The experiences in evaluating the multicriteria traffic environmental impacts in urban road networks using SIMESEPT

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Abstract

Spatial Intelligent Multicriteria Environmental Sensitivity Planning Tool (SIMESEPT) is a microcomputer-based decision support system that was developed to evaluate traffic environmental impacts of urban road network. SIMESEPT integrates various advanced information technologies (eg GIS and KES), some MADM methods, and some traffic environmental impact evaluation models. SIMESEPT can efficiently be used to evaluate both separate and multiple criteria environmental impacts at the local (link-based) level, identify and rank the environmental problem locations, and specify the possible causes (criteria) and key contributing factors to those problems. In addition, it was found that the TAHP method and the FMADM method illustrates the similar capability in differentiating links according to their composite environmental impacts characteristics, and both of them perform better than the FCAHP does. However, the latter can be used as conservative decision-making tool when considering only the most critical environmental criterion. Sensivity analysis was also conducted to examine the influences of the variation of relative weights of each environmental criterion in each land use type.

1 Introduction

The estimation and assessment of safety, amenity, and environmental degradation caused by road traffic is difficult and complex. This is because although some aspects can possibly be quantified (eg air pollution and noise
level), others can only be qualitatively gauged (e.g. social severance, visual intrusion, fear and intimidation). Furthermore, both qualitative and quantitative environmental impacts normally vary, ranging from annoyance effects to direct health hazards. Consequently, the development of a decision support tool is needed to estimate and evaluate the traffic environmental impacts. Such tools are of particular importance in prioritising the special attention and investigation for roads indicated as problematic sites, establishing appropriate functional road hierarchy classes, and allocating limited government funds for the implementation of the suitable traffic calming schemes.

Spatial Intelligent Multicriteria Environmental Sensitivity Planning Tool (SIMESEPT) can be utilised to evaluate both separate and multicriteria environmental impacts 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. SIMESEPT has been applied to several areas (e.g. the City of Prospect in Adelaide, South Australia, the Geelong City in Victoria, Australia, and the City of Unley, South Australia, Australia). In this paper, SIMESEPT is applied to investigate and evaluate the environmental impacts characteristics of the Khon Kaen road network in Thailand. This paper is organised to present the following topics: (i) fundamental structure of SIMESEPT; (ii) environmental sensitivity method (ESM); (iii) the Khon Kaen case study; (iv) future development and finally (v) the conclusions.

2 The Fundamental Structure of SIMESEPT

SIMESEPT is a microcomputer-aided system. SIMESEPT is an integration of the traffic environmental impacts evaluation methods (Environmental Sensitivity Method, ESM) [1] and the Mathematical Modeling Method (MMM), the Multiattribute Decision-Making (MADM) methods (Analytic Hierarchy Process (AHP) [2] and Fuzzy Multiattribute Decision Making (FMADM) method [3]), Fuzzy Set Theory (FST), the Knowledge-Based Expert System (KBES) approach, and the Geographical Information System (GIS) technology. Currently, SIMESEPT can be applied to estimate and assess three important environmental criteria: difficulty of access, noise pollution, and pedestrian safety. The Composite Environmental Sensitivity Indices (CESI) obtained from the use of KBES (based on the ESM concept) and MADM methods are suitable for gauging the traffic environmental sensitivity (preliminary ESM effects), while the Composite Environmental Consequences Indices (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. The detailed discussion was given in [4]. The fundamental structure of SIMESEPT is illustrated in Figure 1.

The KBES, the MADM, and the MMM components of SIMESEPT were developed entirely within the K_PWin programming environment. For KBES, the
rule-based structure was used as a knowledge representation. The inference mechanism used in this research is the backward chaining method. The user interface efficiently provides interactive two-way communication between the user and SIMESEPT. For MMM, three mathematical models have been developed in SIMESEPT to estimate the traffic environmental impacts for difficulty of access using the Troutbeck’s model [5], noise pollution using CoRTN [6], and pedestrian safety using the Song’s probabilistic model [7]. 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 that will be described in the next section.

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 composite traffic environmental impacts of separate links in
an urban road network. Such composite environmental impacts can be utilized to disclose the ranking order of different links according to the degree of composite environmental impacts. Typical Analytic Hierarchy Process (TAHP), Fuzzy Compositional AHP evaluation method (FCAHP) [8], and the Fuzzy Multiattribute Decision-Making (FMADM) methods [3] have been developed and utilized to handle this difficulty. Each of these methods was described in details in [9]. The theoretical foundation of TAHP that is the ordinary AHP methodology using the principle of hierarchical composition, and FCAHP that is the ordinary AHP methodology using the fuzzy compositional evaluation method were described in [8]. Because of the limited space, the AHP theoretical foundation will not be elaborated in this paper. For the FMADM methodology, the general calculating procedures are almost identical to TAHP, except the numerical values of each ES index for all criteria. The Simple Additive Weight (SAW) is used as the MADM method and the Fuzzy Scoring method [3] is adopted to convert the linguistic terms (e.g., low, medium, and high) to the corresponding numerical values. The detailed discussion of the FMADM methodology can be found in [10].

All SIMESEPT components are designed and organized as separate files (modules) and these modules are connected, operated, and interacted 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. A GUI module (developed by using the MapBasic programming language) was designed to manipulate the communication between the GIS and other modules residing within the KPWin environment. The details of each component and the operational procedures of SIMESEPT can be found elsewhere [10].

3 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 utilized 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.
4 The Khon Kaen Case Study

4.1 Data Collection and Presentation of the Khon Kaen Road network

Khon Kaen is located in the central north eastern region of Thailand and in 1994 contained a population of approximately 1.7 million of which 172,000 live in the Muang district. Khon Kaen is currently one of the fastest growing cities in the Northeast due to its geographical location and government promotion of the city as a gateway to Indochina. Khon Kaen has been designated a regional institutional center and is one of the nine main industrial cities in the country [10]. The Khon Kaen CBD road network was adopted as a case study area with its road network in a grid-based system as shown in Figure 2. This case study is concentrated on the determination of the traffic environmental impacts of all road links on the residents, pedestrians, and visitors who live or undertake their activities in the abutting land uses along these links. Difficulty of access, noise sensitivity, and pedestrian safety are selected as the important criteria for the case study. Eleven major roads were selected and divided into 39 homogenous links consistent with the method used by [1]. The categories of the data used in the Khon Kaen case study include road physical characteristics, availability of pedestrian facilities, nature of parking restrictions, types and practicality of land use access, land use categories, existence of the opposite building facade, traffic conditions, and traffic management schemes. The database was generated, integrated, and stored in a GIS (MapInfo) environment as shown in Figure 2.

Figure 2: The Khon Kaen CBD road network study area.
4.2 The Modeled Results of Khon Kaen

Given the required data of road physical and land use characteristics of any road links, the KBES component (based on the ESM concept) of SIMESEPT was used to determine the appropriate ES indices of each link for difficulty of access, noise sensitivity, and pedestrian safety. As an illustration, Figure 3 shows the output window presenting all necessary data required for determining the ES index for pedestrian safety, the fired rule to derive the final outcome and its relevant explanation.

![Figure 3: An example of the output window of pedestrian safety.](image)

As an example, the spatially distributive patterns of all ES indices of each links for pedestrian safety is illustrated in Figure 4. All links identified as the "High" ES index can be considered as the potential problem sites in the Khon Kaen road network for the pedestrian safety criterion. Special attention and/or investigation regarding the pedestrian safety aspect may be needed for these links. The key factors contributing to any problematic link for each criterion can be identified from the road physical and land use characteristics data of that link.

The estimated CESI values can be used to determine the composite environmental sensitivity of each link for multiple criteria and identify potential problem locations in the urban road network. In addition, these CESI indices can also be utilized to reveal the ranking order of all links according to the magnitudes of their CESI values. All CESI values estimated for all links in the
Figure 4: The ES indices of all links in the Khon Kaen road network for pedestrian safety.

Figure 5: The estimated CESI values (based on the TAHP approach) of all links in the Khon Kaen road network.
Khon Kaen road network were grouped into eight intervals and displayed in Figure 5. The CESI values of seven links (link numbers: 9, 10, 11, 23, 27, 28, and 29) are high (say greater than 0.7000) and therefore identify the potential problem locations. According to the output data contained in the output file, the rank of these links according to the magnitudes of their CESI values in descending order are: link numbers 10, 11, 28, and 29 (CESI = 1.000), link numbers 23 and 27 (0.840), and link number 9 (0.700). In addition, the numerical composition of CESI values can be used to determine the potential causes of the problems for each link.

4.3 Comparisons among TAHP, FCAHP and FMADM Approaches

The estimated CESI values of all links using TAHP and FMADM methods, and FCAHP methods were illustrated in Figure 6. It was clearly that the TAHP and the FMADM methods perform better in terms of differentiating capability than FCAHP. While TAHP and FMADM takes all criteria into account, the FCAHP will take only the most critical criterion into consideration. Therefore, the latter can be used as a conservative decision-making approach. However, as shown in Figure 6, the FCAHP can generally capture a number of very high and very low CESI values which well match to the CESI values estimated by the TAHP and the FMADM methods. Based on the findings derived from this study and elsewhere [8], the FCAHP method can possibly be used as a screening approach for preliminarily detection of the candidates of road links that show the potential environmental problem locations.

![Figure 6: Comparisons of the CESI values based the TAHP, FCAHP, and FMADM methods](image)

4.4 Sensitivity Analysis

The sensitivity analysis of the CESI values of all road links of the Khon Kaen
road network with respect to the variations of the relative weights of each criterion for each land use type was conducted in this research. In the Khon Kaen case study, only land use types 1 and 2 were presented. Therefore, the sensitivity analysis for land use types 1 and 2 was done. For each land use type, any links having identical ES indices for each criterion will be grouped as the same link. Therefore, the sensitivity analysis will be concentrated only on the variation of the CESI values of links in each land use type. The following analysis will utilise the results of the sensitivity analysis of the CESI values of all links by varying the relative weight of pedestrian safety for land use type 1 as an example.

As an example, Figure 7 illustrates the results of the sensitivity analysis of the CESI values of all links (in land use type 1) of the Khon Kaen road network with respect to pedestrian safety. While the relative weights of pedestrian safety increase, the CESI values of link number 18 and link number 26 increase. The CESI values of all remaining links decrease. Link number 26 is highly sensitive to the variation of the relative weights of pedestrian safety. Link number 4, link numbers 14, 35, 36, and 39, and link number 15 are moderately sensitive to such variation, while link number 18 and link number 31 are less sensitive to such changes. If the relative weights of pedestrian safety are greater than 0.42, the ranking order of all links remains constant. The ranking order of all links in this land use type is varied according to the changes of the relative weights of pedestrian safety when such relative weights are less than 0.42. It was found that most links in both land use types 1 and 2 are generally sensitive to the changes of the relative weights of each criterion in terms of the alterations of their CESI values and their ranking order.

Figure 7: Sensitivity Analysis with respect to pedestrian safety for land use type 1 (the Khon Kaen case study)
5 Future Development

SIMSEPT has been improved by including more modeling components. Air pollution, pedestrian delays and others are being developed and then added into the existing SIMSEPT. In addition, the available traffic environmental impacts evaluation modules such as noise levels, pedestrian accident risk and difficulty of access have been expanded to incorporate more applicable models for each criterion. For example, for traffic noise levels, the ROADNOISE software package is being developed at Transport Research Center (TRC), Department of Civil Engineering, Faculty of Engineering, Khon Kaen University (KKU), Thailand by including four traffic noise prediction models (e.g. CoRTN [6] and etc.). These models are currently validated by using the field data of the Khon Kaen City case study for their appropriateness and applicability. Also KKU-TAPP have been developed at TRC by incorporating four air emission models (e.g. Taylor [11] and etc.). However, the Khon Kaen University Traffic Air Pollution Prediction (KKU-TAPP) model are being improved by the inclusion of emission dispersion model based on the Guassian Dispersion theory. Figure 8 illustrates two main windows of both ROADNOISE and KKU-TAPP packages.

Figure 8: Main windows of ROADNOISE & KKU-TAPP software packages
In addition, the on-going research at TRC, KKU is to develop the knowledge-acquisition tool for extracting the knowledge and expertise of both experts and people who live and undertake their activities in different land uses adjacent to various road types in urban areas in terms of their perception and attitudes towards the relative importance of a variety environmental criteria (e.g., traffic noise levels, air pollution, pedestrian safety, pedestrian delays, difficulty of access, etc). The derived research findings will be stored in the existing knowledge module of SIMESEPT and will finally be used to determine the CESI and CECI values and enhance the accuracy of SIMESEPT.

6 Conclusions

This paper described the fundamental structure and the application of the SIMESEPT model for evaluating the multicriteria ES of the Khon Kaen road network, Thailand. The results of the case study indicate that the SIMESEPT package can be used to determine, understand, and evaluate both the separate and multicriteria environmental impacts of road traffic on urban road networks at the local (link-based) level, identify and prioritise problem locations in the road networks according the degree of their environmental impacts, and specify the possible causes (criteria) and factors contributing to those problems. It was also found that the TAHP and the FMADM methods appear to be more powerful in differentiating links according to their combined ES characteristics than FCAHP. However, the latter can be used as a conservative decision making tool when considering only the most critical environmental criterion. It was found that most links in both land use types 1 and 2 are generally sensitive to the changes of the relative weights of each criterion in terms of the changes of their CESI values and ranking order.

7 References


