



A Comprehensive Evaluation Method of Smart City Based on Combination of Subjective and Objective Weighting

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ABSTRACT

Smart city has already become an important development direction for cities around the world. With the deepening of smart cities construction, how to scientifically evaluate the construction and development of smart cities has been a significant topic in academic and the government. The paper analyzes the evaluation methods and practices of smart cities, and proposes a comprehensive evaluation method with the combination of subjective expert consultation method and objective entropy weight method. Based on China's 2019 national new smart city evaluation data, a comprehensive evaluation method application is carried out., and the weights and rankings of the indicators are obtained and analyzed. This comprehensive evaluation method is both reasonable and operable, and has some guiding implications for the development of smart cities.

Keywords: smart city, evaluation method, entropy weight method

1. INTRODUCTION

Smart cities aim to promote the intelligentization of urban planning, construction, management and service by using the new generation of information technologies such as the Internet of Things, cloud computing, big data, spatial geographic information integration and so on. Smart cities help to improve the efficiency of resource utilization, the capabilities of urban management, the satisfaction of residents and the development of digital economy. The construction of smart cities is highly valued by the government and society. Through the evaluation of smart cities, we can measure the effectiveness of smart city construction, summarize the typical practical experience of cities, better steer the development direction, and help the healthy development of cities. The evaluation method is the basic theoretical system to support the evaluation work, and it is also an important reference to promote the construction of smart cities by classification.

2. RELATED WORK

There are various methods for evaluating smart cities. The project team headed by Professor Giffinger, R. of

Vienna University of Technology (2007) [1] built a smart city evaluation system for medium-sized cities in the EU, evaluated and ranked 70 medium-sized cities. After standardization of the evaluation data, the evaluation results are directly summed, except for a few small weight corrections based on index coverage. That is to say, indicators are equally weighted in the method. The Intelligent Community Forum (ICF) has been conducting annual intelligent community evaluations since 1999, which cover a wide range of sizes from large cities such as New York and Singapore to rural areas of 10,000 people. Questionnaire survey is its mainly evaluation method, in which there are more qualitative indicators and less quantitative indicators. It is scored by experts according to ICF standards and methods. Boyd Cohen built the Smart City Wheel evaluation model and conducted the first global smart cities ranking based on the research of Vienna University of Technology and others. In terms of indicators weights and scores calculation, the method first standardizes the data, the city with the best performance in each of the six primary indicators is assigned equivalent 15 points in this dimension, and the scores of other cities are converted accordingly, that is, if a city is optimal in all six dimensions, it will get the highest score of 90 points.

Lazaroiu, G. C. and Roscia, M. (2012) [2] proposed an evaluation method called the smart City Index, which is used to guide the allocation of funds in the European Fund 2020 Strategic Plan. Aiming at the difficulty of assigning weights of indicators in this method, the proposer used fuzzy algorithm to determine the weights to optimize.

In the practice of smart city evaluation in China, the national new smart city evaluation has great influence. In 2016, the Evaluation Indicators for New-type Smart Cities was published and the first nationwide smart city evaluation was carried out. In December 2018, an updated version of the Evaluation Indicators for New-type Smart Cities was released, and the second national smart city evaluation was launched in 2019. As it is relatively mature and measurable, many scholars in China have adopted and learned from the Evaluation Indicators for New-type Smart Cities to develop smart city evaluation research. Shandong Province, Yangzhou City, Changsha City, Hubei Province and other places organized the evaluation of local smart city or digital economy construction based on the Evaluation Indicators for New-type Smart Cities. On the determination of indicator weights, China's national and local smart city evaluation practices mostly used expert consultation method.

In the index-based evaluation, the method of determining weight of the index includes two categories: subjective and objective. In academic research related to smart city evaluation, subjective weight determination methods include Delphi method, expert consultation method, analytic hierarchy process, fuzzy comprehensive evaluation method and so on. In the meantime, objective weight determination methods include entropy weight method, dispersion and mean square error method, principal component analysis method, factor analysis method, grey relational analysis method, projection pursuit method, etc. As a commonly used objective weighting method, the entropy weight method has been widely used in academic research on smart city evaluation. Shen, L. et al. (2018) [5] applied entropy method and technique for order preference by similarity to ideal solution (TOPSIS) technique to evaluate the performance of smart cities in 44 sample cities in China. Liu, G. et al. (2018) [3] adopted information entropy method and grey correlation analysis to evaluate the city smartness level, and took 20 major cities in China as cases for evaluation.

In concept entropy originated from thermodynamics in physics to measure the disorderly state of molecular motion. It was later introduced into information theory to measure uncertainty, and the amount of information is inversely proportional to uncertainty. Based on the characteristics of entropy, the data results of entropy method are completely based on the relationship of data itself, and the entropy method measures the degree of

influence of different factors on the evaluation object through the discrete degree of indicators, which has strong objectivity and operability.

In summary, the methods such as equal weight and expert consultation method used in the larger-scale practice of smart city evaluation are relatively simple and easy to implement, and the methods proposed by the academic community for the assignment of smart city evaluation indicators are more diverse, among which the entropy method is widely used. Scientific evaluation of smart cities is of great significance to guide the healthy development of smart cities, and it is necessary to study and propose a reasonable and practical smart city evaluation method.

3. METHODOLOGY

Among the methods used in smart city evaluation of large-scale practice, simple weighting methods such as the equal weight method are not sufficiently persuasive, and the expert consultation method is easily influenced by the subjective perception of experts. The entropy weight method commonly used in academic research on smart city evaluation is carried out entirely on actual data, however, it has high sensitivity to data and is prone to too small or too large weighting results. Especially when all entropy values tend to be close to 1, small differences can cause the entropy weights to change exponentially, resulting in some indicators being given weights that are inconsistent with their importance [4].

In this paper, in order to determine the weights scientifically and reasonably, a combination of subjective and objective assignment method is proposed. The method combines the subjective expert consultation method and the objective entropy weight method, and the indicators weights are calculated based on the principle of minimum information entropy.

Step1: Data preparation

Suppose there are m evaluation objects and n evaluation indicators, x_{ij} represents the value of the i th evaluation object in the j th evaluation indicator, forming the original data matrix

$$X = (x_{ij})_{m \times n} \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \quad (1)$$

Assume that the weights of expert consultation method is W_{1j}

$$W_{1j} = (w_{11} \quad w_{12} \quad \dots \quad w_{1n}) \quad (j = 1, 2, \dots, n) \quad (2)$$

Step2: Weight calculation by entropy weight method

Step2.1: Data standardization

The data is standardized based on the maximum and minimum values of each indicator in the original data matrix.

The standardized processing of positive and negative indicators are respectively as (3) and (4). Within a certain range, for positive indicators, the larger the value, the better the evaluation result, while for negative indicators, the smaller the value, the better the evaluation result.

$$y_{ij} = \frac{x_{ij} - \min_{i=1,2,\dots,m} x_{ij}}{\max_{i=1,2,\dots,m} x_{ij} - \min_{i=1,2,\dots,m} x_{ij}} \quad (3)$$

$$y_{ij} = \frac{\max_{i=1,2,\dots,m} x_{ij} - x_{ij}}{\max_{i=1,2,\dots,m} x_{ij} - \min_{i=1,2,\dots,m} x_{ij}} \quad (4)$$

$$Y = (y_{ij})_{m \times n} \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \quad (5)$$

Thus, the standardized matrix between 0 and 1 is obtained as (5), which eliminates the dimension between evaluation indicators, so that the evaluation indicators are comparable.

Step2.2: Entropy calculation

$$E_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (6)$$

$$(i = 1, 2, \dots, m; j = 1, 2, \dots, n)$$

$$k = (\ln m)^{-1}; p_{ij} = y_{ij} / \sum_{i=1}^m y_{ij}$$

Step2.3: Weight calculation on Entropy Weight Method

$$W_{2j} = (1 - E_j) / (n - \sum_{j=1}^n E_j) \quad (j = 1, 2, \dots, n) \quad (7)$$

Step3: Comprehensive weight calculation

W_{1j} and W_{2j} are calculated synthetically to obtain the comprehensive weight W_j . W_j should be as close as possible to W_{1j} and W_{2j} according to the principle of minimum relative information entropy [6] [7].

$$\begin{aligned} \min F &= \sum_{j=1}^n w_j (\ln w_j - \ln w_{1j}) \\ &+ \sum_{j=1}^n w_j (\ln w_j - \ln w_{2j}) \end{aligned} \quad (8)$$

$$\text{s.t. } \sum_{j=1}^n w_j = 1; w_j > 0, j = 1, 2, \dots, n$$

Using the Lagrange multiplier method to solve the above optimization problem, we get

$$w_j = \frac{\sqrt{w_{1j} w_{2j}}}{\sum_{j=1}^n \sqrt{w_{1j} w_{2j}}} \quad (j = 1, 2, \dots, n) \quad (9)$$

Step4: Comprehensive evaluation results

The standardized matrix and the comprehensive weight W_j are synthesized and calculated to obtain the comprehensive evaluation result.

$$z_i = \sum_{j=1}^n y_{ij} w_j \quad (i = 1, 2, \dots, m) \quad (10)$$

4. APPLICATION

4.1 Research object and data

Based on the evaluation results of prefecture-level cities in China's 2019 national new smart city evaluation, the above comprehensive evaluation method is carried out. The 2019 Evaluation Indicators for New-type Smart Cities contains 8 primary indicators, including 7 basic evaluation indicators and 1 citizen experience indicator. There are 22 secondary indicators under the 7 basic evaluation indicators. The full score is 100 points, including 60 points for the basic evaluation and 40 points for the subjective evaluation of citizen experience. The indicators are weighted according to the expert consultation method, and the weights of the primary indicators are the sum of the weights of the secondary indicators. This research is based on the basic evaluation part. 275 cities at prefecture level and above completed the evaluation in 2019, and the following research is based on 275 valid samples.

4.2 Comprehensive evaluation process

Carry out weight conversion for the basic evaluation indicators of L1-L7. L6 is a deduction item, and its expert consultation method weight is calculated based on its highest deduction score. The sum of the original weights of the six primary indicators from L1 to L5 and L7 is 60%, which corresponds to 100% to obtain the weight of the expert consultation method.

Based on the secondary index score rate (%) $\times 100$ of each city's new smart city evaluation in 2019, the original data matrix is formed. In order to carry out data analysis in a unified manner, the deduction indicators are positively processed and converted into positive score rates consistent with other indicators. Then conduct the weight calculation of entropy weight method according to (3) - (7).

Finally, the comprehensive weights are calculated according to formula (9), and the comprehensive evaluation results are calculated as formula (10).

4.3 Results and findings

4.3.1 Secondary indicators weight results and analysis

Table 1: Secondary indicators weight results.

Code	Secondary indicators	Expert consultation method		Entropy weight method		Comprehensive evaluation method			
		Weight value	Weight ranking	Weight value	Weight ranking	Weight value	Weight ranking	Weight ranking changes compared with expert consultation method	Weight ranking changes compared with entropy weight method
L1P1	Government Services	8%	1	3%	14	5%	6	-5	8
L1P2	Transportation Services	3%	13	5%	6	5%	11	2	-5
L1P3	Social Security Services	3%	14	2%	15	3%	18	-4	-3
L1P4	Medical Services	5%	7	3%	12	4%	12	-5	0
L1P5	Education Services	5%	8	2%	19	3%	17	-9	2
L1P6	Employment Services	3%	15	2%	17	3%	19	-4	-2
L1P7	Urban Services	5%	9	4%	7	5%	8	1	-1
L1P8	Assistance Services	3%	16	9%	4	6%	5	11	-1
L1P9	Smart Agriculture	3%	17	3%	13	3%	15	2	-2
L1P10	Smart Community	3%	18	16%	1	8%	2	16	-1
L2P1	Urban Management	5%	10	4%	8	5%	9	1	-1
L2P2	Public Safety	8%	2	0%	21	2%	21	-19	0
L2P3	Social Credit	5%	11	2%	18	3%	16	-5	2
L3P1	Smart Environmental Protection	6%	3	2%	16	4%	14	-11	2
L3P2	Green and Energy-Saving	3%	19	14%	2	7%	3	16	-1
L4P1	Broadband Network Facilities	3%	20	2%	20	2%	20	0	0
L4P2	Space-Time Information Platform	5%	12	4%	9	5%	10	2	-1
L5P1	Information Resources Opening and Sharing	6%	4	6%	5	7%	4	0	1
L5P2	Information Resources Development and Utilization	6%	5	11%	3	10%	1	4	2
L6P1	Confidentiality	3%	21	0%	22	1%	22	-1	0
L6P2	Password Application	3%	22	4%	11	4%	13	9	-2
L7P1	System and Mechanism	6%	6	4%	10	5%	7	-1	3

It can be seen from Table 1 that the weight of the secondary indicators of the expert consultation method is between 3% and 8%. The entropy weight method broadens the width of the overall distribution, with the small secondary indicators weight ranging close to 0 (L2P2 0.48%, L6P1 0.15%, Table 1 shows the rounded retention results), and the large one reaching 16% (L1P10). The comprehensive weight combines the results of the two, and finally forms a weight distribution of 1% to 10%.

The top-ranked indicators in the comprehensive weight method include Information Resources Development

and Utilization, Smart Community, Green and Energy-Saving, Information Resources Opening and Sharing, Assistance Services, Government Services, System and Mechanism, Urban Services, and Urban Management. Information Resources Development and Utilization ranks first. The development and utilization of information resources is the basis for cities to carry out all kinds of smart services, governance, and industrial development. It is the core ability of smart city construction and development, and plays a key role in the promotion of smart city development. Smart Community ranks second. Smart community is a micro-unit of smart city construction, and it is the concentrated embodiment of smart city

governance and service capabilities on the residents' side. In recent years, smart community construction has been in full swing, but the overall development is uneven. It will greatly help improve residents' sense of experience and gain in smart cities, and it is also the trend of further construction of smart cities. Green and Energy-Saving ranks third. Since China proposed the goal of carbon peaking and carbon neutrality in September 2020, green development has become one of the main themes of the times, and the importance of adhering to green energy conservation and low-carbon development in smart cities has become more prominent. Information Resources Opening and Sharing ranks fourth, and it belongs to the primary indicator of Information Resources along with the first-ranked indicator. The opening and sharing of information resources is the premise of development and utilization, and is the foundation of smart city connectivity and linkage. Intergovernmental data sharing facilitates the informatization of departments and provides the possibility for business linkage. The opening and sharing of public information resources will help increase the vitality of social innovation and make it possible to build more smart scenarios. The indicators of Assistance Services, Government Services, Urban Services and Urban Management emphasize the importance of inclusive barrier-free services, convenient government services, diversified urban services, and refined urban management in smart cities from the specific construction aspect. System and Mechanism emphasizes that the construction of smart cities is not only technology-driven, but also needs supporting mechanisms. Only by improving the overall planning, management and operation systems and mechanisms can intelligent construction be effective, useful and sustainable. In the process of developing smart cities, local governments should pay more attention to the indicators ahead of the examination.

4.3.2 Primary indicators weight results and analysis

The weights of the secondary indicators are summed respectively to obtain the weights of the primary indicators, as shown in Table 2. It can be seen that compared with the weight of expert consultation method, when the entropy weight method is used, the weights of the indicators of People Services, Ecological Livability, and Information Resources are increased, while the weights of Information Security and Innovation Development are decreased. The comprehensive weighting method combines the expert consultation method and the entropy weight method, and the results are between the two. Compared with the weights of the expert consultation method, in the case of using the comprehensive weight method, the weight of the indicator of People Services is increased by 4 percentage points, Ecological Livability is increased by 2 percentage points, Information Resources is increased by 3

percentage points, and Precise Governance is decreased by 7 percentage points. Intelligent Facilities, Information Security, and Innovation Development are decreased by 1 percentage point each. When the comprehensive weight method is applied, the indicators of People Services, Ecological Livability, and Information Resources become more important, which is related to the needs of China's smart city construction in the new era.

Table 2: Primary indicators weight results.

Code	Primary indicators	Comprehensive weight	Weight of expert consultation method	Weight of entropy weight method
L1	People Services	45%	41%	49%
L2	Precise Governance	10%	17%	6%
L3	Ecological Livability	11%	9%	15%
L4	Intelligent Facilities	7%	8%	5%
L5	Information Resources	16%	13%	17%
L6	Information Security	5%	6%	4%
L7	Innovation Development	5%	6%	4%

5. CONCLUSIONS

The comprehensive weight method combining the entropy weight method and the expert consultation method can make a larger and reasonable distinction among the performance of smart cities. In the longitudinal comparison of the performance evaluation of a certain indicator in various cities, the evaluation of the comprehensive weight method reduces the limitation of the original expert consultation method, which is lack of discrimination to a certain extent. In the overall city evaluation comparison, the comprehensive evaluation method gives higher evaluation results to cities with outstanding development in certain aspects and cities that perform well in relatively important aspects, and lowers evaluation results for cities that perform mediocre in all aspects and cities that underperform in relatively important aspects.

As a smart city evaluation method combining subjective and objective, this method not only combines the experts' consideration of the indicators meaning, but also takes into account the information reflected by objective data results. Additionally, it avoids the wild

swings in results that come with extreme data. The comprehensive evaluation method and evaluation results have some guiding implications for the construction and development of smart cities.

Firstly, by changing the weight of indicators, the comprehensive evaluation method can be used to guide local governments to focus on important content while coordinating the promotion of smart city construction. From the perspective of weight change, the results remind cities to pay more attention to information resources opening, sharing, development and utilization while focusing on People Services in the development, and to take into account the informatization of ecology and environmental protection. From the perspective of weights, the results give relative importance reference rankings of the indicators.

Secondly, through the application of comprehensive evaluation method, cities will be encouraged to develop their own characteristics and highlights, and reduce the situation of balanced promotion in all fields but no comparative advantage in each field, which is also in line with the requirements of the times of building distinctive smart cities.

Thirdly, this method constructs a new comprehensive evaluation system for smart cities that keeps pace with the times. The original smart city evaluation system based on the expert consultation method relies on the experts' observation and understanding of existing theories and practices. The new comprehensive evaluation method combines the inherent information of fresh and actual data, which not only reflects the current situation of urban development, but also pointed out the direction for future development.

Finally, the comprehensive evaluation method reduces the weights of indicators in areas where the development of smart cities is relatively good and balanced, and increases the weights of indicators in areas where the level of development varies greatly. The adoption of this evaluation method helps to establish the example of advanced cities in the field, discover excellent and typical cases. It helps cities to learn advanced technology and experience, and make up for shortcomings in development, thus driving smart cities to better development as a whole.

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