World Applied Sciences Journal 3 (Supple 1): 01-08, 2008
ISSN 1818-4952

Compatibility Assessment of Urban Land Uses: A Spatial Multi-Criteria Decision-Making Approach

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Abstract: The aim of the paper is to develop a model for evaluating compatibility of various urban detailed land uses in a neighborhood area. To develop the proposed model some concepts and tools such as Geospatial Information System (GIS) and Multi-criteria decision making (MCDM) were utilized. Noise, air pollution, safety, welfare and aesthetics were considered as major factors causing incompatibility. Various interviews with urban planning specialists were done to develop compatibility matrix related to each factors. AHP and Fuzzy methods were used to quantify experts' judgment regarding the severity of incompatibility among detail urban land uses. The results show that the model is robust in clarifying different levels of compatibility among urban land uses. The paper describes the various steps of developing the proposed model.

Key words: Compatibility evaluation · Urban Land Use · GIS · Fuzzy Model · AHP

INTRODUCTION

Urban neighbored land uses have external effects on each other. These effects can be positive or negative [1, 2]. Positive effects lead to increase the efficiency as well as the value of neighbor land uses that caused sustainable development and better lifestyles, while negative effects lead to decrease the efficiency and value of land uses that caused incompatibility between urban land uses. Because of the negative effects urban planners attempt to allocate available lands to proper land uses based on separating incompatible land uses.

Compatibility matrix utilizes generally to evaluate the severity of compatibility among urban land uses. Many researchers have been studied the compatibility between land uses from various perspectives. Their researches were focused on developing some spatial techniques to quantify externalities among land uses from economic perspectives [3-10]; Also Hughes and Sirmans [7]; Waddell [8]; Waddell and Nourzad [9] have considered the relationship between land use and transportation elements of urban planning in order to develop some integrated transportation-land use models. Willis [11] studied the physical impacts of highway developments and then tried to evaluate their environmental externalities to assist decision-makers to judge the merit of a highway scheme.

Specifically, Taleai [1] and Taleai *et al.* [2] have been developed a GIS-based decision making model to evaluate the compatibility of detailed urban land uses. They considered compatibility matrix to evaluate the compatibility but did not include other various effective parameters which may cause incompatibility.

The paper aim to develop a spatial model and consider various effective factors that cause incompatibility. An appropriate model using Delphi method could be developed through interviews with urban planning specialists and establishing a separate compatibility matrix for each factor. Fuzzy and Analytical Hierarchy Process (AHP) methods are employed to quantify experts' preferences as well as perceives and to determine the compatibility / incompatibility severity of each detailed urban land use.

MATERIALS AND METHODS

Land use plans must consider the relation among various land uses and their surrounding environment to minimize undesirable effects. In other words urban neighbored land uses have external effects on each other, which can be positive or negative.

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As the severity of the compatibility between a pair of land uses, depends on the scale as well as the type of their land uses, at first we should determine them. For instance, highways make some high noise particularly during the night (on the subject of its characteristics such as traffic level, modal split, road surface, speed levels, environmental conditions, etc.) which is unacceptable for residential land uses. Therefore, highways produce some negative externalities on residential land uses at micro-scale. On the other hand, the existence of a highway near residential areas increase the latter's accessibility, which is an evidence of positive externality at macro-scale [1-2]. Land use compatibility evaluation can restrict developing incompatible land use in built-up urban areas [1-2].

Various factors such as noise, air pollution, improper mixing of land uses and etc. may cause incompatibility. It should be mentioned that time of activities, using of some engineering solution etc. can decrease the negative effects. To support compatibility among various land uses often two techniques are utilized: engineering techniques and urban planning. The engineering technique needs more investment compared to planning technique. From sustainable development point of view urban planning technique is better and it's used usually by urban planners to prepare urban plans.

As various factors should be considered in the compatibility evaluation, they should be classified as multi-criteria decision making (MCDM) problem, while the spatial nature of the urban phenomena asks for a spatial-MCDM.

Compatibility Matrix: In this research, compatibility matrix has been used as useful tools to evaluate compatibility among different urban land uses. Compatibility matrix is one of the main and simplest ways for land use compatibility assessment. In this matrix each land use is compare with others and based on estimated compatibility that exist between them a value will be assigned to associated cell (Fig. 1).

Proposed Compatibility Assessment Model: Developed compatibility evaluation model includes 9 processes, as illustrated in Figure 2.

Process 1: In this model urban maps at 1:2000 scales were used as base spatial data and land use type of each floor have been collected.

Process 2: To produce fully structured data needed for GIS application, base maps edited to clean from some errors such as overshoots, gaps and etc. At the end of this process, attribute data was linked to each parcel.

Process 3: By study many references and policies in some detailed and comprehensive plans as well as interview with five urban planners, main urban land use types (47 land uses) were investigated. Also the characteristics of each land use type were determined to estimate existence externalities between various land uses.

Process 4: Based on the results of process 3, five parameters were defined as effective factors for compatibility evaluation, as follows:

- Noise (sound pollution)
- Air pollution
- Safety
- Welfare
- Aesthetics

Compatibility levels have been classified as follows (adapted from [1-2]):

- High compatibility (HC): those land uses, which are harmonious and consistent with each other and produce high level of usability when they are adjacent.
- Medium compatibility (MC): those land uses, which are moderately compatible with each other and produce a moderate level of usability when they are adjacent.
- Neutral/low compatibility (NC): those land uses, which have low compatibility with each other and which do not noticeably affect each other when they are adjacent.
- Medium incompatibility/very low compatibility (MI): those land uses, which are incompatible unless exceptional mitigation measures are occurring. The usability level of this kind of land uses will be reduced when they are adjacent.
- High incompatibility (HI): these land uses should only be located adjacent to each other when extensive and extraordinary mitigating measures can effectively address all compatibility concerns.

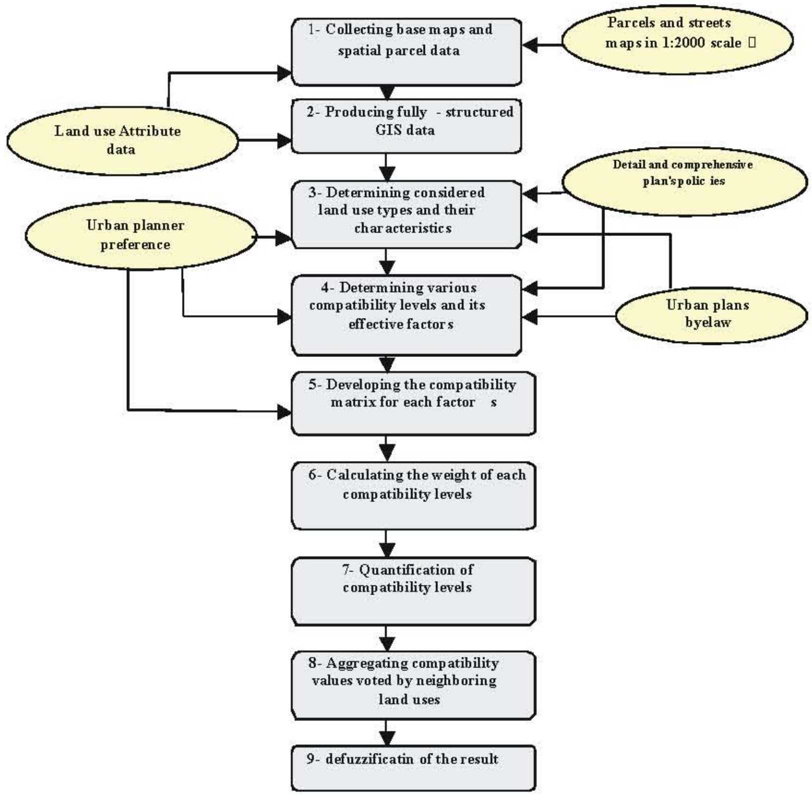

Fig. 2: Compatibility evaluation model

Table 1: Using AHP methods for calculating the weights

Compatibility levels	HI	MI	N	MC	HC	Arithmetic mean	Standard score	Standard weight
HI	1	2	3	5	7	3.6	0.375	1
MI	0.5	1	2	4	6	2.7	0.281	0.75
N	0.333	0.5	1	3	5	1.967	0.205	0.55
MC	0.2	0.25	0.333	1	3	0.957	0.1	0.01
HC	0.143	0.167	0.2	0.333	1	0.369	0.04	0.004

Process 5: Based on determined parameters in process 4, a compatibility matrix was constructed for each parameter separately and then was sent to 10 urban planners to determine the compatibility level between each pair of land uses corresponding to each parameter.

In this research the Delphi method as an iterative process designed to achieve consensus among a group of experts, is used to construct detailed compatibility matrix. This approach overcomes the difficulty to quantify variables and their relative importance [2]. Results of this process are five matrixes based on five determined parameters in process 4.

Process 6: Analytic hierarchy process (AHP) and structured pair-wise comparison have been used as a framework for calculating the weights of compatibility levels mentioned at compatibility matrix in process 5, while negative effects are more important than positive ones. As a pessimistic decision to highlight incompatible land uses, highest value is assigned to HI and least value is assigned to HC levels. In Table 1, change from N to MI is therefore considered more important than a change from N to MC. Similarly a change from MI to HI is more important than a change from MC to HC [2]. Table 1 shows the result of this process.

Process 7: Linguistic quantifier and fuzzy number are used for quantification and fuzzfication of compatibility levels.

The concept of linguistic quantifiers was introduced by Zadeh [10]. The quantifiers are represented as fuzzy sets, and consequently they are also referred to as fuzzy quantifiers [11-13]. The concept of fuzzy quantifiers is to translate the natural language

Table 2: Converting linguistic terms to fuzzy number [14]

Number of linguistic quantifier				
7	5	3	2	Linguistic quantifier
(0,0,0,0.1)	(0,0,0.1,0.2)			Very Low
(0.1,0.2,0.2,0.3)	(0.1,0.25,0.25,0.4)	(0,0,0.2,0.4)		Low
(0.2,0.3,0.4,0.5)				Low-Medium
(0.4,0.5,0.5,0.6)	(0.3,0.5,0.5,0.7)	(0.2,0.5,0.5,0.7)	(0.4,0.5,0.5,0.8)	Medium
(0.5,0.6,0.7,0.8)				Medium-High
(0.7,0.8,0.8,0.9)	(0.6,0.75,0.75,0.9)	(0.6,0.8,1,1)	(0.5,0.8,0.8,1)	High
(0.8,0.9,1,1)	(0.8,0.9,1,1)			Very High

specifications into formal mathematical expressions, which directly leads to the formulation of the multi-criteria decision/evaluation functions [10]. Based on the type of linguistically quantified statements one can distinguish between: the absolute linguistic quantifiers and the relative (or proportional) linguistic quantifiers. The absolute linguistic quantifiers are defined as fuzzy subsets [0, 4]. They can be used to represent linguistic statements such as about five, or more than ten. The relative quantifiers are closely related to imprecise proportions. They are defined as fuzzy subset of [0, 1] with proportional terms such as a few, half, many, most, etc [11-2]. In process 4, we used five compatibility levels: HC, MC, N, MI, HI. In fact we limit ourselves to a class of relative quantifiers.

Fuzzy numbers is a fuzzy set defined on the domain of real numbers. Fuzzy numbers are assumed to have the properties of both normality and convexity [14].therefore special fuzzy numbers have been suggested to simplify fuzzy modeling. In this paper we limit our discussion to the trapezoidal numbers. This category of fuzzy numbers has a relatively simple structure. It is important to note that the trapezoidal fuzzy numbers include crisp numbers, interval numbers and triangular numbers [14]. An example of trapezoidal fuzzy number is given in Fig. 3. Alternatively a trapezoidal number can be written as *(a, b, c, d)*. If *b=c* it converts to a triangular fuzzy number. Figure 3 shows a trapezoidal fuzzy number as (0.1, 0.4, 0.7, 1).

The concept of a fuzzy number provides us with the basis for defining linguistic quantifier. Specifically, the fuzzy numbers are state of linguistic quantifier while each linguistic quantifier defined in terms of a base variable, the values of which are real numbers within a specific range.

A number of numerical approximation systems have been proposed to convert linguistic terms systemically to their corresponding fuzzy number (Table 2).

In this paper to determine compatibility levels, five linguistic quantifiers are used, so we have 5 linguistic quantifiers as shown in Fig. 4. W axis represents weight and $\mu(x)$ axis represents membership degree in fuzzy set.

In this paper at first compatibility level between each land use pair is obtained based on compatibility matrix (process 5), as a linguistic quantifier. Then, based on Table 2 and Figure 4 compatibility levels have been converted to a fuzzy number. For instance in Fig. 5, suppose that A and B are two land uses with high incompatible effect based on developed compatibility matrix for noise parameter. Land use D and land use C are indicated with medium incompatible. Thus we can assign some fuzzy numbers, based on Table 2, corresponding to mentioned compatibility levels as shown in Figure 5.

Process 8: In this process compatibility fuzzy numbers voted by all neighbor land uses have been aggregated and then one value as overall compatibility index is obtained. To calculate this index, two aggregations process have been done: i) aggregating different compatibility fuzzy numbers voted by all neighbor land uses separately for each parameters and ii) aggregating five resulted values from i.

At first aggregation process, based on formula (I) the weight of each compatibility levels (process 6) has been multiplied in related fuzzy number.

$$F_i = W_j X_i \qquad \text{(I)}$$

Where, *Xi* represent fuzzy number and *W* represent the weight of compatibility levels. For instance, in Fig. 6 several compatibility levels have been assigned to a subject parcel based on noise parameter.

Based on Table (2) a fuzzy number is assigning to each compatibility level. For example for HI, MI relation in Fig. 6, fuzzy number (0.8, 0.9, 1, 1) and (0.6, 0.75, 0.75, 0.9) is determined respectively. Based on Table 1, standard weight for HI and MI is equal to 1 and 0.75, respectively. Therefore, after multiplying fuzzy numbers in corresponding weights new fuzzy numbers should be (0.8, 0.9, 1, 1) for HI and (0.45, 0.56, 0.56, 0.68) for MI levels.

To reach a general evaluation index for compatibility assessment, fuzzy numbers must be aggregated for each subject land use. To do this, based on formula (II)

weighted average method has been utilized to aggregate fuzzy numbers.

$$F_{fin} = \frac{1}{n}\sum_{n=1}^{n=i} w_j x_i \qquad \text{(II)}$$

Where, *F*fin represent final fuzzy number for each subject land use, n is number of neighborhood land uses, *Xi* is fuzzy number and *W* is the weight of compatibility levels.

At second aggregation process, corresponding to consideration of five parameters, five values resulted from first aggregation process have been aggregated. We assumed that all parameters have equal weight and then arithmetic mean method was used at final aggregation process.

Process 9: All compatibility index has been obtained at process 8 is in subset of [0, 1]. Numbers near to 1 are represent as high incompatibility when numbers near to 0 represent high compatibility relation. Defuzzification of these values to some linguistic variable is the next action.

RESULTS AND DISCUSSION

Because fuzzy numbers are not linearly ordered, a ranking method is needed to order the resulted fuzzy numbers. This can be accomplished by ranking the *d* parameter values of the trapezoidal fuzzy numbers (Fig. 3). As utilization of *d* parameter depends on the spread of the trapezoidal fuzzy number, the method can be used only if large spread is tolerable [11, 12]. According to this, the threshold method is used to define various compatibility classes as follows:

- ✓ High Incompatible (HI) $1 \geq C_s \geq 0.82$
- ✓ Medium Incompatible (MI) $0.82 \geq C_s \geq 0.54$
- ✓ Neutral/low compatibility (N) $0.54 \geq C_s \geq 0.26$
- ✓ Medium compatibility (MC) $0.26 \geq C_s 0.13$
- ✓ High compatibility (HC) $0.13 \geq C_s \geq 0$

These different classes show the relative severity of land use incompatibility. For example, subclass “medium compatible” indicates that the rated land unit has moderate limitations because of its compatibility. Each class of compatibility may call for different land use policy responses or decisions, perhaps also including some more macro-scale and social-economic evaluation to solve the problem. Planners then can decide if this level of incompatibility is severe enough to warrant a specific policy or needs intervention to reduce the incompatibility.

CONCLUSION

Analysis of compatibility is essential to understand the physical acceptability of land uses in order to promote intensive and mixed land use in cities while maintaining a high quality for life. Various factors such as noise, pollution, dust etc. can trigger various level of incompatibility between two adjacent land uses. Obviously considering each factor separately will potentially result in higher accuracy by setting separate compatibility matrix for each factor.

This paper focused on the spatial interaction between different adjacent land uses and the ability of two or more land use types to co-exist in close proximity to each other without negative effects.

We believe that, urban land uses compatibility assessment model should lead to:

1. Providing appropriate information to urban planning and urban management,
2. Increase economic value of urban regions,
3. Identifying best area for new urban generations and developments,
4. Determining problematic areas in built-up urban areas that could be useful to formulate strategies, policies and decisions to reduce negative externalities associated with land uses,
5. Prevent developing of unsuitable area from social, economic and environmental aspects that result in sustainable development, and
6. Implementing the suggested model in GIS environment can lead to better result.

ACKNOWLEDGMENT

The paper is based on an ongoing research activity at K.N. Toosi University of Technology and we hope to publish new findings at forthcoming papers.

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