Research on Service Quality Evaluation Model of Medical Institutions Based on Dempster-Shafer Evidence Theory—Taking Jiangsu Province, China as an Example

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Abstract: From the perspective of patients and medical insurance agencies, the paper used the fuzzy rough set method to select the indexes and established the service quality evaluation index system of medical institutions. Using Dempster-Shafer evidence theory to synthesize the subjective weights and the objective weights, the combined weights of the evaluation indexes were obtained. Combining grey relational analysis and Dempster-Shafer evidence theory to establish a regional medical service level evaluation model in an asymmetric environment. The model can accurately identify the quality of medical service in various regions. We can compare and analyze the service quality of medical institutions in various regions from different dimensions, and provide a theoretical basis for each region to formulate policies related to the rational allocation of medical resources.

1. Introduction
In recent years, China’s health service system has continued to develop. From 2009 to 2019, the total national health expenditure jumped from 1.8 trillion yuan to 6.5 trillion yuan, and the percentage of health investment in GDP increased from 5.2% to 6.6%. However, there are still problems such as waste of medical resources, unreasonable allocation of medical resources, uneven supply of medical services, and low quality of medical services. At the same time, due to the introduction of medical activities by the market mechanism, the doctor-patient relationship is distorted into an economic relationship. The information asymmetry between the government, patients, and medical institutions leads to frequent occurrences of malignant medical incidents and affects the harmonious and stable development of the society. “The Difficulty and High Cost of Getting Medical Service ” is still one of the urgent problems in China’s medical and health service system. Therefore, in an environment of information asymmetry, from the perspective of the government and patients, comprehensively consider the internal process of medical services, patient perception, social benefits and other factors, construct a scientific and reasonable method for measuring the service quality of medical institution, and optimize the allocation of medical and health resources for the government. It is of great significance to improve the level of medical and health services and provide a basis for decision-making.

2. The evaluation index system of service quality of medical institutions
The service quality evaluation index system reflects the specific contents of service quality evaluation of medical institutions, which affects the accuracy and reliability of the evaluation results. According to the theory of quality evaluation level proposed by Avedis Donabedian, from the perspective of patients
and medical insurance agencies, the service quality evaluation index system is divided into three dimensions: basic service quality, medical service process quality and medical terminal quality [1-7].

Table 1. Evaluation indexes of service quality of medical institutions

| Dimension                  | Rule Layer | Indexes                                      | Dimension                  | Rule Layer | Indexes                                      |
|----------------------------|------------|----------------------------------------------|----------------------------|------------|----------------------------------------------|
| Basic Service Quality      | Layer      | Number of medical institutions (c1)          | Basic Service Quality      | Layer      | Growth rate of Annual medical expense (c17)  |
|                            | Layer      | Proportion of doctors and nurses (c2)        |                            | Layer      | The average number of residents going to the hospital (c18) |
|                            | Layer      | Proportion of doctors and beds (c3)          |                            | Layer      | Average visits of residents (c19)            |
|                            | Layer      | Average number of beds per thousand population (c4) |                            | Layer      | Number of bed turnover (c20)                |
|                            | Layer      | Fixed assets of medical institutions (c5)    |                            | Layer      | Proportion of drug and examination expenses in hospitalization expenses (c21) |
| Medical Service Process Quality | Layer | The average number of doctors per 1,000 people (c6) | Medical Service Process Quality | Layer | Proportion of medical expenses and examination fees to outpatient expenses (c22) |
|                            | Layer      | Average bed utilization rate (c7)            |                            | Layer      | Proportion of medical income (c23)          |
|                            | Layer      | Average outpatient cost (c8)                |                            | Layer      | Doctors are responsible for the number of hospital bed everyday (c25) |
|                            | Layer      | Hospitalization expenses per capita (c9)    |                            | Layer      | Average bed working day (c24)              |
|                            | Layer      | Average number of patients of per doctor per day (c10) |                            | Layer      |                            |
|                            | Layer      | Average duration hospitalization (c11)       |                            | Layer      |                            |
|                            | Layer      | Proportion of appointment of patients (c12)  |                            | Layer      |                            |
| Medical Terminal Quality   | Layer      | Mortality of emergency Department (c13)      | Medical Terminal Quality   | Layer      | Proportion of emergency treatment (c26)     |
|                            | Layer      | Mortality of observation room (c14)          |                            | Layer      | Hospitalization rate (c27)                 |
|                            | Layer      | Mortality of inpatient department (c15)      |                            | Layer      | Proportion of patients undergoing surgery (c28) |
|                            | Layer      | Proportion of treatment improvement (c16)    |                            | Layer      | Proportion of patient transferred from other hospital (c29) |
|                            | Layer      |                                         |                            | Layer      | Proportion of patient transferred to other hospital (c30) |

3. Service quality evaluation model of medical institutions

3.1. Index selection based on fuzzy rough sets

The algorithm of using Fuzzy Rough Sets (called FRS for short) to select the evaluation index is as follows:

Step1: The indexes were dimensionless. In order to convert each index value into dimensionless fuzzy value, the following processing is carried out: there is an information system

\[ s = (U, C, V, f) \]

where \( U = \{x_1, x_2, \ldots, x_n\} \) is the object set; \( C = \{c_1, c_2, \ldots, c_m\} \) is the index set; \( V_c \) is the range of the index \( c \), \( V_i (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \) is the value of the \( i \) object under the \( j \) index; \( f: U \times C \rightarrow V \) is the information function, where \( x \in U \), \( c \in C \), \( f(x, c) \in V_c \). The result of dimensionless treatment of any index is \( v_{ij} \) [8, 9].

Step2: Calculate fuzzy similar classes. The fuzzy similarity class to the evaluation object \( x_i \) can be expressed as
where $\chi$ is the similarity of $x_0$ and $x_i$ [8].

Step 3: Calculate variable precision approximation set. $X$ is the category that contains all indexes, and $D$ is the category after deleting some indexes. Setting threshold $0.5 < \gamma \leq 1$, the lower approximation set of variable precision rough set of $X$ is

$$R_\chi(X) = \bigcup \{ D \in U \mid |X \cap FR(D)| \leq |FR(D)| \geq \gamma \}$$

where $|FR(D)|$ is the number of elements in classification set [8].

Step 4: Calculate the approximate classification quality. The quality of the approximate classification is expressed as

$$V_\chi(X) = \sum_{i=1}^n |R_\chi(X_i)| / |U|$$

When $V_\chi(X) = 1$, it means that the approximate classification is the same as the classification generated by all indexes after deleting the index, and the index $c_j$ can be deleted; otherwise, it cannot be deleted.

3.2. Dempster-Shafer evidence theory determines the index weight

The methods for determining the weight of indexes can be divided into subjective weighting method, objective weighting method and combination weighting method. The paper uses Analytic Hierarchy Process (called AHP for short) to determine the subjective weights of evaluation indexes, Entropy Method (called EM for short) to calculate the objective weights of evaluation indexes, and uses DS evidence theory to synthesize subjective and objective weights to obtain a combination of indexes weights.

3.2.1. AHP determines subjective weight

The AHP method is mainly to establish a hierarchical structure model, according to the importance of each factor at each level given by experts, construct a pairwise comparison judgment matrix, and conduct a consistency test. The objective weight $w_o$ of the evaluation index calculated by the judgment matrix.

3.2.2. EM determines objective weight

EM is an objective weighting method, which can avoid the subjectivity of artificially determining weights, and has high credibility and accuracy. For an index, if the entropy value is smaller, it indicates that the degree of dispersion of the index is greater, and the weight of the index is greater. The objective weight of the index obtained by using EM is $w_o$.

3.2.3. Comprehensive determination of index weight based on Dempster-Shafer evidence theory

Dempster-Shafer (called DS for short) evidence theory is applicable to the fusion of multi-source and uncertain information, and can transform a large amount of complicated and uncertain information into deterministic decision results. In DS evidence theory, the complete set of mutually incompatible basic propositions is called the recognition framework $\Theta$. The basic probability assignment (called BPA for short) is a function $m : 2^\Theta \rightarrow [0,1]$, which should satisfy the following conditions[10]:

$$\begin{cases}
    m(\emptyset) = 0 \\
    \sum_{\Theta} m(A) = 1
\end{cases}$$

Where proposition $A$ satisfying $m(A) > 0$ ($A \subseteq \Theta$) is called a focal element. Suppose that $m_1, m_2, \ldots, m_n$ are $n$ mutually independent BPAs, then the DS combination rule can be defined as
\[ m(A) = \begin{cases} \frac{1}{1-k} \sum_{A \subseteq \Phi} m(A) & A \neq \Phi \\ 0 & A = \Phi \end{cases} \quad (5) \]

Where \( k = \sum_{A \subseteq \Phi} \prod_{i \in A} m_i(A_i) \) is called the total conflict factor and it represents the total conflicts between evidences.

When the DS evidence theory is used to synthesize the subjective and objective weights of service quality evaluation indexes of medical institutions, assuming that the framework of system is \( \Theta = \{c_1, c_2, \ldots, c_l\} \). Subjective weight \( \omega : \{0, 1\}^l \rightarrow [0, 1] \), which satisfy the following conditions: \( \omega(\Phi) = 0 \), \( \sum_{A \subseteq \Theta} \omega(A) = 1 \), so, \( \omega \) is a basic probability assignment function on \( \Theta \). Similarly, \( e_\omega \) is also a basic probability assignment function on \( \Theta \), then paper uses the DS evidence theory to synthesize the subjective and objective weights, and get the combined weight \( \omega \).

3.3. Construct the basic probability assignment

The paper uses Grey relational Analysis (called GRA for short) to solve the uncertainty of evidence [11], and the steps of constructing the Mass function are as follows:

Step1: Construct a decision matrix. A decision matrix is \( Y = (y_{ij})_{n \times l} \), then normalizing it to a decision matrix \( Y = (y_{ij})_{n \times l} \). Substitute the combined weight \( \omega \) into the normalized decision matrix \( Y \) to obtain a weighted decision matrix \( X = (x_{ij})_{n \times l} = (\omega \cdot y_{ij})_{n \times l} \).

Step2: Calculate gray correlation coefficient. Assuming that the system behavior sequence is \( (x_1, x_2, \ldots, x_n) \), where \( x_0 \) is the feature sequence and \( x_i \) is factor sequence. The feature sequence of the system is \( x_0 \); \( x_j \) is the feature sequence of the system at \( k \) points as:

\[ r_{ij}(k) = (\alpha + \rho \beta) / (|x_0(k) - x_i(k)| + \rho \beta) \quad (6) \]

Where \( \alpha = \min_{k} |x_0(k) - x_i(k)| \), \( \beta = \max_{k} |x_0(k) - x_i(k)| \), \( \rho \in (0, 1) \), in generally \( \rho = 0.5 \).

Step3: Calculate the uncertainty. Grey relation coefficient by all points is \( r_{ij}(k) \), the uncertainty of each index is

\[ DOI(c_j) = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (r_{ij}(i))^2} \quad (7) \]

Certainty of index \( c_j \) is \( 1 - DOI(c_j) \).

Step4: Construct basic probability assignment function. The basic probability assignment function of each region under index \( c_j \) is

\[ m_{ij} = y_{ij} (1 - DOI(c_j)) \quad (8) \]

The basic probability assignment function of the overall uncertainty under the index \( c_j \) is

\[ m(c_j) = 1 - \sum_{i=1}^{m} m_{ij} \quad (9) \]

Step5: Information fusion. Getting the basic probability assignment function \( m_1, m_2, \ldots, m_v \) of each region under different indexes, then using DS evidence theory to synthesize evidences.
4. Empirical research

4.1. Data collection and model analysis

4.1.1. Data Sources
The model was verified according to the relevant data of 《Jiangsu Statistical Yearbook》, 《Jiangsu Health and Family Planning Yearbook》 of 2019. Taking 13 cities of Jiangsu Province, China as the sample area, the object set is \( \Theta = \{ x_1, x_2, \cdots, x_{13} \} \).

4.1.2. Model application
The FRS is used to select the evaluation indexes, make \( \chi = 0.3, \quad \gamma = 0.9 \), and remove the indexes that make \( V_{x}(Y) = 1 \). 13 indexes were selected from the 30 evaluation indexes (see Table 2), Use AHP to calculate the weights of the rule layer and index layer, where the weight of the rule layer is \( \omega_{a} = (0.105, 0.258, 0.637) \), the subjective weight of the index layer is recorded as \( \omega_{a} \). The objective weight determined by EM is recorded as \( \omega_{o} \). Use the DS evidence theory to synthesize \( \omega_{a} \) and \( \omega_{o} \) to get the combined weight \( \omega \) (Table 2).

### Table 2. Medical institution service quality evaluation indexes and related weight

| Scheme Layer | Rule Layer | Indexes | AHP Subjective weight \( \omega_{a} \) | EM Objective weight \( \omega_{o} \) | DS Combined weight \( \omega \) |
|--------------|------------|---------|-------------------------------|-------------------------------|----------------|
| Basic Service Quality 0.105 | Proportion of doctors and nurses (c2) | 0.250 | 0.328 | 0.140 |
| | Average number of beds per thousand population (c4) | 0.750 | 0.672 | 0.860 |
| Medical Service Process Quality 0.258 | Average bed utilization rate (c7) | 0.039 | 0.142 | 0.046 |
| | Hospitalization expenses per capita (c9) | 0.402 | 0.064 | 0.215 |
| | Average duration hospitalization (c11) | 0.240 | 0.141 | 0.283 |
| | Proportion of appointment of patients (c12) | 0.129 | 0.197 | 0.213 |
| | Proportion of medical income (c23) | 0.100 | 0.144 | 0.121 |
| | Average bed working day (c24) | 0.029 | 0.141 | 0.035 |
| | Doctors are responsible for the number of hospital bed everyday (c25) | 0.061 | 0.171 | 0.087 |
| Medical Terminal Quality 0.637 | Mortality of inpatient department (c15) | 0.190 | 0.150 | 0.156 |
| | Proportion of treatment improvement (c16) | 0.631 | 0.145 | 0.499 |
| | Proportion of patients undergoing surgery (c28) | 0.110 | 0.355 | 0.213 |
| | Proportion of patient transferred to other hospital (c30) | 0.069 | 0.350 | 0.132 |

The paper normalized 13 evaluation indexes data to obtain a normalized decision matrix \( Y \). According to the normalized decision matrix \( Y \) and combined weight \( \omega \), the uncertainty of each evaluation index is calculated using formulas (6) and (7), as shown in Table 3.

### Table 3. Uncertainty results of evaluation indexes

| Indexes | c2 | c4 | c7 | c9 | c11 | c12 | c23 | c24 | c25 | c15 | c16 | c28 | c30 |
|---------|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| DOI     | 0.22 | 0.16 | 0.26 | 0.23 | 0.20 | 0.24 | 0.25 | 0.27 | 0.25 | 0.26 | 0.24 | 0.24 | 0.25 |

When evaluating the service quality of medical institutions in various regions, evidences are \( m_{1}, m_{2}, \cdots, m_{3} \), and the basic probability assignment function matrix based on index certainty is:
The paper uses DS evidence theory to synthesize the basic service quality evaluation evidence body \((m_1,m_2)\), the medical service process quality evaluation evidence body \((m_3,\ldots,m_9)\), and the medical terminal quality evaluation evidence body \((m_{10},\ldots,m_{13})\). It will get a composite result of basic service quality, medical service process quality, and medical terminal quality in various regions of Jiangsu Province. According to the obtained criterion-level composite results and relative weights, the paper uses formulas (6) and (7) to obtain the Mass matrix for evaluating the service quality of medical institutions in various regions of Jiangsu Province.

\[
M = \begin{bmatrix}
0.15 & 0.09 & 0.05 & 0.00 & 0.08 & 0.06 & 0.10 & 0.05 & 0.01 & 0.00 & 0.04 & 0.00 & 0.06 \\
0.06 & 0.13 & 0.06 & 0.05 & 0.04 & 0.01 & 0.07 & 0.06 & 0.06 & 0.08 & 0.05 & 0.06 \\
0.07 & 0.10 & 0.03 & 0.05 & 0.06 & 0.08 & 0.01 & 0.03 & 0.00 & 0.06 & 0.07 & 0.02 & 0.06 \\
0.09 & 0.05 & 0.01 & 0.05 & 0.00 & 0.09 & 0.09 & 0.00 & 0.07 & 0.06 & 0.07 & 0.05 & 0.04 \\
0.06 & 0.09 & 0.10 & 0.05 & 0.01 & 0.00 & 0.10 & 0.10 & 0.11 & 0.05 & 0.00 & 0.08 & 0.01 \\
0.02 & 0.08 & 0.11 & 0.05 & 0.04 & 0.10 & 0.09 & 0.11 & 0.10 & 0.06 & 0.08 & 0.07 & 0.02 \\
0.04 & 0.05 & 0.00 & 0.08 & 0.11 & 0.09 & 0.05 & 0.00 & 0.06 & 0.06 & 0.00 & 0.10 & 0.07 \\
0.07 & 0.06 & 0.06 & 0.07 & 0.04 & 0.09 & 0.08 & 0.06 & 0.01 & 0.07 & 0.04 & 0.10 & 0.07 \\
0.00 & 0.04 & 0.07 & 0.08 & 0.12 & 0.00 & 0.02 & 0.07 & 0.09 & 0.08 & 0.07 & 0.09 & 0.00 \\
0.05 & 0.02 & 0.02 & 0.07 & 0.07 & 0.10 & 0.00 & 0.02 & 0.08 & 0.07 & 0.07 & 0.10 & 0.07 \\
0.11 & 0.00 & 0.08 & 0.06 & 0.06 & 0.10 & 0.04 & 0.08 & 0.03 & 0.03 & 0.05 & 0.06 & 0.08 \\
0.01 & 0.07 & 0.10 & 0.06 & 0.04 & 0.03 & 0.07 & 0.10 & 0.04 & 0.07 & 0.07 & 0.05 & 0.10 \\
0.05 & 0.06 & 0.05 & 0.11 & 0.13 & 0.01 & 0.03 & 0.05 & 0.09 & 0.07 & 0.06 & 0.09 & 0.05 \\
0.22 & 0.16 & 0.26 & 0.23 & 0.20 & 0.24 & 0.25 & 0.27 & 0.25 & 0.26 & 0.24 & 0.24 & 0.25
\end{bmatrix}
\]

According to Figure 1, it can be seen that the service quality of medical institutions in Nantong ranks first, and the service quality of medical institutions in Changzhou is the lowest. In recent years, Nantong has continued to increase financial investment, continuously optimize the allocation of medical and health resources, and deeply promote the improvement of medical service quality. It has continued to
promote appointments for diagnosis and treatment, day surgery, day wards and single-disease payment, so that patients can enjoy safety, efficient and considerate medical services. The service quality of medical institutions in Nantong ranks first in the Jiangsu province. The analysis found that the basic service facilities of medical institutions in Changzhou are better. However, due to the influx of patients from different places into Changzhou for medical treatment, the hospitals are overcrowded and the doctors are overloaded. Therefore, the quality of service of the medical institutions in Changzhou is in a low state.

5. Conclusions
In this paper, we used FRS to select the service quality evaluation indexes of medical institutions, eliminate indexes that do not affect the approximate classification quality. Then, we used DS evidence theory to synthesize subjective weight and objective weight, obtained the combined weight of the evaluation index system. Finally, we proposed a service quality evaluation model for regional medical institutions under asymmetric information environment, which can be used to compare and analyze the service quality of medical institutions in different regions and provide a basis for relevant government departments to formulate medical security policies.

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