Application of AHP and Fuzzy Sets to the Development of a Scale to Measure Urban Growth*

Yaohuang Guo, Jun Li, Xiaobing Gao and Jianmin Jia
Department of Industrial Management
Southwest Jiaotong University
Chengdu, Sichuan 610031, Peoples Republic of China

Abstract

This paper outlines a systematic method based on the Analytic Hierarchy Process and Fuzzy Sets to develop a scale with which to measure urban growth. The method has been applied successfully to a developing city in China.

I. Introduction

A city is the outcome of social development. The modern city is a large society as well as a spacious region system with an aggregation of population, economy, science, technology, culture and information. Characterized by the effective utilization of the space and the natural environment, to accrue economic and social benefits.

Cities in China are developing at an unprecedented rate. The size of a city has a direct effect on its economic development, its layout, municipal construction projects and the quality of life of the dwellers. A reasonable urban growth can bring large economic benefits and make a comfortable environment for the city-dwellers' their work and their life. If the urban gerowth is not reasonable, it not only affects the benefits and wastes resources, but also causes social problems.

Urban growth is considered reasonable if it conforms to objective natural and economic laws that the urban system must abide by in the course of development to achieve optimum comprehensive economic, societal and ecological benefits. The growth of a city has dynamic characteristics, because of the close

* The authors gratefully acknowledge the support of K.C. Wang Education Foundation, Hong Kong.

relationship to the forces that influence productivity. Moreover, it has a relative meaning. Urban growth includes population, economic and regional growth. Because people play a dominant role in a city, the urban growth usually parallels population growth.

The reasonable growth of a city is the major objective of urban planning and urban construction. It is one of the most important bases for mapping out the strategy of urban development. Studies on urban growth go back to ancient times. Internal and external academic circles have conducted studies in economics, sociology, urban planning science, ecology etc., but there is not an integrated theory and effective quantitative analysis method which can be used to determine what is reasonable urban growth.

Because China is at the primary stage of industrialization, the study of urban growth will help not just to develop urban science, but will also have an important practical significance for the process of modernization and urban development.

Based on the extensive investigation of the present urban situation, we have developed a synthetic method to evaluate whether urban growth is reasonable or not. Because the degree of reasonableness of urban growth is a systematic concept and has not an absolute unified standard of judgement, we combine the Analytic Hierarchy Proces (AHP) with Fuzzy sets to evaluate it. This method is described in detail in the case of De Yang, a developing city in China.

II. The Method with the AHP and the Fuzzy Comprehensive Evaluation Process

The systematic evaluation method is described in the following steps.

1. Setting Up an Evaluating Index System

The measurement of the degree of urban growth is complicated because it is characterized by multiple objectives. Considering the relations of various factors on the basis of the specific conditions of De Yang, we constructed a hierarchy structure model to evaluate urban growth (Figure 1).

Figure 1: The Hierarchy Model for the Evaluation of Reasonable Urban Growth

In Figure 1 there are three levels. The first one is the overall objective, the reasonable urban growth; the second one is the set of criteria, and the third one is an index level.

The set of evaluation criteria is given by:

$\{ B_1, B_2, B_3, B_4, B_5, B_6 \}$

and the sets of evaluation indexes are given by:

$$\{ C_1, C_2, C_3, C_4 \}$$
$$\{ C_5, C_6, C_7, C_8, C_9, C_{10} \}$$
$$\{ C_{11}, C_{12} \}$$
$$\{ C_{13}, C_{14} \}$$
$$\{ C_{15}, C_{16} \}$$

The means of criteria and indexes are defined as follows:

A : reasonable growth
B_1 : economy
B_2 : society
B_3 : ecological environment
B_4 : resources
B_5 : additional urban characteristics
B_6 : regional requirements
C_1 : gross social product
C_2 : per capita gross social product
C_3 : the level of capital profits
C_4 : economic structure
C_5 : land area occupied
C_6 : inhabitation condition
C_7 : traffic condition
C_8 : public order
C_9 : culture and education
C_{10} : inhabitant real income
C_{11} : the degree of atmospheric pollution
C_{12} : the degree of water pollution
C_{13} : the condition of energy resources
C_{14} : the condition of water resources
C_{15} : the capability of information service
C_{16} : the capability of science and technology

2. Constructing Pairwise Comparison Matrices and Computing the Weight of Each Factor.

The pairwise comparison matrices are derived from the composite judgments of experts after the consistency test. The weight of relative importance of each index in the same level relative to the upper level can be computed by means of AHP [4,5], and moreover the consistency index and the average consistency random index are also obtained.

The pairwise comparison matrices and the calculated results are given below (Tables 1-6)

Table 1

A	B_1	B_2	B_3	B_4	B_5	B_6	W
B_1	1	1.27	1.78	2.75	2.18	3.20	0.2939
B_2	0.4608	1	1.08	1.94	2.42	3.00	0.1983
B_3	0.5618	0.9529	1	3.33	2.72	4.18	0.2355
B_4	0.3626	0.5155	0.3003	1	1.86	3.64	0.1223
B_5	0.4587	0.4132	0.3676	0.5319	1	2.46	0.0962
B_6	0.3125	0.3333	0.2392	0.2747	0.4065	1	0.0538

$\lambda_{max} = 6.2732$
CI = 0.0546, RI = 1.24, CR = 0.044

Table 2

B_1	C_1	C_2	C_3	C_4	W
C_1	1	1.87	1.18	2.39	0.3527
C_2	0.5348	1	1.52	2.11	0.2669
C_3	0.8475	0.6579	1	2.82	0.2607
C_4	0.4184	0.4739	0.3521	1	0.1197

$\lambda_{max} = 4.1021$
CI = 0.034, RI = 0.9, CR = 0.038

Table 3

B_2	C_5	C_6	C_7	C_8	C_9	C_{10}	W
C_5	1	2.02	1.81	1.74	1.60	1.32	0.2417
C_6	0.4951	1	1.68	2.03	1.35	0.92	0.1774
C_7	0.5525	0.5952	1	1.53	1.25	1.01	0.1454
C_8	0.5747	0.4926	0.6536	1	1.12	1.66	0.1621
C_9	0.625	0.7407	0.8	0.8929	1	3.46	0.1603
C_{10}	0.7576	1.087	0.9901	0.6024	0.2891	1	0.1131

$\lambda_{max} = 6.3291$
CI = 0.0658, RI = 1.24, CR = 0.0531

Table 4

B_3	C_{11}	C_{12}	W
C_{11}	1	1	0.5
C_{12}	1	1	0.5

Table 5

B_4	C_{13}	C_{14}	W
C_{13}	1	4	0.6667
C_{14}	1/4	1	0.3333

Table 6

B_5	C_{15}	C_{16}	W
C_{15}	1	1	0.5
C_{16}	1	1	0.5

3. Given a Comment Set and Determining the Membership Degree of Each Index

Because of the fuzzy characteristic of the degree of reasonableness, membership degree is used to indicate the degree of closeness of each factor to the elements of comment set which is the appropriate degree of each factor relative to the reasonable urban growth. The comment set is given by:

$$Y = \{ Y_1, Y_2, Y_3, Y_4, Y_5 \}$$

where

Y_1 : over large
Y_2 : large
Y_3 : appropriate
Y_4 : small
Y_5 : over small

The membership degree matrix obtained from expert judgments is shown in Table 7.

Table 7

	Y_1	Y_2	Y_3	Y_4	Y_5
C_1	0.1667	0.3333	0.1667	0.25	0.0833
C_2	0	0.4167	0.25	0.25	0.0833
C_3	0	0.0833	0.25	0.5	0.1667
C_4	0	0.3333	0.1667	0.25	0.25
C_5	0.1667	0.6667	0.0833	0.0833	0
C_6	0.1667	0.75	0.0833	0.0833	0
C_7	0.0833	0.0833	0.6667	0.0833	0.0833
C_8	0	0.3334	0.5	0.0833	0.0833
C_9	0	0	0.25	0.5	0.25
C_{10}	0	0.1667	0.5	0.25	0.0833
C_{11}	0	0.4167	0.25	0.3333	0
C_{12}	0	0.0833	0.5833	0.1667	0.1667
C_{13}	0	0	0.0833	0.5	0.4167
C_{14}	0.0833	0.25	0.5	0.0833	0.0834
C_{15}	0	0	0.1667	0.3333	0.5
C_{16}	0	0	0	0.6667	0.3333
B_6	-0	0.4167	0.3333	0.25	0

4. Making Fuzzy Comprehensive Evaluation

Combining the weights of factors with the membership grades of factors, we obtain the final evaluation model.

$$U = V * R$$

$$R = \begin{bmatrix} V_1 * R_1 \\ V_2 * R_2 \\ \cdot \\ \cdot \\ \cdot \\ V_6 * R_6 \end{bmatrix}$$

where

V, V_i : the weight vectors of factors, obtained by AHP;

$R_i = (r_{ij})mx5$: the first evaluation matrix derived from Table 7; m means the numbers of the indexes which each criterion contains; if i=1, m=4; i=2, m=6; i=3,4,5, m=2;

$R = (r'_{ij})6x5$: the second evaluation matrix that is obtained on the basis of the first evaluation matrix and the weight vectors of indices;

* : fuzzy operator. Considering the joint effects of the various factors, we adopt the Weighted Average Type, that is $(\oplus, \cdot)$.

For criterion B_1

$$V_1 * R_1 = (0.3527\ 0.2669\ 0.2607\ 0.1197) * \begin{bmatrix} 0.1667 & 0.3333 & 0.1667 & 0.25 & 0.0833 \\ 0 & 0.4167 & 0.25 & 0.25 & 0.0833 \\ 0 & 0.0833 & 0.25 & 0.5 & 0.1667 \\ 0 & 0.3333 & 0.1667 & 0.25 & 0.25 \end{bmatrix}$$

$$= (0.0588\ 0.2904\ 0.2107\ 0.3151\ 0.125)$$

and the others can be calculated by analogy. Then the second evaluation matrix is given by:

$$R = \begin{bmatrix} 0.0588 & 0.2904 & 0.2107 & 0.3151 & 0.1250 \\ 0.082 & 0.3825 & 0.3195 & 0.1591 & 0.0767 \\ 0 & 0.2500 & 0.4167 & 0.2500 & 0.0833 \\ 0.0278 & 0.0833 & 0.2223 & 0.3610 & 0.3056 \\ 0 & 0 & 0.1250 & 0.4583 & 0.4167 \\ 0 & 0.4167 & 0.3333 & 0.2500 & 0 \end{bmatrix}$$

thus the evaluation result is $U = (0.0369\ 0.2522\ 0.2797\ 0.2842\ 0.14)$

According to the principle of the maximal degree of membership,

$$U^* = \max\{U_{(1)}, U_{(2)}, \ldots, U_{(5)}\}$$
$$= \max\{0,0369\ 0.2522\ 0.2797\ 0.2842\ 0.14\} = 0.2842$$

Hence, the judgment result is Y_4, that is, the urban growth of De Yang is not reasonable but small.

III. Analysis of Results

Tracing the evaluation result to its source, we can find the following problems:

1. The economic structure in De Yang, including industrial structure, investment structure, etc., is not reasonable. Therefore the economic development of De Yang is not well coordinated with the urban development.

2. The overall economic benefit of the city is not very good. The economic assembly benefits have not fully formed because of the small urban scale.

3. The shortage of energy in the city has limited the speed of economic development and further has affected the speed of urban development.

4. Culture, education, science and technology have not been paid much attention, so the attraction of the city is low.

The above aspects have made the expansion of the urban scale of De Yang to be restricted. Conversely, the small urban scale has affected the well development of the city in every aspect.

IV. Conclusion

Considering the hierarchical and fuzzy characteristics of urban systems, we present the synthetical evaluation method of urban growth with the Analytic Hierarchy Process and the Fuzzy Evaluation Process. It has practical and theoretical significance. By evaluating the reasonable degree of urban growth and comparing it with other cities, we find what the problems of urban development are. The results can provide objective and reliable grounds to guide the decision making for urban development planning. Moreover the method has an important value to the development of urban planning science. It provides widespread application prospects to synthesize various methodologies for the urban studies.

References

1. Eltrmi, Edward J., Models for Public Systems Analysis, Academic Press, Inc. Ltd, 1977.

2. Guo, Yaohuang and others, The Study of Reasonable Urban Scale, unpublished paper (in chinese), Southwest Jiaotong University, 1989.

3. Hoch, Irving, City Size and U.S. Urban Policy, Urban Studies, 1987.

4. Saaty, Thomas L., The Analytic Hierarchy Process, McGraw-Hill Inc., New York, 1980.

5. Xu, Shubo, The Principle of the Analytic Hierarchy Process, Tianjin University Press, (in chinese) 1988.

6. Zimmermann, H.J., Fuzzy Set Theory and Its Applications, Kluwer-Nijhoff Publishing, 1985.