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Evaluation of the Development Level of Intelligent City Based on Analytic Hierarchy Process and Fuzzy Forest

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Abstract: The sustainable development of the city is based on the current development mode and rational planning. This paper studies the development of three different types of cities, first, we use a similar analytic approach to select the dynamic variables that can reflect the level of development of smart cities, there are 62 indicators, and to find 62 indicators of data from 1990 to 2016. For the large amount of data, high dimensional characteristics, we use the random forest algorithm dimensionality, and finally find the representative index 32. Then we construct the judgment matrix according to the analytic hierarchy process and calculate the weight, and obtain the fuzzy evaluation matrix according to the experience expert method. The final weight matrix and the fuzzy matrix product to get a comprehensive evaluation model. And then we do quantitative analysis, change one or several indicators 10%, verify that the model is reasonable. And finally the applicability and robustness of this evaluation model are strong.
Keywords: intelligent city, random forest, analytic hierarchy process - fuzzy algorithm, comprehensive evaluation

INTRODUCTION

With the deepening of global economic integration, the development of smart city to become an important way to achieve sustainable development of the city [1]. The development of high-tech industry and the integrated use of the status of the city's core system is more and more important, the construction of urban intelligence requires the application of modern communication technology and computer computing to improve the environment, government administration, public facilities, and residents' lives, so as to promote the government to better regulate the market, manage the society and provide public services [2]. Many cities to actively explore the wisdom of urban construction, but there is a serious one-sidedness. The fundamental reason is that there is no complete intelligent city construction evaluation index system, intelligent city construction lack of systematic guidance.

The intelligent buildings that emerged in the 1970s and 1980s were the core of the early theoretical research of intelligent cities [3]. 2010 IBM presented the wisdom of the city's six elements are group (person), business / government, transportation, communications, water and energy, these systems are systems that are not fragmented, but in a collaborative way. The 21st century, with the rapid development of Internet of things and cloud computing, smart city once again become a "tuyere". In this paper, we propose a new comprehensive evaluation system, in order to measure the city's intelligent level to provide a theoretical basis.

THEORETICAL PREPARATION

Level analysis

Analytic Hierarchy Process, referred to as AHP, is a professor of the University of Pittsburgh, a well-known operations scientist T. Respectively. Saaty made in the early 1970s [4]. The method combines the quantitative analysis and qualitative analysis method, with the system, flexible, easy to use and so on, this method can simplify the complex problem into orderly hierarchical structure, and then the subjective judgments of the program in good or bad order, it belongs to a multi-criteria, concise and effective decision-making methods, can be unified decision-making in the quantitative and qualitative factors. The structure is shown in Figure 1 below.

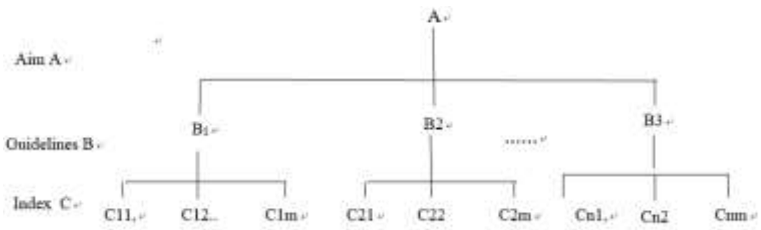

Fig-1: The structure of the analytic hierarchy process

Construct judgment matrix

Scoring experts in the importance of the two factors to be compared, according to the following quantitative scale to determine the relative importance of each indicator [5]. Indicators of the degree of importance generally used 1-9 scale table, its meaning as shown in Table 1 below:

Table1: Standard degree of 1-9 scale table

Scale a_{ij}	**meaning**
1	The factor i is just as important as the factor j
4	Factor i is slightly more important than factor j
6	Factor i is more important than factor j
8	Factor i is very more important than factor j
10	Factor i is definitely more important than factor j
2,3,5,9	Determine the value of the intermediate state between the two values
reciprocal	When the factor i is compared with the factor j , $a_{ij} = 1/a_{ji}$

The construction of the decision matrix is based on the correlation between the relevant elements, according to the scale to determine its relative importance. The result of the comparison is to construct the judgment matrix. The rule is to first determine the level of a certain element in the hierarchy [6]. For example, indexes in the i layer are $B_1, B_2 \cdots B_n$, one of the factors in the adjacent hierarchy is A_k ,compare the influence degree of each two indexes. $b_{ij} = b_i / b_j$ means the value of the relative importance of the factor b_i to A_k ,and $b_{ij} > 0$; $c_{ii} = 1; b_{ij} = b_{ji}$.

Sorting and consistency test

In the judgment matrix, there is a largest eigenvalue of a certain factor $\lambda_{\max}$ to one in the upper level [7]. The corresponding normalized feature vector of $\lambda_{\max}$ is $W = (w_1, w_2 \cdots w_n)^T$, of which the component w_j is the ranking weight value of the relative importance of the corresponding factor of the level to the factor of the upper level, that is, the single ranking weight of the corresponding indexes. In order to check the consistency of the judgment matrix, we need to calculate the consistency index CI and random consistency ratio CR :

$$CI = (\lambda \max - n) / (n-1)$$
$$CR = CI / RI \qquad (1)$$

Among them, RI is the average random consistency index. When $CR < 0.1$, the matrix is sentenced to be of satisfactory consistency, otherwise it is necessary to adjust the value of the judgment matrix [8].

Table 2: Measuring standard

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Random forest

The random forest can explain the effect of multiple arguments $X_1, X_2 \cdots X_k$ on the dependent variable Y . If the dependent variable Y has n observations, and there are k independent variables associated with it; When constructing a classification tree, the random forest randomly re-selects n observations in the original data, some of these observations are selected many times, and some are not selected [9], which is Bootstrap re-sampling method, at the same time, the random forest randomly selected the variables from the k independent variables to determine the classification of tree nodes. In this way, each time we build the classification tree may not be the same.

Fuzzy decision algorithm

According to the fuzzy decision theory [10], the comprehensive evaluation method can go through the following steps:

- the establishment of evaluation factors for the domain $U=\{u_1,u_2,\cdots,u_m\}$, The level of evaluation is $V=\{v_1,v_2,\cdots,v_m\}$, The principle is to consider a comprehensive while seizing the main contradiction. First, the single factor $u_i\,(i=1,2\cdots m)$ in the evaluation factor domain U is judged by the single factor,
  From the factor u_i to determine the factors for the hierarchical degree of $v_j\,(j=1,2\cdots n)$ membership degree r_{ij} ,In this way, we can get the single factor evaluation set $r_i(r_{i1},r_{i2},\cdots r_{im})$ of the i-first factor u_i , which is the fuzzy subset on the commentary domain V .
- Determine the weight vector of the influencing factors A . According to the relative importance of the influencing factors, the weight of each influencing factor is determined in turn. According to the authority of n expert according to the importance of the factors agreed to score derived structural membership function.
- Constructing membership functions. According to the actual situation, to determine the corresponding membership formula.
- The original data is processed according to the rules of the membership function, and the target influencing factors of each scheme are obtained and the fuzzy evaluation matrix R .

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{31,1} & r_{31,2} & \cdots & r_{31,n} \end{bmatrix}$$

R is the fuzzy factor of the evaluation factor domain U to the evaluation level domain V , and r_{ij} is the membership degree of the evaluation commentary domain r_{ij} .

- The appropriate algorithm is used to evaluate the evaluation factors fuzzyly. Considering the multi-level and multi-factor assignment, the fuzzy comprehensive evaluation model is obtained as follows:

$$B=A\cdot R=\{b_1,b_2,\ \cdots\ ,b_n\} \qquad (2)$$

in which

$$b_j=\left(a_1\overset{\cdot}{*}r_{1j}\right)\overset{+}{*}\left(a_2\overset{\cdot}{*}r_{2j}\right)\overset{+}{*}\cdots\overset{+}{*}\left(a_m\overset{\cdot}{*}r_{mj}\right),(j=1,2,\ \cdots\ ,n) \qquad (3)$$

as a model $M(\overset{\cdot}{*}\overset{+}{*})$, in which $\overset{\cdot}{*}$ is generalized fuzzy, represents "and" operation; $\overset{+}{*}$ is generalized fuzzy, represents "or" operation.

Established The AHP-Fuzzy Algorithm Summary

In order to enhance the applicability of the model, we choose respectively three cities in different continents, namely, Qingdao, San Francisco and Birmingham [11].

Index selection

According to the principle of stratification, we choose target layer A; the target layer refinement is divided into 10 criteria layer B; The criterion layer is further refined to index layer C with 62 indicators. By analyzing the relationship between the various indicators we can find some indicators between the links, such as per capita GDP and mobile communication coverage.

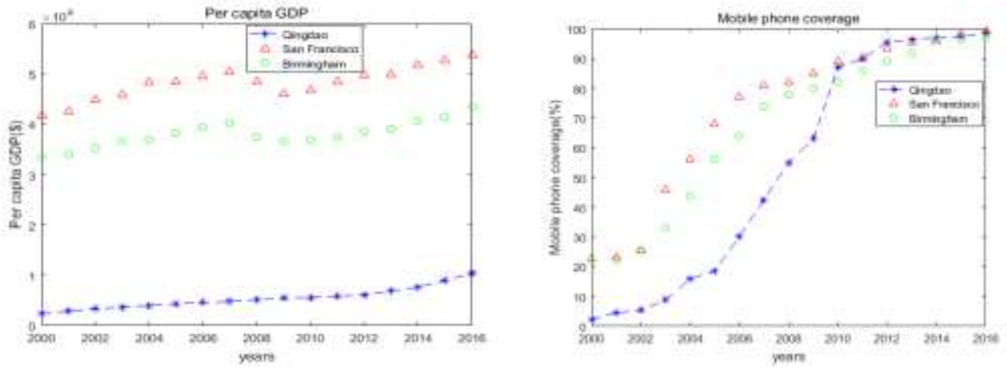

Fig-2: The trend of per capita GDP in three cities

Data processing

For data missing, we use the interpolation method to complete [12]. For the high dimensionality of data, we use the random forest algorithm to reduce the dimension of the data, and to rank the importance of the variables. Finally, we select 32 indicators as variables to further establish the model. 32 variables are shown in Table 3 below:

Table 3: Screening of 32 indicators

Criteria layer (B)	Index layer (C)		
Broadband network coverage	Fiber access rate	Line network coverage	Public places WLAN coverage
Infrastructure level	Basic network facilities investment accounted for	Sense of network construction level	
Intelligent government	Government approval project online for the proportion	Government behavior of the electronic monitoring rate	
	Government non - secret documents online rate	Residents and government network interaction rate	
Smart transportation	Information coverage of road	Bus station electronic rate	
	Parking guidance system coverage	Road sensor terminal installation rate	
Intelligent medication	Electronic medical record use rate	Inter - hospital resource sharing rate	
Intelligent education	Per capita education expenditure water	The proportion of network teaching	
Intelligent community	Community information system coverage	Community service information push rate	
	Elderly Information Guardianship Service Coverage	Safety monitoring sensor installation rate	
Intelligent environment	Environmental quality monitoring ratio	Focus on the proportion of pollution monitoring	Carbon emission targets
Intelligent Energy Management	Family smart table with mounting rate	The proportion of new energy vehicles	
	Residents consume percentage of renewable resources	Enterprise consume percentage of renewable resources	
Intelligent city security	Food and Drug Traceability System Coverage	Natural disaster warning release rate	
	The coverage of urban grid management	Dangerous chemicals transport monitoring level	

Determine the weight of the indicator

First, we use the invitation expert method to compare the importance of each factor in the evaluation at all levels, and compare the results used to establish the AHP judgment matrix distribution weight [13]. We get the quantitative judgment matrix, we use 1-9 scale method to Qingdao city data as an example (part of the judgment matrix as follows).

Table 4: A-B layer judgment matrix

A	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	1	2	3	5	1/4	6	3	1/2	5	3
B2	1/2	1	3	5	6	2	5	8	2	4
B3	1/3	1/3	1	3	3	1/5	1/2	1/6	4	5
B4	1/5	1/5	1/3	1	4	2	5	3	5	1/2
B5	4	1/6	1/3	1/4	1	1/4	2	5	1/3	5
B6	1/6	1/2	5	1/2	4	1	3	1/4	5	2
B7	1/3	1/5	2	1/5	1/2	1/3	1	5	2	2
B8	2	1/8	6	1/3	1/5	4	1/5	1	4	6
B9	1/5	1/2	1/4	1/5	3	1/5	1/2	1/4	1	1/3
B10	1/3	1/4	1/5	2	1/5	1/2	1/2	1/6	3	1

We take the B layer criterion layer relative to the A layer of the weight of the calculation process as an example, detailing the weight of the determination process, including the following three steps:

- Calculate the arithmetic mean of all the elements of each row of the judgment matrix.
- Run the Matlab program and calculate the A-B judgment matrix is set to A, the running result A is the eigenvector, never got the largest feature $\lambda = 13.23$.
- We test A-B, B-C layer consistency, and compare with the Measuring standard, the results show that through the consistency test.

Calculate the weight. (Table 5 below is the result of Qingdao).

Table 5: Weight of the indexes in each level

Index	C-B	C-A	Index	C-B	C-A	Index	C-B	C-A
C_1	0.324	0.012	C_2	0.327	0.0521	C_3	0.349	0.023
C_4	0.435	0.042	C_5	0.565	0.0137	C_6	0.235	0.0724
C_7	0.213	0.021	C_8	0.329	0.0103	C_9	0.223	0.0193
C_{10}	0.183	0.019	C_{11}	0.234	0.0421	C_{12}	0.401	0.032
C_{13}	0.182	0.0209	C_{14}	0.631	0.0241	C_{15}	0.369	0.062
C_{16}	0.523	0.0133	C_{17}	0.477	0.0524	C_{18}	0.132	0.015
C_{19}	0.321	0.0308	C_{20}	0.321	0.0213	C_{21}	0.226	0.057
C_{22}	0.452	0.0421	C_{23}	0.448	0.0512	C_{24}	0.100	0.041
C_{25}	0.361	0.0125	C_{26}	0.129	0.0201	C_{27}	0.314	0.023
C_{28}	0.196	0.0162	C_{29}	0.412	0.0231	C_{30}	0.109	0.042
C_{31}	0.112	0.0305	C_{32}	0.367	0.0426			

Comprehensive evaluation using fuzzy comprehensive evaluation method

(1) membership function calculation of quantitative indicators comment set.

The following is the "Basic network operation led for (C1)" comment set to determine the quantitative indicators of the degree of membership determination process.

Table 6: Evaluation standard

Evaluation index	Fuzzy comprehensive evaluation system		
City	Weak	Average	Good
Basic network facilities investment	80%	90%	100%
Example	Qing	San Francisco	Birmingh
Rate	93%	97%	95%

We can get $x_1 = 0.92, v_1 = 0.8, v_2 = 0.9, v_3 = 1$, So we have the following calculations:

$r_1 = 0 \quad x_1 > v_2$

$$r_2 = \frac{v_3 - x_1}{v_3 - v_2} = \frac{1 - 0.92}{1.0 - 0.9} = 0.7 \quad v_2 < x_1 < v_3$$

$r_3 = 1 - r_2 = 0.3 \qquad v_2 < x_1 < v_3$

To get Qingdao on the evaluation of C1 is [0 0.7 0.3], indicating that the city's "family light access rate" of 70% may belong to the "average" level, 30% may belong to "good level". According to the above steps to calculate the membership of other indicators, the final membership will be aggregated fuzzy comprehensive evaluation matrix.

Comprehensive evaluation

According to the formula $B_i = W_i \times R_i$ (B is the result of the comprehensive fuzzy operation of each subordinate factor included in the i-th index of B layer; W_i is the weight of the subordinate level of the B layer. R_i is a fuzzy evaluation matrix which indicates that the B layer is the relationship between the factors of the i-th index relative to the comment set). We get the fuzzy comprehensive evaluation matrix (Qingdao City as an example).

Table 7: Evaluation standard

Criteria layer (B)	Index layer (C)	Fuzzy comprehensive evaluation system		
		Weak	Average	Good
B_1	C_1	0.01	0.32	0.67
	C_2	0	0.32	0.68
	C_3	0.012	0.42	0.568
B_2	C_4	0.023	0.13	0.847
	C_5	0.02	0.42	0.56
B_3	C_6	0.421	0.412	0.167
	C_7	0.321	0.223	0.456
	C_8	0.423	0.451	0.126
	C_9	0.09	0.283	0.627
B_4	C_{10}	0.082	0.42	0.498
	C_{11}	0.103	0.623	0.274
	C_{12}	0	0.672	0.328
	C_{13}	0.023	0.521	0.456
B_5	C_{14}	0.032	0.321	0.647
	C_{15}	0.05	0.124	0.826
B_6	C_{16}	0.128	0.232	0.64
	C_{17}	0.089	0.251	0.66
B_7	C_{18}	0.036	0.321	0.643
	C_{19}	0.053	0.1243	0.8227
	C_{20}	0.358	0.421	0.221
	C_{21}	0.0954	0.153	0.7516
B_8	C_{22}	0.032	0.235	0.733
	C_{23}	0.1987	0.241	0.5603
	C_{24}	0.093	0.284	0.623
B_9	C_{25}	0.426	0.236	0.338
	C_{26}	0.0342	0.264	0.7018
	C_{27}	0.158	0.342	0.5
	C_{28}	0.0352	0.474	0.4908
B_{10}	C_{29}	0.524	0.332	0.144
	C_{30}	0.551	0.201	0.248
	C_{31}	0.038	0.422	0.54
	C_{32}	0.072	0.423	0.505

Similarly, we can get a comprehensive rating of the target layer A, the comprehensive rating of the three cities.

Table 8: Grade 1 evaluation results

	City	Evaluation results		
		Weak	Average	Good
Intelligent city construction level	Qingdao	0.184	0.631	0.185
	San Francisco	0.082	0.369	0.549
	Birmingham	0.092	0.462	0.446

Evaluation conclusion

Through the comprehensive evaluation of the AHP and fuzzy comprehensive evaluation methods, it can be seen that 18.4% of the intelligent urban construction level in Qingdao may be " Weak "; 63.1% may belong to " Average "; 18.5% may belong to " Good". According to the principle of maximum membership degree, 63.1% of the membership of the three grades are the largest, so it can be considered that the level of intelligent city construction in Qingdao is " Average ". Similarly, San Francisco smart city construction level is "Good", Birmingham intelligent city construction level is "Average".

Sensitivity verification

In order to verify the validity and sensitivity of the model, we do quantitative analysis, when the index C2 decreased by 15% and 15%, the comprehensive evaluation of the changes as shown below (Qingdao, San Francisco).

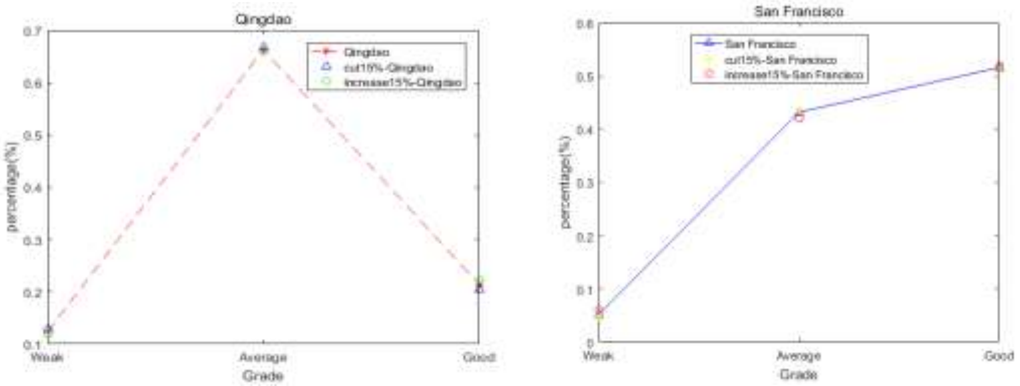

Fig-3: Sensitivity analysis trends

There is a trend of change we can get, comprehensive evaluation model of low sensitivity, robustness, which has a certain general applicability.

CONCLUSIONS

Based on the previous research on fuzzy AHP method, after clarifying the connotation of the basic theory and concept, we put forward a more comprehensive evaluation system of intelligent city construction level, And through case analysis to verify the effectiveness and reliability of the system. This paper chooses the fuzzy comprehensive evaluation method to evaluate the level of intelligent city construction.

On the one hand, the fuzzy comprehensive evaluation method can filter the influence of the subjective factors on the evaluation results to a certain extent, so that the evaluation results are more objective and comprehensive. The fuzzy comprehensive evaluation method is applicable to the complex evaluation index system of multiple evaluation subjects, multiple index levels and multiple types of indicators. On the other hand, the use of data processing methods, so that the intelligent city construction level comprehensive evaluation system design is not too subjective, which for the intelligent city construction level evaluation results objectivity and effectiveness provided a guarantee.

The research results of this paper have improved the evaluation method and content of the urban intelligent construction level to a certain extent, which is of great practical significance to guide the future urban intelligent construction. The research work can provide the theoretical basis for the intelligent city research, and provide the feasible technical method for the evaluation of the intelligent city construction level.

REFERENCES

1. Lingjiao Y. Comprehensive evaluation of the level of intelligent city construction. North China Electric Power University (Beijing) North China Electric Power University, 2012.

2. Hai Y. China's wisdom city construction level evaluation research. Taiyuan: Taiyuan University of Science and Technology, management science and engineering, 2013.
3. Xianyi L, Xiaoyu D. Intelligent city evaluation index system research. Telecom network technology. 2011;10: 43-47.
4. Linghui L, Yinrong C, Weiwei S. Evaluation of Land Intensive Use in Liuzhou City Based on Fuzzy Comprehensive Evaluation Method. Land and Resources Science and Technology Management. 2007;24(6):1-6.
5. Bunn F, Adair R. Video surveillance data analysis algorithms, with local and network-shared communications for facial, physical condition, and intoxication recognition, fuzzy logic intelligent camera system: U.S. Patent Application 11/062,601. 2005-2-22.
6. Harris CJ, Moore CG, Brown M. Intelligent control: aspects of fuzzy logic and neural nets. World scientific, 1993.
7. Hollands R G. Will the real smart city please stand up? Intelligent, progressive or entrepreneurial?. City. 2008;12(3):303-320.
8. Cocchia A. Smart and digital city: A systematic literature review. Smart city. Springer International Publishing. 2014;13-43.
9. Bowerman B, Braverman J, Taylor J. The vision of a smart city. 2nd International Life Extension Technology Workshop, Paris. 2000;28.
10. Neirotti P, De Marco A, Cagliano A C. Current trends in Smart City initiatives: Some stylised facts. Cities. 2014;38:25-36.
11. Su K, Li J, Fu H. Smart city and the applications. Electronics, Communications and Control (ICECC), 2011 International Conference on. IEEE. 2011;1028-1031.
12. Lombardi P, Giordano S, Farouh H. Modelling the smart city performance. Innovation: The European Journal of Social Science Research. 2012;25(2):137-149.
13. Liang Z, Yang K, Sun Y. Decision support for choice optimal power generation projects: Fuzzy comprehensive evaluation model based on the electricity market. Energy Policy. 2006;34(17):3359-3364.