Fuzzy Comprehensive Evaluation of Accessibility to Primary Care in Chengdu

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Abstract. Accessibility to primary care is an important factor in evaluating a community, however, the methods for evaluating access to medical care are imperfect. In order to solve this problem, this paper comprehensively considers the impact of real-time road conditions on traffic, divide the day into six time periods, According to the characteristics of this scheme, the membership decreases with the increase of the minimum medical treatment time, obtain the membership function of evaluation factors, further standardization and rationalization of evaluation matrix, and according to Amap API obtain the time that 704 communities reach the nearest hospital, then get all community membership degree matrix evaluation. Using a scale of 1-9 scale to construct the matrix of the time, according to the hierarchy process the weights of the various times that are scientifically reasonable and pass the consistency test. Finally, an objective and reasonable quantitative evaluation result is made by fuzzy transformation to community primary care accessibility.

1. Introduction
In October 2017, the National Health and Family Planning Commission (NHFPC) announced that the task of establishing the basic medical and health system with Chinese characteristics has been basically completed; more than 80% of residents can reach nearby hospitals within 15 minutes [1]. At present, many scholars make the correlative study of residents' accessibility to primary care, but a complete system of evaluation methods for accessibility to primary care is still missing. Also, there is no clear standard for the accessibility of primary care between communities.

Fuzzy comprehensive evaluation has been very mature and applied in many aspects. For example, Xinguang Duan evaluated the carrying capacity of water resources in Xinjiang by using fuzzy comprehensive evaluation [2]; Xiaoyan Yang evaluated the environmental air quality in five districts of Beijing by using the method of fuzzy comprehensive evaluation [3]; Li Yang evaluated the coal mine emergency rescue capability [4] and so on, all confirmed the scientific nature of this method in evaluating fuzzy things.

Considering the impact of real-time traffic conditions, the time of each community to the nearest hospital fluctuates with the road condition, while the road condition changes periodically with time. Therefore, it is particularly important to take into account the evaluation factors in the demand time of each community at all times of the day. Taking the five urban districts of Chengdu as an example, this paper proposes a set of fuzzy comprehensive evaluation methods for primary care accessibility under the influence of real-time road conditions, which provides a scientific and reasonable basis for hospital accessibility evaluation.
2. Establishment of membership function
In 1965, professor L.A. Zadeh published a paper named Fuzzy Sets in Information and Control [5]. This paper first proposed the concept of Fuzzy mathematics, and used "subordinate function" to describe the intermediate (Fuzzy) nature of things, making the description closer to reality. When judging and judging a "fuzzy" thing, it is often impossible to describe it quantitatively. Therefore, it is necessary to use the "membership function" to describe the transition of the thing. In this function fuzzy theory, if A is a fuzzy subset on the theoretic domain U, then for any \( x \in U \), specify that there is \( \mu_A(x) \in A \) and \( \mu_A(x) \in [0,1] \), the value \( \mu_A(x) \) is called \( x \) for A's membership, mapping \( \mu_A: U \to [0,1] \) makes \( \mu_A: x \to \mu_A(x) \), which is called the membership function of \( x \).

2.1. Establishment of optional set
Membership function is usually obtained through comparative test and some additional constraints, so it has some subjective experience [6]. Before establishing membership function, we need to establish the optional set \( V \), \( V = \{v_1, v_2, v_3, ..., v_n\} \), which contains all the evaluation results. The concentrated elements \( v_j \in U \) and \( v_j \notin U \) must satisfy one of them. The optional set in this evaluation is \( V = [v_1, v_2, v_3, v_4, v_5] = [\text{Perfect community, Best community, Suitable community, usual community, worst community}] \).

According to the national "15-minute medical and health service circle", the corresponding relation between the optional set summarized comprehensively and the corresponding time threshold is shown in table 1:

| Factors index | Suitability level | Perfect community | Best community | Suitable community | usual community | worst community |
|---------------|-------------------|-------------------|----------------|-------------------|----------------|----------------|
| Time required to arrive at the nearest hospital (min) | \( \leq 15 \) | 15–25 | 25–35 | 35–45 | \( \geq 45 \) |

2.2. Time division
The research area of this paper is the five urban districts of Jinjiang District, Jinniu District, Chenghua District, Wuhou District and Qingyang District of Chengdu City, Sichuan Province. In this study area, there are 99 secondary and above general hospitals, 704 residential communities, and the distribution of residential areas and hospitals is shown in figure 1 and figure 2. Community and hospital coordinates are obtained by calling the address matching function of the Amap API [7]. Hospital related information comes from 99 Health Network [8]. Considering the impact of real-time road conditions, this paper divides the day into six periods, and the corresponding intervals and sections are shown in table 2. The access time of each period can be obtained in real time through the call of Amap API, and the change law of the access time of some communities with the time period is shown in figure 3. The six abscissa time periods in figure 3 correspond to the time division in table 2 respectively. The selected community locations are shown in red dots in figure 1. Two communities are selected in each district and these ten communities are uniformly distributed, so the change law obtained is more representative.

| Time division | morning peak | Forenoon | noon | afternoon | evening peak | night |
|---------------|--------------|----------|------|-----------|-------------|-------|
| time span     | 7: 00-       | 9: 30-   | 11: 30- | 14: 00-   | 17: 00-     | 19: 30- |
|               | 9: 30-       | 11: 30-  | 14: 00- | 17: 00-   | 19: 30-     | 7: 00-  |
2.3. Establish membership function

The process of establishing membership function is a process of seeking the most close to the function of essence, due to people's subjective consciousness, the fuzzy understanding of things is not exactly the same, therefore, to determine the membership degree of size will vary [9], in order to reduce the effect of the objective differences, which takes the form of construct membership functions, factors make an objective evaluation and measure standards. Since the magnitude of the subordinate level varies linearly with the linear variation of the characteristic value, the higher the value, the higher the level of subordination, or the lower the level of subordination of the value. In this evaluation, it belongs to the second one, its membership function can be defined as:

\[
R_1 = \begin{cases} 
0, & x \leq S_2 \\
\frac{x - S_2}{S_1 - S_2}, & S_2 < x < S_1 \\
1, & x \geq S_1 
\end{cases}
\]

\[
R_j = \begin{cases} 
\frac{x - S_{(j+1)}}{S_j - S_{(j+1)}}, & S_{(j+1)} < x < S_j \\
\frac{(S_{(j-1)} - x)}{(S_j - S_{(j-1)})}, & S_j < x < S_{(j-1)} \\
0, & x \leq S_{(j+1)} \text{ or } x \geq S_{(j-1)} 
\end{cases}
\]

Where \( j = 2, 3, 4 \)

\[
R_5 = \begin{cases} 
1, & x \leq S_5 \\
\frac{S_4 - x}{S_4 - S_5}, & S_5 < x < S_4 \\
0, & x \geq S_4 
\end{cases}
\]

In the above function, \( x \) is the characteristic value of evaluation factors, and \( S_j \) is the standard value of the shortest time to the \( j \)-th community suitability.

\[\text{Figure 1. Distribution of residential areas.} \]
\[\text{Figure 2. Distribution of secondary and above general hospitals.} \]
\[\text{Figure 3. The variation of access time of some communities with time period.} \]
From the shortest possible time and suitability in table 1 for each rank as you can see, appropriate grade standard generally in a range, not explicitly given numerical value, so this article proposed the appropriateness of each interval in the middle of the value corresponding to levels of maximum membership value, the value is 1, and the greater the difference between numerical corresponding membership degree is lower. In this paper, the minimum primary care time reduces the degree of membership as its value increases. The membership function of this scheme can be obtained by substituting each interval value in table 1 into the formula, as shown below:

\[ R_1 = \begin{cases} 1, & x \leq 10 \\ \frac{(20 - x)}{10}, & 10 < x \leq 20 \\ 0, & x \geq 20 \end{cases} \]

\[ R_2 = \begin{cases} \frac{(x - 10)}{10}, & 10 < x \leq 20 \\ \frac{(30 - x)}{10}, & 20 < x \leq 30 \\ 0, & x \leq 10 \text{ or } x \geq 30 \end{cases} \]

\[ R_3 = \begin{cases} \frac{(40 - x)}{10}, & 10 < x \leq 20 \\ \frac{(x - 30)}{10}, & 20 < x \leq 30 \\ \frac{(50 - x)}{10}, & 30 < x \leq 40 \\ 0, & x \leq 20 \text{ or } x \geq 40 \end{cases} \]

\[ R_4 = \begin{cases} \frac{(x - 30)}{10}, & 30 < x \leq 40 \\ \frac{(50 - x)}{10}, & 40 < x \leq 50 \\ 0, & x \leq 30 \text{ or } x \geq 50 \end{cases} \]

\[ R_5 = \begin{cases} \frac{(x - 40)}{10}, & 40 < x \leq 50 \\ 0, & x \leq 40 \end{cases} \]

3. Analytic hierarchy process

It can be seen from that time variation of the time of arrival at the hospital in part of the community point of figure 3 that most of the community seek hospital time at the peak hour of the hospital higher than the other time period. The overall time of some communities does not change much, while some communities need more time in the forenoon and afternoon. Therefore, the weight coefficient can be introduced to consider the influence of all time periods comprehensively, so that the final evaluation result is more comprehensive and reasonable. The analytic hierarchy process is a mature and scientific method to determine the right. Specific calculation steps are shown in follows.

3.1. Construct judgment matrix

Judgment matrix \( R \) is a matrix of relative importance formed by pairwise comparison of factors of the same level, and all values in the matrix are determined according to scale method 1-9 [10]. Usually, 1-9 scale method is used to measure the significance of one factor to another factor. Its value and meaning are shown in table 3:

| Scale Value | Meaning                                      |
|-------------|----------------------------------------------|
| 1           | One element is as important as another       |
| 3           | One element is slightly more important than the other |
| 5           | One element is important than another        |
| 7           | One element is more important than another   |
| 9           | One element is exceedingly important than another |
| 2,4,6,8     | The intermediate value of an adjacent element |
| Reciprocal  | On the contrary relationship                 |

According to the objective reality, expert opinions and 1-9 scale method, the weight judgment matrix can be obtained as shown in table 4:

| Time division | morning peak | Forenoon | noon | afternoon | evening peak | night |
|---------------|--------------|----------|------|-----------|-------------|-------|
| morning peak  | 1            | 2        | 3    | 2         | 1/2         | 6     |
| forenoon      | 1/2          | 1        | 2    | 1         | 1/3         | 5     |
| noon          | 1/3          | 1/2      | 1    | 1/2       | 1/4         | 4     |
| afternoon     | 1/2          | 1        | 2    | 1         | 1/3         | 5     |
| evening peak  | 2            | 3        | 4    | 3         | 1           | 7     |
| night         | 1/6          | 1/5      | 1/4  | 1/5       | 1/7         | 1     |
3.2. Calculating weight
After the judgment matrix, calculate the multiple of a single factor to each factor’s weight ratio, and calculate the root of factors’ dimensional.

\[
\omega_i = \left( \prod_{j=1}^{n} R_{ij} \right)^{1/n}, \text{Where } i = 1, 2, \ldots, n \tag{4}
\]

The weight vector \(\omega_i\) is normalized, get weight \(\omega_i^*\):

\[
\omega_i^* = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \tag{5}
\]

Therefore, the weight of each factor can be obtained in the evaluation criterion, and the weight of each factor is

\[
\omega_1 = 0.235, \omega_2 = 0.141, \omega_3 = 0.086, \omega_4 = 0.141, \omega_5 = 0.365, \omega_6 = 0.032.
\]

3.3. Consistency check
In the process of constructing judgment matrix, the ratio between the two factors will have certain error due to human subjectivity. At this point, the weight vector obtained by this judgment matrix must also have errors. If this judgment matrix with errors is called \(A'\), then \(A'\) is the incompatible judgment matrix.

\[
A'W' = \lambda_{\text{max}} W'
\]

\[
\lambda_{\text{max}} = \sum_{i=1}^{n} (A'W')_i \frac{nW_i}{n} \tag{7}
\]

The consistency index (CI) can be obtained:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} \tag{8}
\]

In the construction of judgment matrix, the more factors, the more times of inter-factor comparison required, the larger the error, and the less the ability of the matrix to pass the test. Therefore, in all the analytic hierarchy process, with the increase of dimension, the modified RI is introduced, and its ratio CI/RI is taken as the standard of whether it passes the test and denoted as CR. The modified RI is shown in Table 5:

| Dimensional | RI |
|-------------|----|
| 1           | 0  |
| 2           | 0.58 |
| 3           | 0.90 |
| 4           | 1.12 |
| 5           | 1.24 |
| 6           | 1.32 |
| 7           | 1.41 |
| 8           | 1.45 |
| 9           | 1.49 |
| 10          | 1.51 |

By substituting the weight vector into the above formula, \(\lambda_{\text{max}} = 6.124\), \(CI = 0.025\), and \(CR = 0.020 < 0.1\). Therefore, the above six-dimensional judgment matrix (Tab.4) can be proved to be acceptable, so the weight vector obtained by calculation is reasonable.

4. Fuzzy comprehensive evaluation
When making certain decisions by the subjective mind of a person, the influencing factors of the various aspects of the subject are usually taken into account [11]. But not all factors are evaluated intuitively, i.e. factors have certain ambiguity, which is called fuzzy comprehensive judgment [12].

The evaluation result of a single factor on all alternative set factors is \(R_i = [r_{i1} \ r_{i2} \ldots \ r_{im}]\), \(m\) is the number of alternative set factors (\(m = 5\) in this paper), then the evaluation matrix containing \(n\) factors is (\(n = 6\) in this paper, 6 time periods):

\[
R = \begin{bmatrix}
R_1 \\
R_2 \\
\vdots \\
R_n
\end{bmatrix} = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1m} \\
r_{21} & r_{22} & \cdots & r_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
r_{n1} & r_{n2} & \cdots & r_{nm}
\end{bmatrix} \tag{9}
\]

After the weight matrix and evaluation matrix are obtained, the fuzzy comprehensive transformation can be conducted:
By calling the Amap API, the minimum time of arrival for each community is available. For example, the time required by Xinyuan community is (23,19,13,16,25,12). After substituting the required time for each time period into the membership degree formula, the Xinyuan community evaluation matrix \( R_1 \) can be obtained as follows:

\[
R_1 = \begin{bmatrix}
0.5 & 0.5 & 0 & 0 & 0 \\
0.3 & 0.7 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0.7 & 0.3 & 0 & 0 & 0 \\
0.4 & 0.6 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 
\end{bmatrix}
\]

To make fuzzy comprehensive transformation as follows:

\[
B = A \circ R = [0.235 \ 0.141 \ 0.086 \ 0.141 \ 0.365 \ 0.032] \times \begin{bmatrix}
0.5 & 0.5 & 0 & 0 & 0 \\
0.3 & 0.7 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0.7 & 0.3 & 0 & 0 & 0 \\
0.4 & 0.6 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 
\end{bmatrix}
= [0.1563 \ 0.5907 \ 0.253 \ 0 \ 0]
\]

In the final evaluation result vector \( B \) of Xinyuan community, its value in the corresponding grade, appropriateness, largest logic according to the actual objective membership degree, the second index is 0.5907, corresponding to the level of "suitable community", which can be evaluated as a community with "appropriate" medical treatment level, thus making a comprehensive evaluation of the community with the shortest medical treatment time. In addition, to make the final judgment a little more intuitive, the evaluation result can be added to the evaluation score vector \( C = [100 \ 90 \ 80 \ 70 \ 60] \), the last of the garden community of evaluation results for \( P = B \ast C^T = 89.033 \).

Similarly, the evaluation matrix and the final evaluation vector of each community in the research area can be obtained, and the final evaluation results of each community can be obtained. The results after adding the evaluation score vector are shown in figure 4. Statistics show that there are 607 communities with a score above 95, 52 communities with a score of 90-95, 34 communities with a score of 85-90, 9 communities with a score of 80-85, and only 2 communities with a score below 80.

**Figure 4.** Final evaluation results of each community.

5. Conclusion

It can be seen from that result graph of the last evaluation that the medical accessibility level of Chengdu city is overall high, but the trend of suitability grade is not totally increase or decreasing with the cent. This also confirms the rationality of this paper to take into account the real-time road
condition and time period division for comprehensive evaluation. Aiming at the fuzzy problem of constructing evaluation matrix for quantitative factors, the method of establishing membership function is adopted to make the evaluation of factors' membership degree of each element in alternative concentration more normative and rationalized, which provides an objective basis for the comparison of medical accessibility between communities.

In this paper, the membership function and analytic hierarchy process are used to make a quantitative fuzzy comprehensive evaluation of the community's medical accessibility, and the fuzzy evaluation of medical accessibility is described objectively. This set of accessibility evaluation scheme for medical treatment under the influence of traffic conditions is operable in practical application, providing a basis for other accessibility evaluation.

Acknowledgments
This work was financially supported by the National Natural Science Foundation of China (41771444).

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