# GIS-BASED IMPACT ASSESSMENT MODEL IN URBAN HISTORIC CULTURE HERITAGE PROTECTION AND PLANNING

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**KEY WORDS:** Cultural Heritage, Planning, GIS, Impact Analysis, Modelling, Fuzzy Logic, Hierarchical

**ABSTRACT:**

Information of the cultural heritage, especially cultural relics, historical architectures and memorial sites, firstly represents their location and time, and then are their cultural or historical attributes and meanings. Moreover, environment and planning also are important information for the protection of urban cultural heritage. Therefore, a lot of the spatial data and related attributes are acquired from urban cultural heritage, which are foundational information to make decision for their protection and planning. Adopting the fuzzy comprehensive judgment and the analytic hierarchy process to build an assessment model for urban historic cultural heritage protection and planning; using GIS functions to analyze and manage spatial data, and visualize the results; making research on the evaluation of the multiple indicants, huge data and the combination of qualitative and quantitative, and then, providing an evaluation method for urban historic cultural heritage protection and planning. The models will embed to a GIS interface to process the spatial and attribute data about historical heritage in the protected area. Finally, a sample for application is given.

## 1. INTRODUCTION

The urban historic cultural heritage protection and planning in China is facing tremendous challenges because of rapid urbanization development and rebuilding of the old city. Adopting new techniques and methods to analyze and forecast social, economic and environmental factors in the urban historic cultural heritage and the surroundings, the comprehensive evaluation could be made to the impacts of the current situation or construction projects in the protected areas following objective, open and impartial principles, and then, putting forward a proposal or resolution to abate bad influence or mitigate adverse effects and provide scientific basis for the protection and prevention planning. Because there are obvious regional characters in the distribution of the urban historic cultural heritage, the influence evaluation would be multi-level, multi-factor, combination of qualitative and quantitative, etc. The current comprehensive evaluation methods are classified as the weighted summation, fuzzy math, grey method, the analytic hierarchy process (AHP) and artificial neural network evaluation and so on. As the factor values in the urban historic cultural heritage protection are not represented precisely and the evaluation grades are indeterminacy, the traditional calculation methods are hard to obtain the satisfying results. A fuzzy comprehensive evaluation is developed and appropriate to solve the uncertainty combination with the quantitative and qualitative indicators, supplemented by AHP for the impact weights, the evaluation model could be further optimized.

The evaluation procedure would involve in data collection, assessment factor selection, assessment analysis and the result display and so forth. Geographic Information Systems (GIS) get power to maintenance, search, inquire and analyze the spatial and attribute data, which can collect, store, manage various evaluation data, and use the graphics to express the evaluation information and results. GIS provide the reliable technical support and effective work platform to further improve the scientific and standardized management for the historic cultural heritage protection and decision analysis.

## 2. MODEL OF EVALUATION

The fuzzy comprehensive evaluation based on fuzzy reasoning is a systemic method to analyse and evaluate fuzzy things, which is a unity of qualitative and quantitative, precision and non-precision. The general approach to establish the fuzzy comprehensive evaluation model for urban historic cultural heritage is designed.

### 2.1 Factor Set

Making evaluation factor set concluding all affecting factors:
U = (economic impact, environmental impact, social impact)
In considering the characteristics of the historic cultural heritage in the city, the indicators selected are based on the man-made causes. Economic impact concludes industrial, commercial, road traffic and the land use types; environmental impact concludes noise pollution and waste emissions, social impact is based on the population, the architecture style and tourism.

### 2.2 Evaluation Set

Making the evaluation set based on the assessment objectives:
V= ( faint impact, mild impact, moderate impact, severe impact)
V represents a classification set for U factors affecting the evaluation, the influence of surrounding factors increased from the faint to the severe.

### 2.3 Weight Vector

The impact scale of the evaluation factors can be decided by the weight coefficient of the impact factors. There are several of methods to calculate the scale in the evaluation, such as experts estimate, Analytic Hierarchy Process, fuzzy inverse equation, integrated sequence law and so on. AHP is used in the study to determine the relative importance of each factor in the evaluation index system. The weight vector is expressed as below:

$$A = (a_1, a_2, \cdots, a_n) \qquad (1)$$

And the steps decided the weight values are following as below:
1. In according to the known hierarchical structure model and experts experience in historic cultural heritage protection, the paired comparison judgement matrix is built. The importance index is shown in table 1.

| Importance | Meaning |
|---|---|
| 1 | Compared two elements，equally important |
| 3 | Compared two elements, the former is slightly important |
| 5 | Compared two elements, The former is obviously important |
| 7 | Compared two elements, The former is strongly important |
| 9 | Compared two elements, The former is vital important |
| 2，4，6，8 | The median said judge |
| reciprocal | If the importance ratio is $a_{ij}$ between elements i and j , the importance ratio is $a_{ji}=1/a_{ij}$ between elements j and i |

Table1. Importance of scaling meaning

2. Several more accurate judgment matrixes are extracted from the earlier judgment matrixes made by the rules and experiences, which should be ranked and pass the consistency test. The Table 2 shows an example.

| goals | economic impact | environmental impact | social impact | weight | Consistency Test |
|---|---|---|---|---|---|
| economic impact | 1 | 5 | 3 | 0.6480 | $\lambda_{max} = 3.0038$ |
| environmental impact | 1/5 | 1 | 1/2 | 0.1222 | $C.I. = 0.0019$ |
| social impact | 1/3 | 2 | 1 | 0.2299 | $C.R. = 0.0037$ |

Table2. Judgment criteria layer matrix and ranking results

3. Using the top-down approach to rank the hierarchical weight. Suppose that:

$$w^{(k-1)} = (w_1^{(k-1)}, w_2^{(k-1)}, \cdots, w_m^{(k-1)})^T$$

Where, $W^{(k-1)}$ is the relative importance to object of the layer k-1, and make that:

$$p^{(k)} = (p_1^{(k)}, p_2^{(k)}, \cdots, p_j^{(k)})$$

Where, $P^{(k)}$ is the relative importance between layer k and layer k-1, then the relative importance to object of the layer k is

$$a^{(k)} = (a_1^{(k)}, a_2^{(k)}, \cdots, a_j^{(k)})^T = p^{(k)} w^{(k-1)}$$

Thus, the weight vector in every layer is obtained after the consistency testing, like expression (1), and that the weight vector for all factors is taken following expression (2).

$$\sum_{i=1}^{n} a_i = 1, a \geq 0, i = 1,2,\cdots,n \qquad (2)$$

### 2.4 Fuzzy Matrix R

The relationship between factor domain U and assessment domain V are represented by the fuzzy matrix R., the essential is:

$$R : U \times V \to [0,1] \qquad (3)$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

Where, $r_{ij} \in [0, 1]$ ( i=1,2,⋯, n; j=1,2,⋯, m ). Because $r_{ij} = \mu(u_i, v_j)$ is the fuzzy membership of $v_j$ for the $u_i$, and

$$R_i = (r_{i1}, r_{i2}, \cdots, r_{im})$$

Where, $R_i$ is the single factor judgement of $u_i$, the membership functions are as following Figure 1 as below:

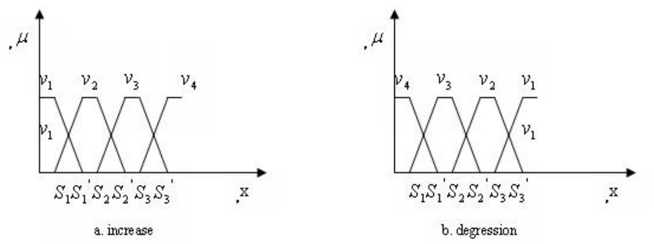


Figure1. The membership functions

Where, $\mu$ is the membership, x is factor value, $S_1$、$S_2$、$S_3$ are the threshold of the degree, $S_1'$、$S_2'$、$S_3'$ are the correctional value of the degree.

### 2.5 Comprehensive Evaluation

From the expression (1) and (3), the final formula is taken by using the fuzzy operators as below:

$$B = A * R$$

Where, *B* represents the comprehensive evaluation result that all evaluation factors are considered, which is a space matrix attached to membership function, the extent of the effect is based on the principle of membership.

## 3. IMPLEMENT OF EVALUATION

Relying on commercial GIS software, a database is established to manage and organize data used in the evaluation. The evaluation model mentioned above is embedded in the GIS platform by the component developing tools. The whole evaluation procedure is shown in Figure 2.

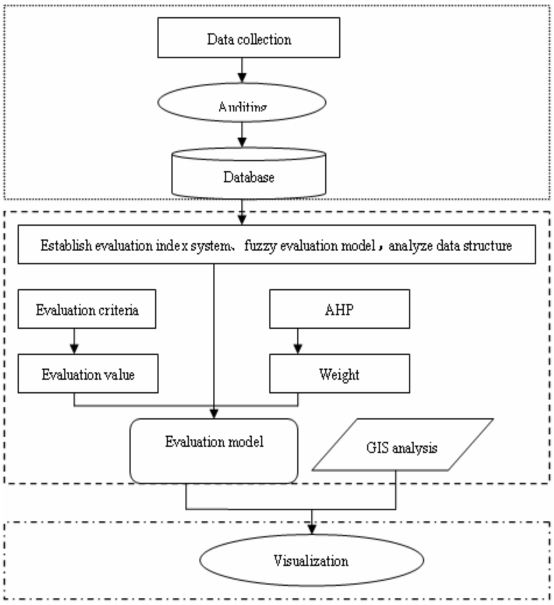


Figure2. Technical flowchart of assessment supported by GIS

There are three major technical sections to implement whole evaluation workflow, which collecting and organizing data, building evaluation model and analysis, and then, visualizing the result.

### 3.1 Factor Collection

Data about the historic cultural heritage protection area would be collected, such as land use map, soil type, road and traffic map, pipeline map, population, pollution sources and construct style and planning map, industrial, commercial and tourism data ,etc. All the information would be reclassified to extraction the impact factors working on the GIS platform. A database is built to store spatial data and attribute data.

### 3.2 Evaluation Processing

The evaluation index system would be built following the evaluation model presented above. According to the evaluation criteria the assessment values could be obtained, and combined with the weights calculated by AHP. Then, a judgement matrix R is taken based on the membership functions. All of the assessment value, the weights and matrix R could be stored and managed by GIS database that organized into the data structure of the middle layer, which link the impact factors and map layers. Finally, the comprehensive evaluation result B is calculated using the map algebra. The explanation about fields to factors and inquire is shown in Table 3.

| Explanation | |
|---|---|
| The name of above middle layer | The name of the middle layer |
| The name of factor | The weight of the middle layer factor |
| Tthe weight of factor | The factor number in the middle layer |
| The linking layer | The factor number in the next layer |

Table 3 The data structure chart of the middle layer

### 3.3 Visualization

The comprehensive evaluation result could be visualized in the windows in GIS platform, and the comparison to different impact class is carried out by the overlay, and unit for assessment is divided by the visual selection. Also the thematic map, chart or table of the results are easy to make.

## 4. APPLICATION

### 4.1 Study Area

Jing Shan district, the study area, is located in the centre of old Beijing city, where total area is 140.45ha, including eight old streets surrounding Jing Shan hill, among them, the protected area is 121.96ha. There are a lot of old constructs and buildings existing, from the Ming and the Qing Dynasty, with high historic, cultural and artistic value.

### 4.2 Evaluation Index System

Firstly, the impact evaluation index system for the protected area is built following the evaluation model presented above and objective, open and impartial principles, which shown in Figure 3.

### 4.3 Evaluation Standard

According to the protection rules and politics for the historic cultural heritage in Beijing and concrete data in the study area, the relational table between the assessment factors and the evaluation sets is made after the fuzzy matrix R is calculated. It is shown in Table 4.

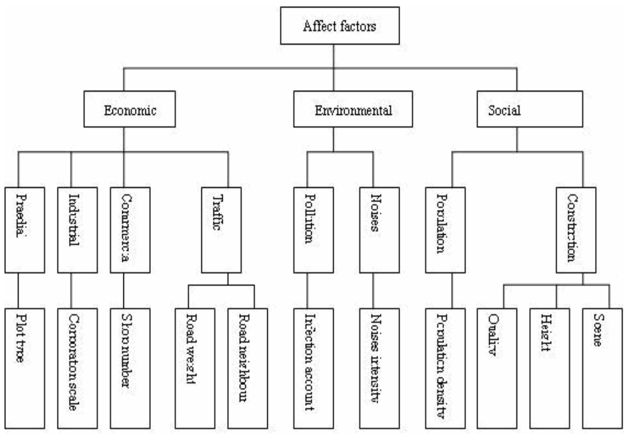


Figure3. Impact evaluation index system for Jing Shan district

| basic index | class index | index | evaluation criteria | | | |
|---|---|---|---|---|---|---|
| | | | weak impact | mild impact | moderate impact | severe impact |
| economic | praedial | plot type | there are little people and tracffic | there are a small quantity of people and tracffic | there are some people and tracffic | there are a lot of people and tracffic |
| | industrial | corporation scale | little area and infectant | mild area and infectant | large area,moderate infectant | large area，severe infectant |
| | commercial | shop number | little shop and passenger traffic | mild shop and passenger traffic | many shops and passenger traffic | lot of shops and passenger traffic |
| | traffic | road weight | ≤3m | 5-7m | 7-9m | ＞9m |
| | | road neighbour | ＞20 m | 10-20 m | 5-10m | ≤5m |
| environmental | pollution | infection account | little infection | there are infection | the fection is not serious | the fection is serious |
| | noises | noises intensity | ≤55dB | 55-60 dB | 60-65 dB | ＞65 dB |
| social | population | population density | ＜4person/100 m² | 4-7 person /100 m² | 7-10 person /100 m² | ＞ 10 person /100 m² |
| | constrrction | quality | | The main structure is intact, retaining integrity components，municipal facilities is completly | The main structure is not intact, support components is not good, municipal facilities is not completly | the main structureis bad, support component is bad ,municipal facilities is not completely |
| | | height | ≤2 layer | 3-4 layer | 5-6 layer | ≥7 layer |
| | | scene | architectural heritage; traditional architecture or modern construction with certain historical and cultural value | the general architecture are coordinational comparing with the traditional style | the modern architecture are coordinational comparing with the traditional style | the architecture are not coordinational comparing with the traditional style |

Table 4 The evaluation standard for Jing Shan District

### 4.4 Weight

The weights for the protected area are calculated by AHP following the evaluation model. They are displayed in Table 5 by comparing the relative importance of the impact factors in different layers to the protection in the study area.

| type | weight | factor | weight | gene | weight |
|---|---|---|---|---|---|
| economic | 0.6480 | praedial | 0.2314 | plot type | 0.2314 |
| | | industrial | 0.0463 | corporation scale | 0.0463 |
| | | commercial | 0.2314 | shop number | 0.2314 |
| | | traffic | 0.1389 | road weight | 0.1042 |
| | | | | road range | 0.0347 |
| environmental | 0.1222 | pollution | 0.0815 | infection account | 0.0815 |
| | | noises | 0.0407 | noises intensity | 0.0407 |
| social | 0.2299 | population | 0.0460 | population density | 0.0460 |
| | | construction | 0.1839 | quality | 0.0306 |
| | | | | height | 0.0613 |
| | | | | scene | 0.0920 |

Table 5. The weights of impact factors in Jin Shan district

### 4.5 Evaluation Result

The comprehensive evaluation result for Jin Shan district is shown in Figure 4. It is obvious that the major degree is moderate impact in the area, and it means that the good measures for the protection have been taken by the government so far. But we should also pay more attention to the areas shown the mild impact and the severe impact in the map.

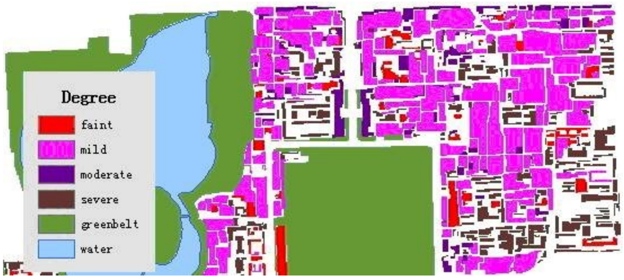


Figure4. Comprehensive evaluation result for Jing Shan district

## 5. CONCLUSION

The impact assessment model combined with GIS technique and fuzzy reasoning has taken advantage for the urban historic cultural heritage protection and planning. The fuzzy mathematical method is objective to use multiple indicators and more information in the protected area, and explores a possible combination way of qualitative, quantitative and positioning. Furthermore comparing to the traditional ways in the protection, the impact assessment model improves the accuracy, speed and quality in the evaluation, as a result the evaluation model support managers to make scientific decision for historic cultural heritage protection.

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