the Simple Additive Weight (SAW) will be used as a traditional MADM to estimate both CESI and Composite Environmental Consequence Indices (CECI) values of any road links. The relative weights of different criteria for each land use type are derived from the use of AHP as described in the previous section. More details can be found in Klungboonkrong (1997). This paper is focused on the use of FMADM in conjunction with the ESM and MMM methods.

It should be note that the Composite Environmental Sensitivity Index (CESI) values of any links in urban road networks can be calculated from the ESM method in conjunction with the FMADM approach. This means that the KBES (using the ESM concept) is applied to determine the ES indices of any links for each criterion and then FMADM is adopted to compute the links' CESI values. On the other hand, the Composite Environmental Consequences Index (CECI) values of any links in urban road networks can be estimated only from the MMM method together with the FMADM approach. Initially, the valid mathematical models are used to calculate the traffic environmental impacts (in a numerical format) of any links for each criterion. These numerical environmental impacts for each criterion will be converted to their corresponding rating scores (very low, low, medium, high and very high) for each criterion. Then FMADM will be used to estimate the links' CECI values.

3.4 The Geographical Information Systems (GIS)

Geographical characteristics are crucial elements to the transportation modelling and planning. Urban road networks typically consist of nodes or points, arcs or links and polygons or areas These spatial locations (X, Y coordinates) and their related characteristics (called attributes) are very important to traffic environmental impact evaluation and transportation modelling and analysis, and can be systematically established within a GIS environment. A GIS technology is capable of efficiently integrating traffic information, road physical and land use characteristics, and other related data from different sources through a set of consistent geo-referencing systems. In addition, GIS can perform spatial analysis and produce excellent graphical map displays that can enhance the efficiency and effectiveness of the communication between traffic engineers/urban planners and the public. Consequently, SIMESEPT is designed to integrate the MapInfo (GIS) package with other SIMESEPT components that were developed by using the KPWin package. The MapBasic programming language (MapInfo Corporation, 1995b) was used to establish the interface between MapInfo and KPWin.

4. SYSTEM INTEGRATION

The KBES, the MADM, and the MMM components of SIMESEPT were developed entirely within the KPWin environment. These SIMESEPT components were designed and organised as separate files (modules) and these modules are connected, operated, and interact with each other through the use of a Graphical User Interface (GUI). The GIS (MapInfo) package was mainly used as the database management system and map-displaying tool. The GIS component was separately developed. This interface approach was adopted in the development of SIMESEPT. A GUI module was established to manipulate the communication between the GIS and other modules residing within the KPWin environment. In SIMESEPT operation, the necessary data contained in GIS can be transferred to other SIMESEPT components by running a specified MapBasic program that will extract the necessary data from MapInfo and then create its corresponding text file. This text file will then be read directly by the appropriate SIMESEPT files. Subsequently, the outputs derived from those SIMESEPT files will be saved to the specified output file that will subsequently be read to and displayed in the GIS environment.

5. TYPICAL SIMESEPT OPERATIONS

SIMESEPT leads the user through simple and clear procedural steps that were intentionally designed to minimise the possible errors occurred during the setting process (eg selection of the data input source, environmental criteria, and environmental-impact evaluation method, etc) and modelling operations. Figure 2 illustrates the procedural steps of SIMESEPT modeling operations. The operational procedures of SIMESEPT will be described in the context of the City of Unley case study in the next section.

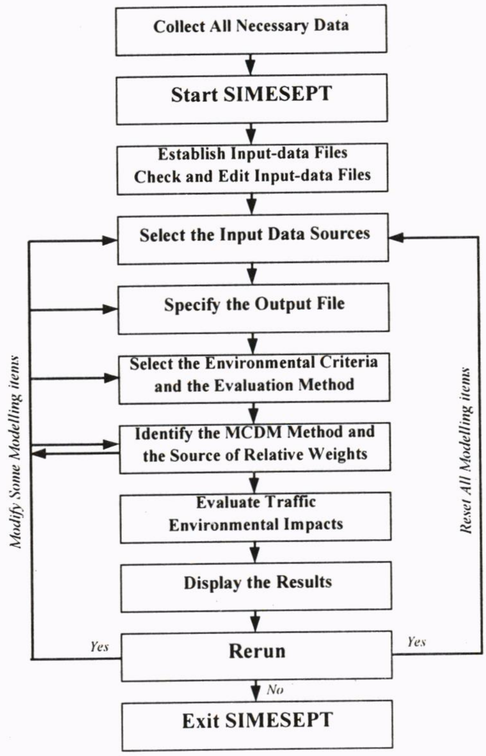

Figure 2 - Schematic diagram showing the procedural steps of the SIMESEPT Operations

6. THE UNLEY CASE STUDY

The City of Unley, a suburb of 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. The main roads which serve both traffic mobility and frontage related activities (eg land use access, shopping, etc) were the main focus of this research. Ten main roads in the City of Unley were selected and divided into 23 homogeneous links. The physical and land use characteristics and traffic conditions along each link were gathered from the existing data and field surveys. These included (i) physical characteristics of roads; (ii) pedestrian facilities; (iii) nature of parking restriction; (iv) type and practicality of land use access; (v) adjacent land use types; (vi) typical building set back distances; (vii) building façade orientation; (viii) existing traffic conditions; and (ix) the current traffic calming practices. These data were refined by using on-road video recordings, aerial photographs, and other relevant documents. The database including geographical locations and other related attributes was established within a GIS (MapInfo) environment.

6.1 SIMESEPT Operations

Initially, the GIS base-map and other related attributes of the Khon Kaen road network were established as a MapInfo (Tab) file. When SIMESEPT is run, the "MapInfo" input-data source is selected and the name of the MapInfo (Tab) input file is also specified. Then, SIMESEPT will ask the user to specify the name of the output MapInfo (Tab) file to be generated and used later. Also, SIMESEPT will request the user to enter the name of the output text file that will store all necessary data to be used by SIMESEPT in the modelling process.

Once both the MapInfo (Tab) and text files are created, the user will be asked to specify the number of links (23 links) to be determined. Subsequently, the user is required to enter the name of the output text file that will record all modelled results. Once all other necessary modelling items (eg traffic environmental impacts evaluation methods (ESM or MMM), environmental criteria, MADM (AHP or FMADM), and the source (Australia or Thailand) of the relative weights of all criteria are selected, the user can start the SIMESEPT operation. SIMESEPT will automatically perform all modelling operations until those operations are completed. Relevant input data and all output data obtained from the SIMESEPT modelling run are saved in the specified output text file. Subsequently, the user can employ the MapInfo package to generate maps displaying the modelling output in terms of the ES indices or the rating scores of all links for each criterion and the links' CESI or CECI values. When the appropriate option of the display method is selected, several map layers displaying the ES indices of all links for each criterion as well as the CESI or CECI values of these links will graphically presented on the screen under the MapInfo (GIS) environment.

6.2 The AHP Relative Weights and the Fuzzy Scores

For an illustration purpose, the AHP group relative weights of different criteria for each land use type (as shown in Table 1 derived from a series of direct interviews with ten Australian experts are presented below. As shown in Table 1, the relative weights of the three selected criteria vary with land use types.

Table 1 – The AHP relative weights of all criteria by land use types by Australian experts

Land Use Types	Environmental Criteria		
	Difficulty of Access	**Noise Sensitivity**	**Pedestrian Safety**
(I) Residential/School/Hospital	0.3080	0.2904	0.4016
(II) Retail/Commercial/Office/Park	0.3357	0.1818	0.4825
(III) Industrial/Railway	0.6169	0.1358	0.247

As shown in Table 2, the estimated crisp scores and their normalised scores (based on Chen and Hwang, 1992) of each linguistic terms for each criterion are presented. The relationship among these estimated scores is linear. It should be noted that for difficulty of access and pedestrian safety, the crisp scores of each rating score used (low, medium, and high) are identical. On the other hand, for noise pollution, the crisp scores for each rating score (very low, low, medium, high, and very high) are different.

Table 2 - The crisp scores of 3- and 5- scales

Fuzzy numbers	Total utility scores		Normalised total utility scores	
Scores	**3-scale**	**5-scale**	**3-scale**	**5-scale**
Very Low	-	0.0909	-	0.1000
Low	0.1667	0.2826	0.2000	0.3109
Medium	0.5000	0.5000	0.6000	0.5500
High	0.8333	0.7174	1.0000	0.7891
Very High	-	0.9091	-	1.0000

6.3 The Modelled Results: The ESM Method

The geographical distribution of all ES indices of each links for pedestrian safety are illustrated in Figure 3. All links identified as the "*High*" ES index can be determined as the potential problem locations for this criterion. Special attention regarding the pedestrian safety aspect may be required for each of these links. In addition, SIMESEPT can also provide the user with the rules that were executed to achieve the conclusions (the "*High*" ES index) and the relevant explanation. For example, at link number 6, the executed rule and their corresponding explanation for the achieved "*High*" ES index for the pedestrian safety is presented below.

Rule:

```
If ?RoadWidth = Wide
and (?FootpathWidth = Wide or ?FootpathWidth = Narrow)
and (?PedFacility = Yes or ?PedFacility = No)
Then Pedestriansafety = High.
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Explanation:

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In general, all land use types are highly sensitive
to a pedestrian safety criterion
when its walked road width is wide.
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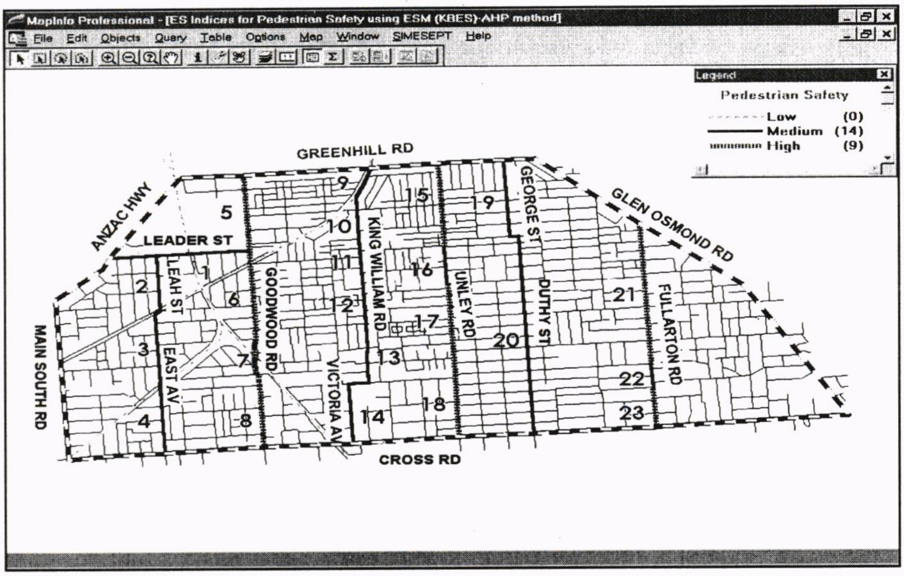

Figure 3 - The ES indices of all links in the City of Unley road network for pedestrian safety

The important factors contributing to any problematic link for each criterion can be identified from the road physical and land use characteristics data of that link contained in either the input and output text or MapInfo (Tab) file. Therefore, the key contributing factors of all problematic links for each criterion can be easily specified. A similar interpretation is also applicable to other remaining links for each criterion. The spatial distribution of all estimated CESI values of each link based on the FMADM methods are shown in Figure 4.

The estimated CESI values can be used to evaluate the degree of the composite environmental sensitivity of each link for multiple criteria and identify potential problem locations in urban road network. In addition, these CESI indices can also be used to uncover the ranking order of all links according to the magnitudes of their CESI values. Link number 6 of the Unley road network is also used as an example of illustrating the numerical computations based on the FMADM method. The estimated relative weights of difficulty of access, noise sensitivity, and pedestrian safety for land use type 2 are 0.3357, 0.1818, and 0.4825, respectively. Based on the fuzzy scoring approach (Chen and Hwang, 1992), the crisp (numerical) scores of the assigned "*Medium*", "*High*", and "*High*" ES indices for difficulty of access, noise sensitivity, and pedestrian safety are 0.6000, 1.0000, and 1.0000, respectively. Based on the Simple Additive Weight (SAW) method, the estimated CESI value of link 6 is 0.866 (= $\{0.3357 \times 0.6000\} + \{0.1818 \times 1.0000\} + \{0.4825 \times 1.0000\}$). All CESI values estimated for every link in the Unley road network were grouped into eight intervals and illustrated in Figure 4.

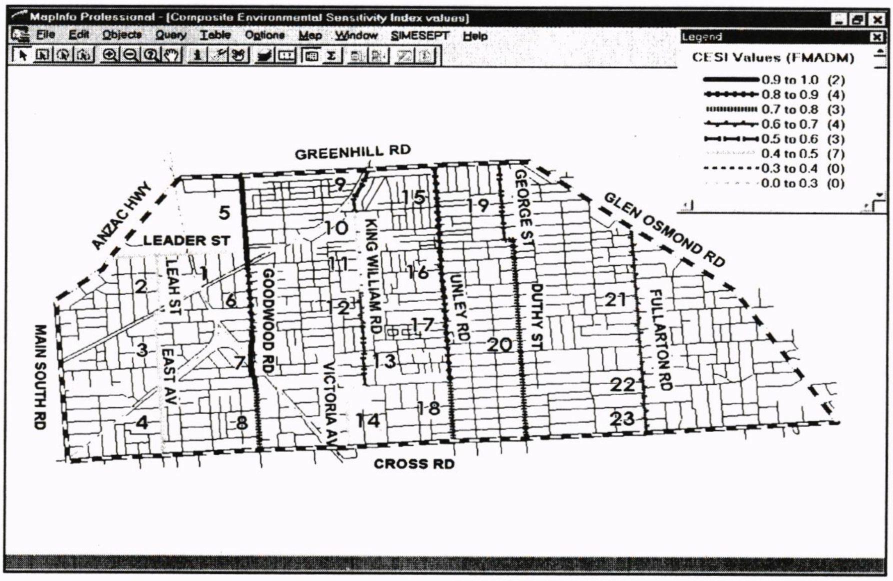

Figure 4 - The estimated CESI values of all links in the City of Unley road network (based on the FMADM approach)

The CESI values of nine links (link number: 5, 6, 7, 8, 15, 16, 17, 18, and 20) are high (greater than 0.7000) and therefore indicate the potential environmental problem locations. The rank of these links according to the magnitudes of their CESI values in descending order are: link 7 (CESI = 1.000), link 5 (0.927), links 6, 15, and 17 (0.866), link 16 (0.807), links 8 and 18 (0.754), and link 20 (0.716), respectively. In addition, the numerical composition of CESI values can also be used to determine the possible causes of the problems for each link. For example, for link 6, the descending rank of likely causes (criteria) of the environmental problem on this link are: pedestrian safety (0.483 = (0.4825×1.0000)); difficulty of access (0.201 = (0.3357×0.6000)); and noise sensitivity (0.182 = (0.1818×1.000)), respectively. The similar interpretation is also applicable to all of the remaining links of the Unley road network.

6.4 The Modelled Results: The MMM Method

The MMM method is applied to assess both the separate and composite environmental consequences of the City of Unley road network and only the FMADM method is adopted as the MADM method. The interpretation of the modeling results derived from the MMM and the ESM methods are generally similar. The spatially distributive pattern of all rating scores of each links for the pedestrian safety criterion is displayed in Figure 5. All links identified as the "*High*" scores can be considered as the potentially problematic locations for each criterion.

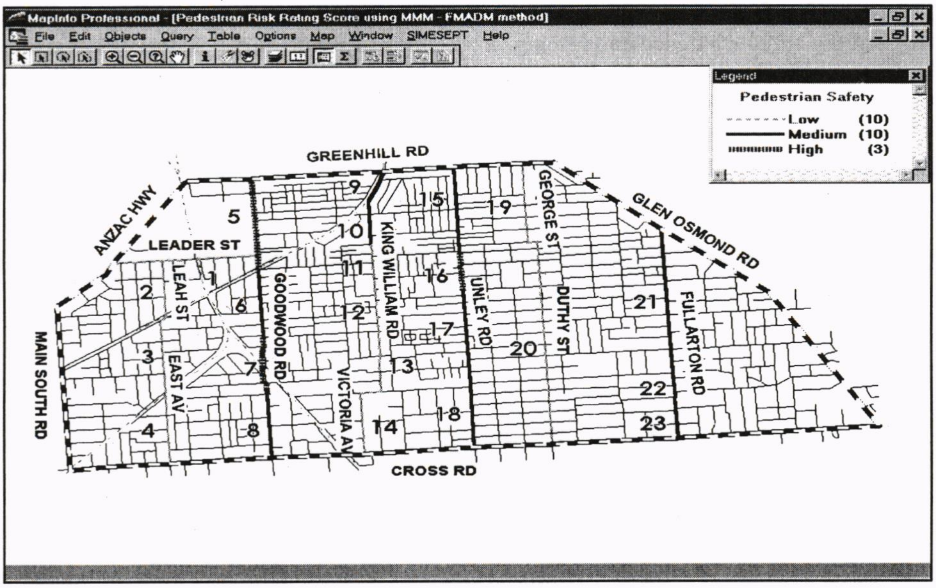

Figure 5 - The pedestrian risk rating scores of all links in the City of Unley road network

Based on the MMM method, the vehicle right-turning delay, traffic noise level, and vehicle-pedestrian accident risk estimated for link number 6 in land use type 2 are 53.5 seconds, 74.2 (L_{10} (18 hour) dB(A)), and 1.71×10^{-5} per year, respectively. Based on the predefined scoring system, this link is therefore, assigned the "*High*", "*High*" and "*Medium*" rating scores for difficulty of access, noise pollution and pedestrian safety, respectively. The estimated relative weights of difficulty of access, noise pollution, and pedestrian safety for land use type 2 are 0.3357, 0.1818, and 0.4825, respectively. The normalised numerical scores of "*High*", "*High*", and "*Medium*" for difficulty of access, noise pollution, and pedestrian safety are 1.0000, 0.7891, and 0.6000, respectively. Based on the Simple Additive Weight (SAW) method, the estimated CECI value of link number 6 is 0.769 (= $\{0.3357 \times 1.0000\} + \{0.1818 \times 0.7891\} + \{0.4825 \times 0.6000\}$). All CECI values estimated for all links in the Unley road network were grouped into eight intervals and illustrated in Figure 6.

The CECI values of four links (link numbers 5, 6, 7, and 16) are high (ie greater than 0.7000) and therefore indicate the potential environmental problem locations. The rank of these links according to the magnitudes of their CECI values in descending order are: link number 5 (CECI value = 0.962), link number 7 (0.939), links number 16 (0.827), and link number 6 (0.769). In addition, the numerical composition of CECI values can also be used to determine the possible causes of the problems for each link. For example, for link number 6, the descending rank of likely causes (criteria) of the environmental impacts on this link are: difficulty of access (0.3357 = (0.3357×1.0000)); pedestrian safety (0.2895 = (0.4825×0.6000)); and noise level (0.1435 = (0.1818×0.7891)), respectively. The similar interpretation is also applicable to all of the remaining links of the Unley road network.

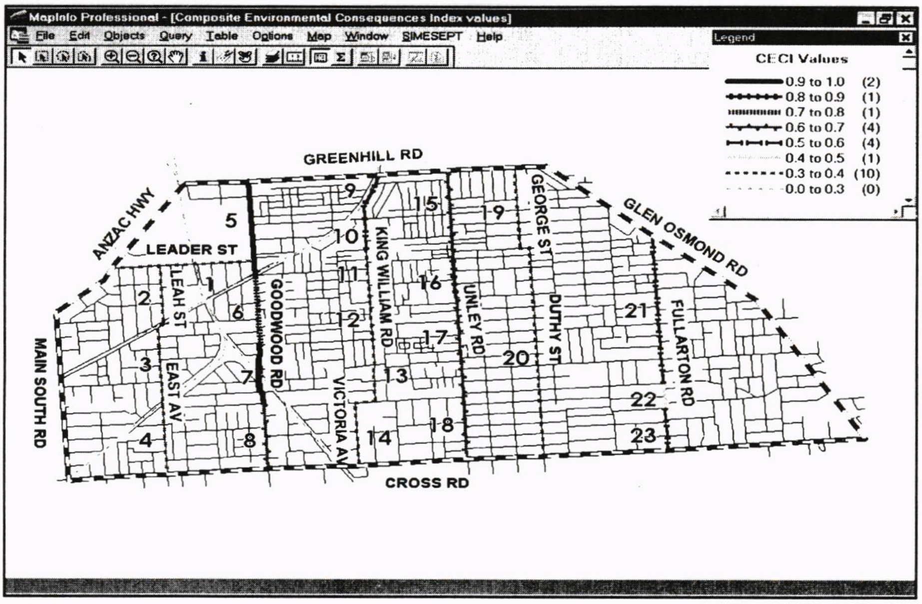

Figure 6 - The estimated CECI values of all links in the City of Unley road network (based on the FMADM method)

6.5 Comparisons of the Results Derived from the ESM and the MMM Method

As shown in Figure 7, the results derived from both the MMM and the ESM methods are relatively different. Given these differences, the direct comparisons of those results can potentially provide useful information that can lead to the more accurate interpretation.

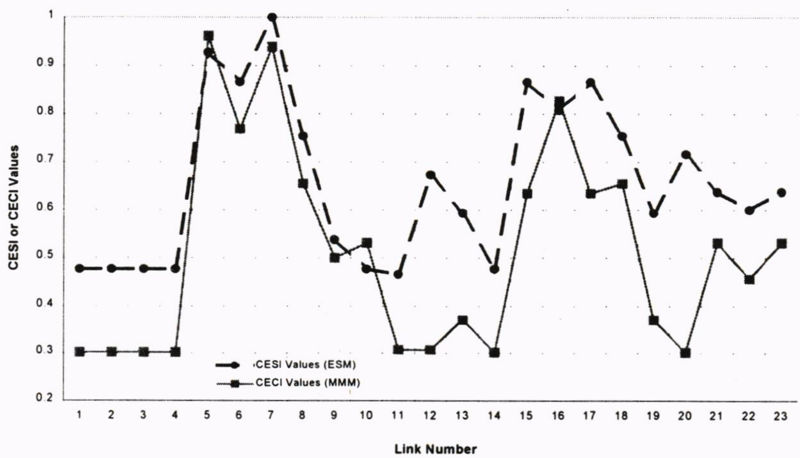

Figure 7 - Comparisons of the CESI values and the CECI values of all links in the City of Unley road network (using the FMADM approach)

The ESM method is a function of only road physical and land use characteristics. The outputs (in terms of "*Low*", "*Medium*", and "*High*" ES indices for each criterion) obtained from this method can be translated as the level of the environmental sensitivity of each road link to the traffic on that link. Any road link having "High" ES index for any criterion (say noise sensitivity) means that if the traffic volume on this link is increased a certain amount, this link will experience higher adverse environmental effects for that criterion compared to another link that has a "Low" ES index for the same criterion. On the other hand, the MMM method is reliant on both physical and land use characteristics and traffic conditions. This method can directly be used to estimate the levels of traffic environmental impacts of each road link for multiple criteria. Any two links that possess the identical physical and land use characteristics, but carrying different traffic conditions will have the same ES indices for each criterion. However, the levels of the traffic environmental impacts (estimated from the MMM method) for each criterion can be considerably different. Figure 7 illustrates the comparisons of the CESI and the CECI values of all links in the City of Unley based on the ESM and the MMM methods (using the FMADM method), respectively. Special attention should be granted to those links that simultaneously display high magnitudes of both the CESI and CECI values. For CESI and CECI values greater than 0.7, Link number 5, 6, 7, and 16 require special attention and/or investigation.

7. CONCLUSIONS

The Spatial Intelligent Multicriteria Environmental Sensitivity Evaluation Planning Tool (SIMESEPT) was developed to assess both the separate and the multicriteria environmental impacts of urban road networks. It is an integration of the traffic environmental impacts evaluation methods (including KBES (based on the ESM concept) and MMM (based on several valid mathematical models)), MADM methods (AHP and FMADM methods), FST, and GIS. A KnowledgePro for Windows (KPWin) programming language was adopted as the main development tool and the MapInfo (GIS) package was employed as a spatial database management system and a map displaying tool. The MapBasic programming language was also used to establish the interface modules to allow the communication between the KPWin and MapInfo possible.

This paper briefly described each component of SIMESEP and the application of SIMESEPT to the City of Unley road network in Adelaide, Australia. Difficulty of access, noise pollution, and pedestrian safety are determined as the major environmental criteria in this research. Both the KBES (based on the ESM concept) and the MMM methods in conjunction with the FMADM method were applied to measure and assess the traffic environmental impacts of the City of Unley road network. The results derived from these two methods were compared and considered. The CESI values estimated from the use of the KBES and FMADM methods are suitable for gauging the preliminary traffic environmental impacts. On the other hand, the CECI values derived from the use of the MMM and the FMADM methods are appropriate to measure the more accurate traffic environmental impacts of the urban road network. In addition, SIMESEPT showed the potential utility of this tool to identify problem locations, and suggest the possible causes and the important factors contributing to those problems. It should be noted that SIMESEPT can also be applied to others developed and developing countries. The similar attempts and findings (as mentioned in this paper) were also conducted for the City of Khon Kaen road network, Thailand. The details of the Khon Kaen case study is beyond the scope of this paper, but can be found elsewhere (Klungboonkrong, 1998).

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REFERENCES

AUSTROADS (1991) **Guide to Traffic Engineering Practice: Roadway Capacity**, Part 2, AUSTROADS.

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

Chen, S J and Hwang, C L (1992) **Fuzzy Multiple Attribute Decision Making – Methods and Applications**, Springer-Verlag, Berlin.

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**, National Cooperative Highway Research Program, Transportation Research Board, Washington DC.

Cowan, R J (1975) Useful headway models, **Transportation Research, 9(6)**, 371-375.

Han, S Y and Kim, T J (1990) Intelligent urban information systems: review and prospects (Chapter 15), In **Expert Systems: Applications to Urban Planning**, Kim, T J, Wiggins, L L and Wright, J R (Editors), Springer-Verlag, New York, Chapter 15, 241-264.

Hayashi, Y (1996) Economic development and its influence on the environment: urbanisation, infrastructure and land use planning systems, in **Transport, Land-Use and the Environment**, Hayashi Y and Roy J (Editors), Kluwer Academic, London, Chapter 1, 3-25.

Holdsworth, J and Singleton, D J (1979) Environmental traffic capacity of roads, **Papers of the Australian Transport Research Forum 5**, 219-238.

Holdsworth, J and Singleton, D J (1980) Environmental capacity as a basis for traffic management at the local government level, **Proceedings of the 10th Australian Road Research Board 10**(5), 165-174.

Klungboonkrong, P. (1997) A decision support tool for the fuzzy multicriteria environmental sensitivity evaluation of urban road networks. **Journal of the Eastern Asia Society for Transportation Studies (EASTS): Spatial Analysis, Environment & Financing, 2** (6), Seoul, Korea, pp.1961-1980

Klungboonkrong P (1998) **Development of A Decision Support Tool for the Multicriteria Environmental Impact Evaluation of Urban Road Networks**, Unpublished PhD Thesis, Transport Systems Centre, School of Geoinformatics, Planning and Building, University of South Australia, Adelaide, SA, Australia.

Klungboonkrong, P. and Taylor, M. A. P. (1998) An integrated planning tool for evaluating road environmental impacts. **Journal of Computer-Aided Civil and Infrastructure Engineering** (Microcomputers for Civil Engineering) (forthcoming).

Knowledge Garden (1991) **KnowledgePro Windows Version 2.0: User Manual**. Knowledge Garden Inc.

Lin, Z C and Shieh, T J (1995) Application of an Analytic Hierarchy Process method and fuzzy compositional evaluation in the expert system of sheet bending design, **International Journal of Advanced Manufacturing Technology 10**, pp 3-10.

Losee S P (1996) **Combining Environmental Modelling and Travel Forcasting Using a GIS**, Unpublished Master Thesis, Faculty of Environmental Sciences, Griffith University, Brisbane.

MapInfo Corporation (1995a) **MapInfo Professional: Reference**, MapInfo Corporation, New York.

MapInfo Corporation (1995a) **MapBasic Professional: User's Guide**, MapInfo Corporation, New York.

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

Seagle, J. P. and Duchessi, P. (1995) Acquiring Expert Rules with the Aid of Decision Tables, **European Journal of Operational Research**, 84, 150-162.

Singleton, D J and Twiney, P J (1985) Environmental sensitivity of arterial roads, **Papers of the Australian Transport Research Forum 10**(**2**), 165-182.

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.

Troutbeck, R J (1986) Average delay at an unsignalized intersection with two major streams each having a dichotomised headway distribution, **Transportation Science, 20**(**4**), pp. 272-286.

Troutbeck, R J (1993) The characteristics of the times drivers are stopped at unsignalised intersections, In **Transportation and Traffic Theory**, Daganzo, C. F. (Editor), Elsevier Science Publishers, pp 575-594.

UK DoT (1988) **Calculation of Road Traffic Noise (CoRTN)**, Department of Transport (Welsh Office), HMSO, London.

Zadeh, L. A. (1965) Fuzzy Sets, **Information and Control**, 8, 338-353.