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Evaluation on the smart growth of cities based on methods of comprehensive evaluation and TOPSIS

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***Abstract*— Many communities are implementing intelligent growth plans to try to address remote, sustainable planning goals. The evaluation of urban intelligent growth and making a more reasonable plan is a real problem. We define the smart growth index of cities according to the three E's and ten principles respectively, and establish the index system. And then presents a comprehensive evaluation method —TOPSIS model based on principal component analysis. This paper gives the evaluation steps of the comprehensive evaluation method. In order to test the feasibility and validity of the proposed evaluation method, we use MATLAB to fetch the data of 30 virtual cities in the range of index and evaluate in addition to rank the 30 virtual cities. Furthermore, in order to test the robustness of the evaluation model, we perform the sensitivity analysis with two index which is the most influential and the least influential index. Last, we analyse the impact that caused by the change of index. The analysis results show the stability of our proposed model.**

***Index Terms*— Evaluation; Smart growth of cities; Comprehensive evaluation method; TOPSIS method**

I. Introduction

Since the beginning of the 21st century, with the rapid development of urbanization, urban land expands rapidly, extensive urbanization causes destructive growth of land resources, urban ecological environment and quality of life decline. Selecting a reasonable urban growth strategy which can guide Urbanization orderly is particularly urgent.

Many scholars have done research on the wisdom of the city. Artmann et al. (2017) introduce a systemic conceptual framework for compact and green cities by combining the concepts of smart growth and green infrastructure. Susanti et al. (2016) point out the indicators that best fits the character of housing in Indonesia to reach smart growth and smart city. Quinn(2014) adds up the impact of regulatory changes implemented. Li et al. (2005) studied the relationship between urban planning and the future land. Wang and Wang (2007) revealed the impact of policy design on social equity.

In this paper, we reference to the evaluation index system from previous researches on the basis of analysis of smart growth, define the smart growth index. We choose Coventry, UK and Windsor, Canada and measure how successful the current plans are by using TOPSIS model based on principal component analysis. Furthermore, we provide smart growth optimization plan for them. It's proved in the paper that the plan is very stable. And we give an example that supposing the population of each city will increase by 50% in 2050 for more specific discussion.

II. Definition of Index System

In order to evaluate the success of smart growth in cities, we need to do the following work. First, according to the principles, select the appropriate index, and establish the index system, then evaluate comprehensively based on index.

We consider the index selection problem from two perspectives. One of point of view is to follow the principle of the three E's—Economically prosperous, socially equitable, and environmentally Sustainable. Another point of view is to meets the smart growth principles.

1) Selection of index based on the three E's.

Considering the three E's, we can use economic prosperity, social equity and environmental sustainability as the primary index. According to previous researches and the data from Bureau of Statistics, we choose the appropriate secondary index and get their reasonable extent. The selected index and their reasonable range of values are shown in the Figure 1 and Table 1:

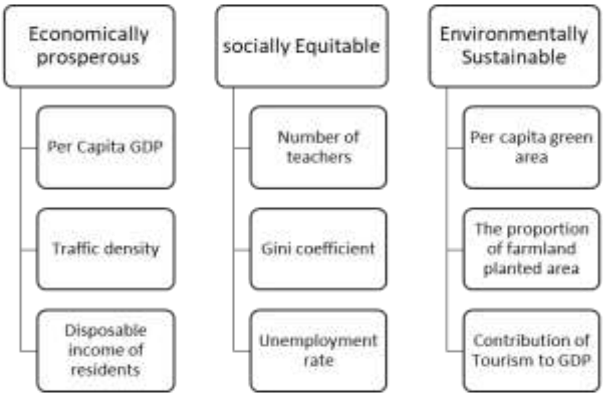

Figure 1 Index based on the three E's

Table 1 The selected index and their reasonable range

Index	*Symbol*	*Range of Index*
Per Capita GDP	A_1	\$8000~\$50000
Traffic density	A_2	0.5~3.0
Disposable income of residents	A_3	\$2000~\$10000
Number of teachers	B_1	4000~8000
Gini coefficient	B_2	0.25~0.48
Unemployment rate	B_3	2%~9%
Per capita green area	E_1	20~300m^2
The proportion of farmland planted	E_2	5%~16%
Contribution of Tourism to GDP	E_3	3%-13%

(2) Selection of index based on the ten principles for smart growth

Based on the ten principles for smart growth, We analyze the land use mixed degree, compact building design utilization, housing opportunities and choice creation, the creation of pedestrian communities, the building of attractive communities, the extent of open space retention, the maintenance of key environmental areas , the development of existing communities, the diversity of transport options, the fairness and cost-effectiveness of development decisions, and the extent to which communities and stakeholders cooperate in development decision-making. To better measure these principles, we select the following proxy metrics and get their reasonable range of values which are shown in Table 2:

Table 2 The selected index and their reasonable range

Principles	*Index*	*Symbol*	*Range of Index*
Mix land uses	Land use mixed degree	F_1	0.3~0.6
Take advantage of compact building design	The compactness of the city	G_1	0.2~0.5
Create a range of housing opportunities and choices	Supply of building area(Ten thousand square meters)	H_1	100~400
Create walkable neighborhoods	Walking network metrics	I_1	25000~27000
Foster distinctive, attractive communities with a strong sense of place	Expenditure on public facilities and services (10 thousand yuan)	J_1	87%~97%
Preserve open space, farmland, natural beauty, and critical environmental areas	the proportion of Non-construction area	K_1	6000~9000
Strengthen and direct development towards existing communities	Urban and rural community investment (million)	L_1	1000~2000
Provide a variety of transportation choices	Equivalent Capacity (pcu / h)	M_1	1000~2000
Make development decisions predictable, fair, and cost effective	Predictability: The proportion of direct indicators	N_1	0-1
	Fairness: Gini Coefficient	N_2	0-1
	Cost-effectiveness: Decision-making rate of return	N_3	0-1
Encourage community and stakeholder collaboration in development decisions	Community and stakeholder participation	O_1	-1，0，1

III. COMPREHENSIVE EVALUATION INDEX SYSTEM

In order to better integrate the indicators and quantify the evaluation results, a comprehensive analysis of the index system needs to be carried out. Many studies have investigated comprehensive evaluation problem. For example, Kramulová and Jablonský (2016) analyzed the problem of competitiveness analysis of countries and regions in the AHP that applies a ranking method. Plebankiewicz and Kubek (2016) propose the fuzzy analytic hierarchical process (FAHP) with extent analysis method, but it's analysis revealed that the model does not have good stability. Kuo (2016) uses TOPSIS model, but the robustness and analytical sensitivity of the model cannot be verified.

Therefore, after the establishment of evaluation system for assessing smart growth success rate, we adopt TOPSIS model based on principal component analysis to evaluate synthetically and test the feasibility and validity of the evaluation model to ensure the evaluation result is real and effective.

TOPSIS model is an effective multi-index, multi-processing decision analysis method, which mainly sorts through detecting the distance between object and the optimal solution, the worst solution. If the evaluation object closest to the best solution and away from the worst solution, it is the optimal decision. Otherwise it is the worst decision. The model includes normalizing the decision matrix, calculating the weight of the evaluation index, determining the optimal and worst vectors of the matrix, calculating the separation measure using the n-dimensional Euclidean distance and calculating the degree of closeness of each evaluation object to the optimal solution and so on.

The TOPSIS model's sorting results makes full use of data and the quantitative results are accurate. The variance contribution rate for the TOPSIS method provided by the principal component analysis can make up for the lack of the objective weight coefficient. In this paper, we choose TOPSIS model based on principal component analysis and evaluate the urban smart growth according to the relative degree of each evaluation index system, and then determine the city's smart growth plan.

The specific steps of TOPSIS method are as follows:

Step 1 Attribute Convergence Treatment.

Change the low-priority index and neutral index into high-quality indexx_{ij}:

$$x_{ij} = \begin{cases} x_{ij}, & x_{ij} \text{ is the High} - \text{priority index} \\ \dfrac{1}{x_{ij}}, & x_{ij} \text{ is the Low} - \text{priority index} \\ \dfrac{M}{[M + |x_{ij} - M|]}, & x_{ij} \text{ is the Neutral indicator} \end{cases}$$

And we can appropriate adjust (enlarge or shrink a certain percentage) the data.

Step 2 Normalize the decision matrix.

The normalized value Z_{ij} is calculated as

$$Z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}(x_{ij})^2}}, i = 1,2,\ldots,m;\ j = 1,2,\ldots,n.$$

Thus we get the normalized matrix Z:

$$Z = \begin{bmatrix} z_{11} & \cdots & z_{1m} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nm} \end{bmatrix}$$

Step 3 Determine the positive ideal solution and the negative ideal solution.

The positive ideal solution Z^+ consists of the maximum of each column in Z:

$$Z^+ = (maxZ_1^+ , maxZ_2^+ , \cdots , max Z_j^+)$$

The negative ideal solution Z^-consists of the minimum of each column in Z:

$$Z^- = (minZ_1^+ , minZ_2^+ , \cdots , minZ_j^+)$$

Step 4 Calculate the seperation measure using the n-dimensional Euclidean distance.

The distance between the i-th evaluation object and the positive ideal solution D_i^+:

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(maxZ_j^+ - Z_{ij}\right)^2}\ , \mathrm{i} = 1\ ,\ 2\ ,\ \cdots\ ,\ \mathrm{m}$$

Similarly, The distance between the i-th evaluation object and the negative ideal solution $D_i^-$is

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left(minZ_j^+ - Z_{ij}\right)^2}\ , \mathrm{i} = 1\ ,\ 2\ ,\ \cdots\ ,\ \mathrm{m}$$

Step 5 Calculate the degree of closeness of each evaluation object to the optimal solution $\boldsymbol{C_i}$is

$$C_i = \frac{D_i}{D_i^+ + D_i^-}\ , \mathrm{i} = 1\ ,\ 2\ ,\ \cdots\ ,\ \mathrm{m}$$

$0 \leq C_i \leq 1$. If $C_i \rightarrow 1$ indicates that the evaluation object is optimal.

Step 6 According to C_i size of the order, given the evaluation results.

The higher the value of C_i is, the more successful the city's smart growth is. In order to test the feasibility and stability of the established evaluation model, we use MATLAB to fetch the data of 30 virtual cities' index (data is shown in appendix), then evaluate and sort the virtual city $K_1 \sim K_{30}$ and test the model.

After analyzing the data of virtual city, we find that our metric is stable reasonable of the proposed evaluation model. And we verify that TOPSIS analysis method based on the principal component analysis can effectively solve the multi-index comprehensive evaluation problem. From the analysis above we can easily find that using TOPSIS analysis method based on the principal component analysis can effectively solve the multi-index comprehensive evaluation problem.

IV. SENSITIVITY ANALYSIS

In order to analyze the validity of the selected indexes to the success rate of the smart city growth, and to test the robustness of the evaluation model, we respectively use the principal component analysis to select the two indexes which are the most influential and least influential in the 3E principle and the ten principles sensitivity analysis.

Step 1 Factor analysis with MATLAB.

Input the original data in the edit window, then obtain % of Variance and Cumulative % by Programming with MATLAB. Because the cumulative contribution rate of the first two factors reached 80%, we respectively determine two principal components with the principles of three E's and ten principles for smart growth.

Step 2 The principal component analysis was carried out by using the factor analysis result, and the principal component expression was obtained.

Two principal component expressions according to the three E's:

$Y_1 = 0.3264A_1 + 0.2683A_2 + 0.0631A_3 - 0.4413B_1 + 0.4480B_2 - 0.0092B_3 + 0.1068E_1 - 0.3750E_2 + 0.5195E_3$

$Y_2 = 0.5245A_1 - 0.2776A_2 + 0.1368A_3 + 0.4407B_1 + 0.0687B_2 + 0.3855B_3 - 0.4542E_1 + 0.0722E_2 + 0.2648E_3$

Therefore, in 3E principle, the most important indicator is E_3 , and the least affected is B_1 . Sensitivity analysis is presented in Figure 2 and Figure 3:

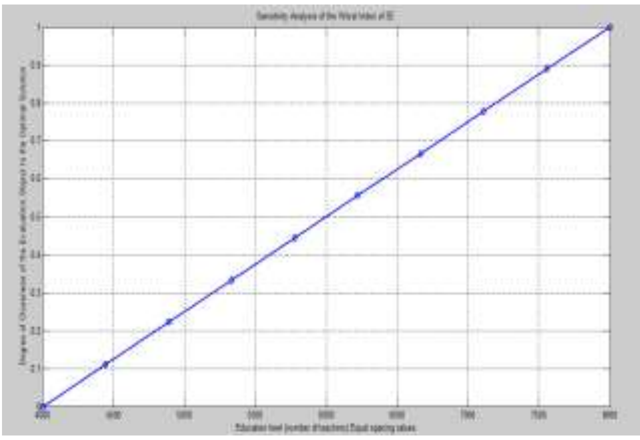

Figure 2 Sensitivity analysis of E_3

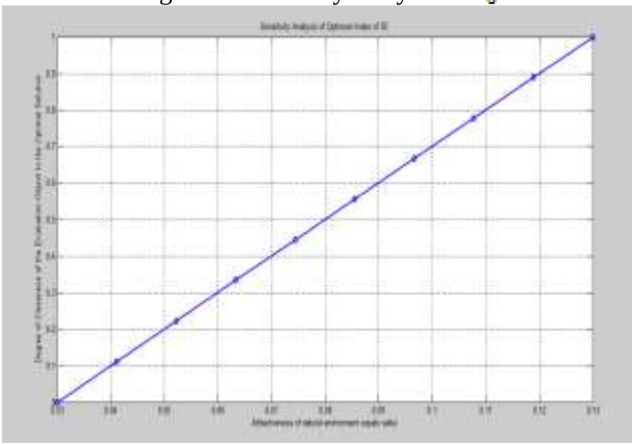

Figure 3 Sensitivity analysis of B_1

Two principal component expressions according to the ten principles for smart growth:

$Y_3 = 0.3039F_1 + 0.3355G_1 + 0.1777H_1 + 0.3202I_1 + 0.3384J_1 - 0.2051K_1 + 0.3512L_1 + 0.3543M_1 - 3.2312e^{-27}N_1 - 0.3277N_2 + 0.3230N_3 + 0.2094O_1$

$Y_4 = 0.0119F_1 - 0.0340G_1 + 0.6775 + 0.1602I_1 + 0.0705J_1 - 0.0895K_1 + 0.0723L_1 + 0.0.0234M_1 - 8.6736e^{-19}N_1 + 0.0924N_2 - 0.2192N_3 - 0.6624O_1$

Consequently, in the ten principles for smart growth, the most important indicator is M_1, and the least affected is N_2. Sensitivity analysis is presented in Figure 4 and Figure 5.

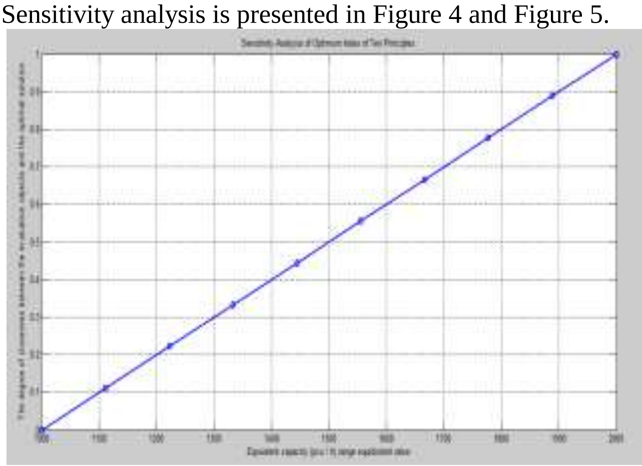

Figure 4 Sensitivity analysis of M_1

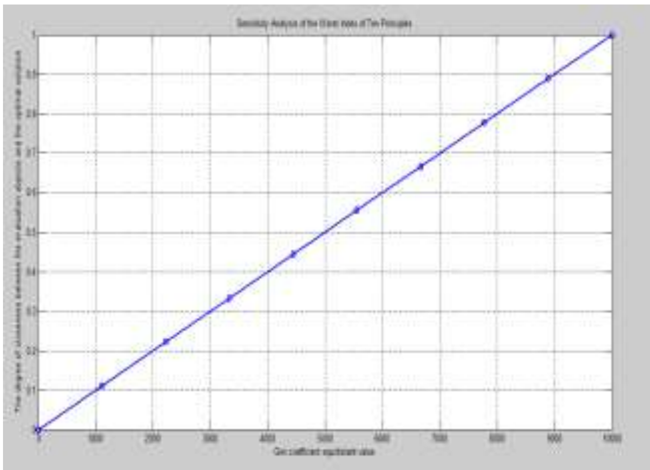

Figure 5 Sensitivity analysis of N_2

V. CONCLUSION

Before defining an evaluation metric, we find the Composition indices of metric base on the three E's and principles. Then we introduce TOPSIS and use it in valid data to evaluate the metric, and adopt the metrics. After that we do sensitivity analysis to the metrics, and pleased to see that the metrics have enough sensitivity.

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