A Study on an Application System for the Sustainable Development of Smart Healthcare in China

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ABSTRACT The purpose of this study is to explore ways to apply information technologies such as big data, Internet of things (IoT), mobile internet, and so on to the healthcare industry. By analyzing the impact path of such high-techs on healthcare, it intends to propose an application system for the sustainable development of so called “smart healthcare”. It identifies the influencing factors of smart healthcare from three different perspectives: society, economy and environment. It then constructs an indicator system containing 14 factors, and comprehensively analyzes the importance and dependence of the factors by using Fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) and Interpretative Structural Modeling Method (ISM) based on a multi-level hierarchy model. Using the theoretical framework of scientific research methods, this paper reveals the hierarchical path of the sustainable development of the whole intelligent healthcare which starts from the social level, combines the social and economic levels to achieve the balanced development of benefits, and finally brings the benefits to the environmental level. Based on this finding, this paper develops a sustainable application system for intelligent medicine in three levels: government, enterprise and user. The development of the sustainable application system for smart healthcare can provide theoretical guidance for model application evaluation.

INDEX TERMS Application system, Fuzzy-DEMATEL, ISM, smart healthcare, sustainable development.

I. INTRODUCTION With economic growth, in general, there has been a growing interest in quality of life. Among many factors affecting quality of life, healthcare has become one of the main issues in people’s lives. The importance of healthcare as a key determinant in quality of life is being recognized not only by individuals or industries but also by societies or nations. Thus, building a comprehensive healthcare system may not just give great benefits to the individuals’ physical or mental health and quality of life, but also bring driving force to the harmonious, stable and orderly development of economy and society [1]. However, with the continuous increase of elderly population, the situation is not that optimistic. In some countries such as China, Korea and Japan, the aging population leads to the rapid increase of medical expenses. The current economic recession worldwide is also causing national governments to adjust their resource allocations to reduce public health budgets. In this background, the issue of sustainable development of healthcare is increasingly gaining importance and should be addressed urgently in both the civil and the national level. It includes the improvement of the efficiency of healthcare infrastructure, the rational allocation of resources, and the coordinated and orderly development of medical ecology which will result in the continuous development in the healthcare field as a whole. Recently, the advent and advancement of information technology such as big data, internet of things (IoT), cloud computing and artificial intelligence is comprehensively transforming the healthcare system into more efficient, convenient, and personalized one [2]. Thus, it has
become a key issue to organize smart healthcare system from the perspectives of individuals, industries and governments and eventually realize the sustainable development of the system.

Existing literatures with regard to the new concept of smart healthcare lack the perspective of sustainability, with most focusing on the unilateral construction of technology, society, environment and economy [3]. Some scholars discuss the application and promotion of the IoT, cloud services, website platforms and other means of smart healthcare services from the perspective of technological innovation [4]. There is still a long way to go for development and introduction of new technologies. Along the way, many challenges are emerging as well [2]. Some studies challenge the construction of intelligent healthcare from the perspective of environment [5], [6], whereas Govind explore the economic impact of smart healthcare, pointing out that smart healthcare has a significant optimization effect on resource allocation [7]. Still others, from the perspective of social level, explore the attraction of smart healthcare to professionals and the upgrading of knowledge system [8]. Most of the prior studies emphasize only intelligent technology in a certain field, and do not consider the application of it to the social and economic environment [9], [10]. Moreover, they lack a systematic and theoretical integration framework to provide guidance for the sustainable development of wisdom [11].

Based on the triple bottom line theory and the perspective of sustainability, this paper sets up a sustainable development system of smart healthcare which combines social, environmental and economic aspects. Combining artificial intelligence with the three aspects will improve the sustainable development of smart hospital [12]. Combined with the theory of ecological efficiency, a systematic integration framework is constructed to provide guidance for the sustainable development of smart healthcare. The integration of healthcare application system and internet of things platform will make it more intelligent, more sustainable, more reliable and efficient, and less concerned with carbon emissions [13]. Udo & Jansson point out that sustainable development is multi-dimensional, and multi-disciplinary with significant complexity and uncertainty [14]. It is also difficult to use traditional methods to deal with a large number of fuzzy information arising in the sustainable development of hospitals. Therefore, this study introduces a fuzzy set to provide a new way of thinking and processing for hospital decision-making. Based on the hospital selection mechanism, it will also provide a visual analysis by considering the hierarchy and interrelationship between decision-making and experimental evaluation laboratory (DEMATEL) and interpretative structural model (ISM), taking into account the indicators [15]. Finally, incorporating the smart city agent theory [16] and stakeholder theory [17], this study constructs a multi-agent coordinated development system that comprehensively considers the social, economic, technological and environmental aspects.

We can draw the following conclusions through this research. First of all, solving social level problems is a first step in the construction of the framework of sustainable development of smart healthcare. Next, based on a supply chain system which is influenced by the social level, the economic level of smart healthcare should be constructed. Third, the social and economic benefits derived from above process should be taken into account in dealing with continuous improvement of environmental problems. Finally, based on the ISM model, this paper establishes the intelligent healthcare application system at three levels: government, company, and user level. The research results of this paper provide an important theoretical reference and the practical contribution for the sustainable development of smart healthcare.

II. LITERATURE REVIEW

A. SUSTAINABLE DEVELOPMENT OF HEALTHCARE

Since the establishment of the United Nations Conference on the human environment in 1972, sustainable development of healthcare has made great progress at the local, national, regional and international levels. However, the famous Brundtland Commission Report points out the unequal development of environment, economy and society [18]. Many researchers have also noticed the negative impact of healthcare on the environment [19], thus focusing on how to reduce the negative environmental impact [20].

Sustainable development may involve the process of institutional reforms to align institutions with current and future needs [18]. Previous studies began to systematically implement impact mitigation to assess hospital practice [20]. Operators of Health Care Information System (HCIS) such as hospitals and local healthcare institutions are responsible for leading the way to sustainable development, including fair provision of care and prevention of unnecessary treatment, which will improve efficiency to reduce the impact on the environment. A research from Italy shows that knowledge capital promotes the transformation of medical institutions to sustainable development, and encourages further investigation of the strategic plan for sustainability within HCIS [21].

In addition, the Health Hospital Initiative1 provides tools and resources to promote sustainable development. The Global Reporting Initiative2 provides sustainability reporting to help organizations measure, understand and communicate the impact on key sustainability issues. The Dow Jones Sustainability Index (DJSI) is an index that evaluates the sustainability of organizations and was developed to help organizations recognize the new opportunities and risks of global sustainability [8]. Therefore, exploring sustainable indicators and assessment tools is the first step towards sustainable HCIS.

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1 HHI, http://healthierhospitals.org/?about-hh/who-we-are
2 GRI, https://www.globalreporting.org/
TABLE 1. Evaluation index of sustainable development of smart healthcare.

| Index Selection       | Index Description                                                                                     | Sources       |
|-----------------------|------------------------------------------------------------------------------------------------------|---------------|
| C1 Talent attraction  | Companies set up various awards and trainings to improve employee satisfaction, reduce turnover rate, and attract talents. Through employee development plan, skill development, academic support, innovation ability improvement, talent training, knowledge spillover can be achieved. Patient service contains patient support, patient care, health guidance and management, patient education, service quality and innovative service. Telemedicine, relying on computer and remote control, gives full play to the medical technology and equipment of large hospitals to conduct diagnosis for the patients in remote areas. Smart hospital actively participates in the construction of community medical system and supports community health education, which has a demonstration effect on the surrounding hospitals. | [38],[39],[40],[41],[26],[42],[43],[54] |
| C2 Knowledge upgrading|                                                                                                      | [38],[40],[41]|
| C3 Patient service    |                                                                                                      | [26],[42],[43],[54]|
| C4 Telemedicine       |                                                                                                      | [4],[10],[13],[21],[22],[45], |
| C5 Social impacts on communities |                                                                                                      | [3],[28],[46],[47], |
| C6 Resource allocation efficiency |                                                                                                      | [11],[48],[57], |
| C7 Smart finance      | It refers to the allocation of total human and material resources and financial resources by the public allocation mechanism. Smart financial of hospital uses the electronic invoice and other information-based vouchers to analyze financial information more deeply, which improves the automation of data processing and the utilization rate of data. It combines sustainable procurement, drug supply, equipment sharing, and information sharing. It is a brand-new marketing model based on big data and data supply chain, which focuses on the personalized and dynamic demands of consumers. | [49],[50],[51],[3],[9],[52], |
| C8 Supply chain management |                                                                                                      | [7],[30],[53], |
| C9 Smart marketing    | Healthcare industry improves labor productivity and capacity utilization level through cost control. It contains waste classification, waste reduction, waste recycling, and hazardous waste management. It contains energy efficiency, energy and carbon management, transportation management, energy consumption and water resource consumption. It contains environmental policy of the hospital and environmental responsibility training for employees. It includes the construction of medical treatment core system and emergency service guarantee system. | [24],[54],[55],[56],[31],[32],[57],[58],[59],[31],[32],[60],[5],[19],[31],[32],[37],[61],[62], |
| C10 Cost control      |                                                                                                      |               |
| C11 Medical waste management |                                                                                                      |               |
| C12 Operational eco-efficiency |                                                                                                      |               |
| C13 Environmental management system |                                                                                                      |               |
| C14 Emergency management |                                                                                                      |               |

B. INTELLIGENT HEALTHCARE
With the development of Internet technology, interconnection and exchanges of medical data have become more intensively needed by individuals and organizations alike. As information technology and intelligence are constantly infiltrating the field of healthcare, the concept of “smart healthcare” has gradually emerged accordingly [3].

Intelligent medicine originates from the concept of “smart planet” put forward by IBM company.3 IBM’s vision of smart planet is based on the instruments, interconnection and intelligence, which provides a way to improve productivity, efficiency and responsiveness for industry, infrastructure, processes, cities and society. Intelligent medicine refers to the construction of an interactive platform for medical information sharing based on electronic health records and the comprehensive use of IoT, internet, cloud computing, big data and other technologies, so as to realize the interaction of patients, medical institutions, medical personnel and medical equipment, and intelligently match the needs of the medical biosphere. Intelligent medicine or smart healthcare is the cross application of information technology and life science,
and is a large health system for medical treatment, rehabilitation, nursing and pension, involving medical services, public health, medical security, drug supply security, health management and other aspects.

The continuous development of IoT and internet provides technical support for medical informatization. Dimitrov expounds the impact of big data on the field of healthcare in the United States from various perspectives, and points out that the combination of big data and the healthcare industry will produce many potential values [22]. Problems in disease diagnosis and epidemic prevention can also be analyzed and predicted by big data medical treatment. The healthcare information system can lead to promotion of data integration and information sharing, and support the establishment of intelligent medical system. Application process of healthcare information system can be divided into: information exchange, organization cooperation, process reengineering, health organization management optimization and organizational culture construction. It can contribute to establishment of local, regional and central health data coordination and exchange mechanism.

**C. INDEX INTERPRETATION**

1) SMART SOCIETY

Intelligent medicine has a great demand for talents in various fields such as theoretical researches, technology application and transformation, and engineering application. So, to attract relevant talents in these fields, improve employee satisfaction, and reduce turnover rate, hospitals, medical organizations, and related institutions should be able to offer various awards and training programs as well [C1] (Ryan-Fogarty et al., 2016). Through employee development plans, they can also upgrade employee knowledge levels and achieve knowledge spillover [C2] [20], [23], [24].

According to the latest clinical guidelines and standards, quality medical care is defined as “continuously to please patients by providing effective and efficient medical services to meet patients’ and providers’ needs”. Providing patients with high-quality patient service [C3] can be said to be the top priority to achieve hospital service quality, which can also effectively avoid conflicts in doctor-patient relationship [25] and improve patient satisfaction [26]. Some small medical institutions may not be able to provide certain medical services due to the limited resources such as medical equipment or skills and capabilities of medical staff, which can be overcome with the help of telemedicine services [C4]. Smart hospitals can also actively participate in the construction of community medical system, providing community medical consultation and health education, which may have a demonstration effect on hospitals nearby [C5] [20].

2) SMART ECONOMY

Inefficient resource allocation is a fundamental defect of public hospitals in developing countries. Inefficiency depletes the limited resources allocated to the public healthcare [27]. Inefficient allocation may arise when most of the relevant resources are transported to a few tertiary healthcare hospitals [28]. Therefore, resource allocation efficiency [C6] is an important index to evaluate the healthcare system. As an important management tool, big data also brings both opportunities and challenges to the innovation and development of smart finance [C7]. In order to seek the further development of smart hospital, traditional financial management needs to make changes in many aspects. Costs of medical care reflects the demand for efficient use of medical resources. Effective supply chain management [C8] improves operational efficiency and is a catalyst for more effective use of medical resources [29]. Smart Marketing [C9] plays an important role in organizational success. It can not only provide sustainable competitive advantage, but also enable to obtain excellent business performance with marketing assets [30]. Therefore, adopting short-term measures to control costs [C10] and improving healthcare efficiency in the long run are the goals of smart healthcare.

3) SMART ENVIRONMENT

With the construction of sustainable medicine, more researches compare the effects of reusable and disposable medical devices [31], water-saving and water-waste treatment [32], energy efficiency [33] and food selection, preparation and waste [34]. Medical waste management [C11] has gradually become a feature of sustainable health researches [35], [36]. Environmental sustainability must address emerging threats to the natural environment, such as climate change and the loss of biodiversity. Based on the social environment, as well as the potentially economically constrained and challenging future (the so-called “triple bottom line” of common welfare of health), combing healthcare provision with social healthcare to improve energy efficiency reduces energy and water consumption, and improves the operational eco-efficiency of the medical sector [C12] [20]. In addition, the establishment of environmental management system [C13], the formulation of a series of relevant hospital environmental policies, and the development of environmental responsibility training for employees can also effectively improve the ecological benefits of smart medicine. Hospitals, in a sense, belong to public places. Their capacities should be improved to handle various types of emergencies. Therefore, construction of hospital emergency management system [C14] is an important foundation to ensure the sustainable development of hospitals [37].

**III. METHOD**

The research process is designed as follows. First of all, we need to clarify our research theme, that is, what it means to construct the sustainable development system of smart healthcare. Then, we invite experts in related fields to revise the index system and fill in the questionnaire. Next, we obtain the calculation results by exploring the Fuzzy-DEMATEL and ISM models. Finally, we build a complete sustainable
A. FUZZY-DEMATEL

Fuzzy mathematics based on fuzzy set theory is applicable to the analysis of fuzzy problem of correlation degree between elements, which is a method to simulate the human brain to process fuzzy information. Introducing fuzzy set theory and subjective judgment of experts in triangular fuzzy quantization can eliminate the subjectivity of experts’ grading [35], [63].

Fuzzy-DEMATEL method not only retains the practical and effective advantages of traditional DEMATEL method in factor identification, but also replaces the original accurate value with a triangular fuzzy number, which can reflect the real situation of the problem more comprehensively, improve the credibility of the analysis results, and provide more valuable reference for managers to make decisions [64].

Our Fuzzy-Dematel model is described in algorithm 1 below:

The Fuzzy-Dematel Algorithm
Step 1: For the problem under study, build a system of influencing factors set to F1, F2, ..., Fn, and get an semantic matrix.

Step 2: Determine the influence relationship between two factors by an expert scoring method and express the relationship in a matrix form. Invite experts to use the language operators “no impact (N)”, “very weak influence (VL)”, “weak influence (L)”, “strong influence (H)”, and “very strong influence (VH)”. The original expert evaluation is converted into a triangular fuzzy number by means of semantic transformation table, as shown in Table 2.

| Linguistic variables | Triangular fuzzy number |
|---------------------|-------------------------|
| N (No influence)    | (0,0,0.2)               |
| VL (Very low influence) | (0,0.2,0.4)           |
| L (Low influence)   | (0.2,0.4,0.6)         |
| H (High influence)  | (0.4,0.6,0.8)         |
| VH (Very high influence) | (0.8,1,1)        |

In converting the identified languages variables to triangular fuzzy numbers, we applied equation (1)

\[
W_{ij}^k = (a_{1ij}^k, a_{2ij}^k, a_{3ij}^k) \\
= (\max \left\{ \frac{i-1}{n}, 0 \right\}, \min \left\{ \frac{i-1}{n}, 1 \right\}) \\
\times i \in \{0, 1, \ldots, n\}
\]

Step 3: Converting the Fuzzy data into Crips Scores (CFCS) [65] to defuzzify the initial values of the expert scores, the nth order directly affects the matrix Z, and the direct influence matrix reflects the direct effect between the factors, including the following four steps:

(1) Normalize triangular fuzzy numbers:

\[
xd_{1ij}^k = (a_{1ij}^k - \min a_{1ij}^k) / \Delta_{\min}^\max \\
xd_{2ij}^k = (a_{2ij}^k - \min a_{1ij}^k) / \Delta_{\min}^\max \\
xd_{3ij}^k = (a_{3ij}^k - \min a_{1ij}^k) / \Delta_{\min}^\max
\]
Among them, \( \Delta_{\text{max}}^{\text{min}} = \max \alpha_{i}^{k} - \min \alpha_{i}^{k} \); In turn, we can calculate \( x_{a}^{k}, x_{d}^{k}, x_{s}^{k} \). In this way, we can calculate the prehnseive matrix, is calculated according to the following:

\[
G_{ij} = \frac{x_{a}^{k} - x_{s}^{k}}{1 + x_{a}^{k} - x_{s}^{k}} \quad (1)
\]

(2) Normalize the left value (ls) and right value (rs):

\[
x_{ls}^{k} = x_{a}^{k}/(1 + x_{a}^{k} - x_{s}^{k}) \quad (3)
\]

(3) Calculate the clear value after defuzzification:

\[
x_{ij}^{k} = [x_{ls}^{k}(1 - x_{ls}^{k}) + x_{rs}^{k}x_{rs}^{k}]/[1 - x_{ls}^{k} + x_{rs}^{k}] \quad (4)
\]

(4) Calculate the average clear value:

\[
z_{ij} = (z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{n})/n \quad (5)
\]

Step 4: Normalize the direct influence matrix \( Z \) to obtain the standardized direct influence matrix \( G \):

\[
\lambda = 1/ \max_{1 \leq i \leq n} \sum_{j=1}^{n} z_{ij}, \quad G = \lambda Z \quad (6)
\]

Step 5: The synthesis matrix \( T \), which is also called comprehensive matrix, is calculated according to the following formula: \( T = G + G^{2} + \cdots + G^{n} \) or \( T = (E + G)^{-1} \) E is the identity matrix.

Step 6: Analyze the comprehensive matrix to reveal the internal structure of the sustainable application system. The elements in matrix \( T \) are added by row as the influence degree \( D_{i} \), which represents the comprehensive influence value of the row factor on all other factors. The elements in matrix \( T \) are added as the affected degree \( R_{i} \), by column, indicating the comprehensive influence value of all other factors in that column. The formulas are as follows:

\[
D_{i} = \sum_{j=1}^{n} t_{ij} (i = 1, 2, \ldots, n) \quad (7)
\]

\[
R_{i} = \sum_{j=1}^{n} t_{ij}(i = 1, 2, \ldots, n) \quad (7)
\]

The sum of the influence degree and affected degree is called centrality, which indicates the position of the factor in the system and the size of its role. The difference between the influence degree and the affected degree is called causality, which reflects the causal relationship between the influencing factors. If the causality is greater than 0, the factor has a great effect on other factors and is called the factor of cause. If the causality is less than 0, the factor is greatly affected by other factors and is called the factor of result. The formulas are as follows:

\[
m_{ij} = D_{i} + R_{j} \quad (i = 1, 2, \ldots, n) \quad (8)
\]

\[
n_{ij} = D_{i} + R_{j} \quad (i = 1, 2, \ldots, n) \quad (8)
\]

Step 7: According to the cartesian coordinate system, the centrality and reason degree of the method are used to mark the position of each method in the coordinate system.

B. ISM

Although DEMATEL method can calculate the importance degree of a specific prevention method in the influencing factor system, it cannot determine the internal correlation of the prevention method and divide the hierarchy. So it is difficult to effectively manage and control the prevention method.

Conversely, as Atrui suggest, ISM is a recognized method for identifying relationships between specific elements that define a problem [66]. ISM originates from an interactive group learning process, and it can also be used by individuals. In this process, a set of directly or indirectly connected elements is constructed into a system model. ISM is used to understand the relationships between barriers and form insights into a collective understanding of these relationships.

ISM is a mature qualitative tool, which can be applied to various disciplines. For example, Luthra et al. through the application of ISM, discuss various obstacles of green supply chain management (GSCM) in Indian automobile industry [67]. Talib et al. apply the ISM method to understand the interaction between total quality management (TQM) barriers in an organization [68]. Haleem et al. analyze the key success factors of world-class manufacturing practices using ISM method [69]. Therefore, we choose to adopt ISM method to classify the system structure in this study.

The basic steps to implement ISM are as follows:

(1) Calculate the overall influence matrix \( F \). The calculation formula is:

\[
F = I + T = [f_{ij}]_{n \times n} \quad (9)
\]

where, the matrix \( I \) is the identity matrix;

(2) The threshold is introduced to eliminate redundant information for the most streamlined matrix. According to the trial calculation, the most suitable threshold calculation model is obtained. The calculation formula is:

\[
\lambda = \alpha + \beta \quad (10)
\]

In this equation, \( \alpha, \beta \) are the mean and standard deviation of all elements in the comprehensive influence matrix \( T \).

(3) According to the overall influence matrix of the system and the threshold value to remove the redundant factors, the reachable matrix \( M \) is obtained.

\[
m_{ij} = \begin{cases} 
1, & f_{ij} \geq \lambda \\
0, & f_{ij} < \lambda 
\end{cases} \quad (i, j = 1, 2, 3, \ldots, n) \quad (11)
\]

In the formula, 1 means there is a direct effect between the two factors, while 0 means there is no direct effect between the two factors.

(4) The accessible set and the preceding item set of each factor were determined, and the accessible set \( R \) and the preceding item set \( S \) were obtained by hierarchical processing.

\[
R_{i} = \{a_{j}/a_{j} \in A, k_{ij} \neq 0\}, \quad (i = 1, \ldots, m)
\]

\[
S_{i} = \{a_{j}/a_{j} \in A, k_{ij} \neq 0\}, \quad (i = 1, \ldots, m) \quad (12)
\]

(5) Check the following. If it is true, it indicates that the corresponding factor is the underlying factor, and then the...
TABLE 3. Direct impact matrix.

|    | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 | C11 | C12 | C13 | C14 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C1 | 0.000 | 0.012 | 0.202 | 0.012 | 0.202 | 0.012 | 0.202 | 0.012 | 0.202 | 0.012 | 0.202 | 0.012 | 0.202 | 0.461 |
| C2 | 0.148 | 0.000 | 0.012 | 0.461 | 0.012 | 0.230 | 0.379 | 0.012 | 0.202 | 0.202 | 0.434 | 0.202 | 0.202 | 0.066 |
| C3 | 0.243 | 0.461 | 0.000 | 0.202 | 0.393 | 0.298 | 0.298 | 0.393 | 0.080 | 0.461 | 0.202 | 0.012 | 0.202 | 0.284 |
| C4 | 0.066 | 0.026 | 0.094 | 0.000 | 0.094 | 0.026 | 0.325 | 0.175 | 0.434 | 0.107 | 0.298 | 0.434 | 0.461 | 0.121 |
| C5 | 0.134 | 0.461 | 0.461 | 0.311 | 0.000 | 0.420 | 0.311 | 0.461 | 0.012 | 0.325 | 0.298 | 0.012 | 0.080 | 0.284 |
| C6 | 0.012 | 0.461 | 0.012 | 0.461 | 0.012 | 0.202 | 0.000 | 0.461 | 0.012 | 0.189 | 0.461 | 0.488 | 0.230 | 0.243 | 0.012 |
| C7 | 0.012 | 0.026 | 0.107 | 0.366 | 0.107 | 0.026 | 0.000 | 0.107 | 0.017 | 0.379 | 0.026 | 0.325 | 0.434 | 0.434 | 0.012 |
| C8 | 0.393 | 0.202 | 0.420 | 0.284 | 0.461 | 0.461 | 0.298 | 0.000 | 0.102 | 0.461 | 0.270 | 0.012 | 0.012 | 0.257 |
| C9 | 0.311 | 0.012 | 0.202 | 0.012 | 0.202 | 0.012 | 0.012 | 0.202 | 0.000 | 0.012 | 0.012 | 0.250 | 0.250 | 0.284 |
| C10 | 0.012 | 0.461 | 0.012 | 0.406 | 0.012 | 0.461 | 0.012 | 0.202 | 0.000 | 0.434 | 0.202 | 0.202 | 0.012 | 0.012 |
| C11 | 0.012 | 0.026 | 0.094 | 0.461 | 0.094 | 0.026 | 0.338 | 0.094 | 0.325 | 0.053 | 0.000 | 0.420 | 0.420 | 0.012 |
| C12 | 0.311 | 0.053 | 0.189 | 0.012 | 0.189 | 0.012 | 0.012 | 0.189 | 0.230 | 0.012 | 0.012 | 0.000 | 0.230 | 0.311 |
| C13 | 0.311 | 0.121 | 0.202 | 0.012 | 0.189 | 0.012 | 0.012 | 0.202 | 0.230 | 0.012 | 0.012 | 0.311 | 0.000 | 0.311 |
| C14 | 0.270 | 0.012 | 0.189 | 0.012 | 0.202 | 0.012 | 0.012 | 0.189 | 0.012 | 0.012 | 0.012 | 0.012 | 0.000 | 0.000 |

rows and columns corresponding to the factors are deleted in the matrix M.

\[ R_i = R_i \cap S_i \]  \hspace{1cm} (13)

(6) Repeat steps (4) and (5) until you get the factor set \( N_q (q = 1, 2, \ldots, n) \) at each level and all factors in the accessibility matrix M are deleted.

(7) According to the matrix obtained in step (6), the hierarchical structure diagram of influencing factors is drawn in the order in which the factors are crossed out.

IV. RESULT

To obtain the original data and design the questionnaire for the analysis, we selected 7 experts who were attending doctors with at least 15 years of working experience from 4 different third-class hospitals located in northeast China.

The draft of the questionnaire was developed through literature review and analysis, and then sent to the 7 experts. If any one of the experts disagrees with the proposed measures in the questionnaire, authors re-discuss the argued points until the 7 experts reach a unanimous agreement. This process went through several iterations. Next, individual interviews were conducted for data collection in order to improve accuracy and prevent mutual influence.

(1) Summarize the answers and corrections to obtain the fuzzy direct impact matrix, and then process the original data according to the CFCS method.

(2) Determine the direct impact matrix between the factors affecting SSP, as shown in Table 3.

(3) According to the formula \( T = G + G^2 + \cdots + G^n \), the comprehensive influence matrix T is obtained, as shown in Table 4.
(4) The comprehensive impact matrix of the internal structure analysis of the indicator system is shown in Table 5.

(5) The DEMATEL cause and effect diagram is shown in Fig. 2.

As shown in Fig. 2, from the perspective of impact, patient service (C3), social impacts on communities (C5) and supply chain management (C8) have a high influence. The results show that C5 and C3 are the primary indicators of SSP development. C5 refers to the smart hospital actively participating in the construction of community medical system, using Internet big data to support community medical care, and playing a demonstration effect on the surrounding hospitals in the community. This index belongs to the combination of “intelligence” and society. It is a new index proposed in this paper. Traditional hospitals are, in general, very sensitive to social impact, but under the SSP development framework, traditional indicators must be updated to meet the new needs. C3 refers to the combination of “wisdom” and medical treatment, which establishes citizens’ electronic medical and health records. It can provide personalized support for patients to improve patient satisfaction, while saving time and resources. This index is also a combination of “intelligence” and society, which belongs to the new index proposed in this paper. In traditional hospitals, patient service is more important in the relationship between doctors and patients, and the role of intelligent technology is not obvious. However,
under the development framework of SSP, new patient service or intelligent medical treatment can be provided in the form of innovative service, electronic medical record, patient care, intelligent consultation and other aspects. In addition, C5 and C3 will promote the development of another key element, C8, which refers to supply chain management strategy and sustainable procurement, drug supply, equipment sharing, and information sharing. The development of C5 and the support for C3 will enhance the support for C8. C8 also seems to be an indicator for smart hospitals, since it represents obtaining more sustainable returns.

(6) According to the test results, expert suggestions and practical requirements, $\lambda$ is set to be 0.16 in the study. According to equation 9–11, as shown in Table 6, the accessibility matrix $M$ composed of 0 and 1 is constructed. 1 indicates a strong relationship between two factors while 0 indicates no or weak relationship between them. Then, the accessible and antecedent set of factors are shown in Table 7.

(7) Finally, build a hierarchical path for indicators to interact with each other from the ISM model, as shown in Fig. 3. The influencing factors are divided into four levels: C3, C5 and C8 are in the highest priority, while C2, C6 and C10 are in the second priority. C4, C7 and C11 are in the general level. C1, C9, C12, C13 and C14 are in the lowest level. The red arrow indicates the same level of interaction. The green arrow indicates the impact on the upper layer, and the black arrow indicates the impact on the cross layer. These provide a complete guidance for SSP. The development of smart medicine needs to start from the first level (C3, C5, C8), through the intermediary of C6, C10, to achieve economic and comprehensive effects. Environmental factors C11, C12, C13, C14 and C15 are in a relatively low priority, and they will be affected by other core elements in smart medicine.

V. DISCUSSION
In the whole model, patient service, social impacts on communities and supply chain management are at the first level, which belong to the social and economic level, respectively. It means that solving social and economic problems is the very first step in the sustainable development of

| $i$ | $R_i$ | $S_{i} | R_i/T\S_{i} | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 |
|-----|-------|-------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C1  | C1    | C1, C8| C1    |
| C2  | C2, C4, C11 | C2, C3, C5 | C2 |
| C3  | C2, C3, C4, C5, C7, C8, C10, C11 | C3, C5, C8 | C3, C5, C8 |
| C4  | C4, C9, C12, C13 | C2, C3, C4, C5, C6, C8, C10 | C4 |
| C5  | C2, C3, C4, C5, C6, C7 | C3, C5, C8 | C3, C5, C8 |
| C6  | C2, C3, C4, C5, C6, C8, C10 | C5, C6, C8 | C6 |
| C7  | C2, C3, C4, C5, C6, C7, C8, C10 | C3, C5, C8 | C7 |
| C8  | C2, C3, C4, C5, C6, C7, C8, C10, C11 | C3, C5, C8 | C3, C5, C8 |
| C9  | C2, C3, C4, C5, C6, C8, C10, C11 | C4, C9 | C9 |
| C10 | C2, C3, C4, C5, C6, C8, C10, C11 | C3, C5, C8 | C10 |
| C11 | C2, C3, C4, C5, C6, C8, C10, C11 | C2, C3, C4, C5, C6, C8, C10 | C11 |
| C12 | C2, C3, C4, C5, C6, C8, C10, C11 | C4, C6, C7, C11, C12 | C12 |
| C13 | C2, C3, C4, C5, C6, C8, C10, C11 | C4, C6, C7, C11, C12 | C13 |
| C14 | C2, C3, C4, C5, C6, C8, C10, C11 | C4, C6, C7, C11, C12 | C14 |
smart healthcare. Solving social problems includes how to improve patient satisfaction and how to perfect the construction of surrounding communities. Patient service is at the first level, which is in line with the core characteristics of smart healthcare. Patient satisfaction with treatment is the most important predictor of overall hospital care satisfaction [70], [71]. Based on stakeholder theory, highly satisfied patients are essential for the sustainability of any healthcare institution [72]. Electronic medical records enable doctors to understand patients quickly and deeply, provide patients with high-quality services, and effectively avoid doctor-patient conflicts [25]. In addition, through electronic means such as websites, the hospital can publish various kinds of information and communicate and interact with patients in no time [45], which can also improve patient satisfaction [26]. As a social indicator, community is at the first level and belongs to the stakeholders of the hospital, which is the core characteristics of smart healthcare. In recent years, due to the increasing demand for public healthcare in China, the increase of medical expenses, the limitation of medical resources and the subsequent changes in medical practices, the government, in allocating the limited public healthcare resources, hopes to assign them to hospitals according to the quality of medical treatment [73], [74]. As there is a growing demand for high-quality healthcare services and appropriate hospitals [44], hospital managers seek to meet the demand by improving the medical quality [42], [73]. Therefore, whether to provide effective community service is an important standard in evaluating smart hospitals. In the meantime, supply chain management connects all hospital stakeholders, which is the first level of economic problems. Supply cost usually accounts for 40% of hospital operating costs [75], and the supply cost ratio is generally regarded as an important indicator of hospital supply chain performance [52]. The healthcare industry needs to pay attention to supply chain innovation, because efficient supply chain management can reduce the cost of hospital supplies considerably. It seems that the research conclusions on patient service, community construction and supply chain management reflect the focus of social and economic development under the smart healthcare.

Knowledge upgrading, resource allocation efficiency and cost control are at the second level. Except for knowledge upgrading, these factors seem to support economic aspects. But, knowledge upgrading, though it seemingly belongs to the social level, cannot be ignored since it also works as an economic indicator from the perspective of human capital. Knowledge upgrading of medical staff can solve various social problems of hospitals. Previous studies have shown that in hospital nursing, the allocation of high-quality medical personnel, comfortable working environment and patient satisfaction have a certain relevance [38], [43]. Therefore, medical talents are not only a core element of evaluating medical institutions, but also an important cornerstone for upgrading medical industrial structure and improving the innovation capabilities [24]. The framework theory of urban capacity proposes that the idea of sustainable development should be emphasized in undertaking urban planning. Therefore, the economic problems of the second level are mainly linked to resource allocation efficiency and cost control [46]. From the perspective of social medical security, there has been a...
chronic shortage of medical resources and the medical supplies have not sufficiently met the demand. Even the solutions put forward by countries at the legal or policy level have proved to be an irrational or uneven resource assignment. So, in order to rationalize the allocation of scarce resources and reduce the relative cost, health authorities, hospitals and other healthcare departments coordinate the allocation of medical materials among different regions [57]. Therefore, assessing whether the resource allocation is appropriate has become one of the important measures to evaluate the hospital operation and management. Another economic index belonging to the second level is cost control. The measurement of medical cost usually focuses on controlling the patient’s medical cost, improving labor productivity, and maintaining a high level of capacity utilization. Some empirical and theoretical studies have shown that successful healthcare institutions often have superior managing ability in cost control [54]. Another study argues that although knowledge upgrading, resource allocation efficiency and cost control belong to different levels of evaluation system, they are related to each other and that knowledge upgrading and efficient resource allocation are at the core of cost control [24]. Therefore, in the dynamic healthcare industry, the cost management of the hospital is closely related to the overall hospital performance.

Telemedicine, intelligent finance and medical waste management are at the third level. Although these three fields look totally different from each other, they are not isolated. The first two factors are associated with social and economic aspects, which belong to the primary stage of smart healthcare. The last one is closely related to the environmental level, which belongs to the development stage of intelligent healthcare. At this level, the value chain of smart healthcare industry is addressed such as telemedicine, intelligent finance and medical waste management. Each link complements each other and has an important connection. Telemedicine belongs to the third level of social problems. Rapid changes in population and market are forcing the healthcare community to adjust their business model. Telemedicine represents a major change in the way doctors care for patients, and is an important method to evaluate the sustainable development of smart healthcare [76], [77]. The application of telemedicine will greatly increase the quality of healthcare, improve the therapeutic effect, and reduce the cost of healthcare [55]. In addition, as the demand for convenient and personalized care is growing, the demand for telemedicine will continue to increase accordingly. In the process of realizing the whole value chain, financial accounting control also has a certain impact on the development of smart healthcare. Smart finance is helpful for data collection, analysis and information transmission, facilitating hospital decision-making. Big data provides new opportunities for accounting management to play an active role in data creation and decision support [50]. Hospitals need to use big data to build and improve their financial relations and adjust them dynamically, so as to give full play to the incentive role of financial relations in financial performance. Finally, medical waste management has become a new environmental issue at this level. In recent years, as the number of hospitals has soared dramatically, the need for medical waste treatment has increased accordingly. Improper treatment and disposal of medical waste may cause high-risk infection and injury, and may pose serious health hazards to medical workers as well as general public [59]. The current treatment capacity of traditional hospitals is not big enough to meet the growing demand for medical waste treatment and disposal. So there is an urgent need for smart healthcare to provide new treatment and disposal methods [58]. It can be said that the effective operation of telemedicine, intelligent finance and medical waste management is inseparable from the construction of big data and intelligent medical internet. At this level, we have verified the importance of telemedicine, smart finance and medical waste management to the sustainable development of smart healthcare from the three bottom lines of society, economy and environment.

Talent attraction, intelligent marketing, operational eco-efficiency, environmental management system and emergency management are at the final level of construction. There is still a long way to go in realizing this last level, from construction of patient, community and supply chain system, to management of internal knowledge system, resource efficiency and operation cost of the hospital, and finally to the leap and upgrading of telemedicine, intelligent finance and waste management. Talent attraction is the last level of social problems. Talent resources are not only the first resource for economic and social development, but also an important support for upgrading the industrial structure and improving innovation capabilities. A hospital’s talent resource is its competitive advantage, so talent attraction is drawing more research attention [39], [40]. In addition, due to the aging population in some countries, changes in patient groups, changes in the labor market and other issues, it is essential to attract, cultivate and retain motivated and high-quality employees [41]. Secondly, the economic problem at the last level is smart marketing. Intelligent marketing integrates big data, Internet and IoT, analyzes patient and market information in time, and dynamically evaluates alternatives. It connects the hospital with its environment, and then helps the hospital become proactive to better adapt to environmental changes [30]. The theory of ecological strategy is consistent with the theory of sustainability, which focuses on relative efficiency gains [60]. Operational eco-efficiency is one of the potential factors of hospitals’ competitive advantage. Good environmental performance can promote the hospital to better production and operation [53]. Therefore, as one of the indicators to measure the sustainable development of the hospital, the operational eco-efficiency not only saves money for the hospital, but also reduces its destructiveness to natural resources. In addition, providing a safe and reliable environmental management system is also one of the key environmental issues of healthcare institutions [78]. On the contrary, inappropriate environmental management systems can make medical waste infectious and toxic. If not handled
FIGURE 4. Application of the sustainable development system of smart healthcare.

properly, medical waste can pose significant potential health and environmental risks [79]. Therefore, based on big data, IoT and other such technologies, it is meaningful to analyze and compare the medical environment, and then establish a reasonable environmental management system for the sustainable development of the hospital. Hospital, as a public place, often involves many aspects of response, from the social public response outside the hospital to the hospital medical professional response related to many aspects and departments. A series of linkage reaction mechanisms need to be established from accident occurrence to pre-hospital, in-hospital, and post-hospital to ensure the timeliness of response [80]. Therefore, unified planning and construction, overall organization and coordination, all-round promotion, and multi department linkage are necessary. Based on these, emergency management ability, as the last level of environmental problems, becomes one of the essential indicators to evaluate intelligent healthcare. Smart hospitals are different from general enterprises. For smart hospitals, the main goal in the early stage is to create social benefits and undertake social responsibilities. But if we expand our vision, we should pay equal attention to social and economic benefits, which is in line with the long-term interests and planning of enterprises. However, the sustainable development of smart hospital is different from that of traditional hospitals. In pursuit of economic and ecological benefits, environmental benefits should also be taken into account, which is consistent with the triple bottom line theory. Therefore, the location of talent attraction, intelligent marketing, operational eco-efficiency, environmental management system and emergency management in the model shows the characteristics of intelligent healthcare. According to the Smart City Agent theory [16], the model can be divided into three levels: government, company and user level [46]. Based on IoT related technologies, smart healthcare integrates relevant data of healthcare-related organizations such as large hospitals, community hospitals, health departments, social security departments, insurance companies and other institutions through cloud data, big data and other technical means [82]. As Figure 4 shows, the medical and health department at the government level have provided a good intelligent healthcare coordination mechanism, which uses the existing public resources to promote internal resource sharing, build a unified healthcare information sharing platform, and break through the barriers between industries. In order to develop a sustainable smart city which includes smart healthcare system, sustainable urban design and planning is necessary [47]. The urban planning department can reasonably plan the location of smart hospitals so as to improve the radiation area of medical resources [46]. Besides, smart drug regulatory system can effectively regulate drug use behavior and reduce drug costs in the healthcare process [24]. Smart medical waste management and smart environment management system can help environmental protection departments improve ecological efficiency and promote sustainable development [60]. At the company level, the smart hospital adopts advanced information technology to improve the hospital process, share information with other healthcare institutions, and improve the patient’s experience. Unlike the supply chain of traditional hospitals, that of the smart hospital adopts cloud information system to provide flexible management ability, which can obtain data from supply chain partners anytime, anywhere through
the network [9]. Accounting and auditing institutions can conduct accounting according to the transaction information of smart finance. As a third-party enterprise, insurance institutions can upload electronic insurance contracts and store them in the form of smart contracts in the big data platform to improve hospital emergency management capabilities [49]. The system uses intelligent terminal equipment and customized professional medical software to provide accurate and efficient customized solutions for the community healthcare center and improve the work efficiency. At the user level, the construction of intelligent healthcare is inseparable from the knowledge upgrading of medical staff and the cultivation of high-quality medical talents, which will eventually enhance patient satisfaction. Along with the help of big data which can improve healthcare and service development policies based on patients’ feedback, personalized intelligent medical service is sure to increase patient satisfaction [25], [26], [83].

VI. CONCLUSION

Currently, researches on smart healthcare, in general, stay in the shallow stages focusing only on single level problems arising in the value chain of smart healthcare industry and lacking a systematic hierarchical framework. Different from what previous researches have done, this study explores the ways to systematically apply information technologies to smart healthcare. To do so, it constructs a sustainable development framework of smart healthcare and provides the interaction and hierarchical influence path between indicators under the framework. Based on triple bottom line theory and stakeholder theory, it has constructed 14 index systems at three levels, analyzed the interaction among the smart healthcare indicators by means of fuzzy, DEMATEL and ISM research methods, obtained the hierarchical model of smart healthcare, and then revealed the path of smart healthcare. This study also considers embeddedness of new technology which can promote system development of intelligent healthcare and sustainability of the smart medical ecology. While providing a useful guidance for model application, this study has some limitations for future studies to address. The future research avenues are as below:

Firstly, this paper constructs a framework which is a systematic and brand-new indicator system, but it is not a complete one and there is still a possibility of missing indicators, which needs further exploration and improvement. Secondly, since the degree of impact relationship between indicators is analyzed based on the information derived from a survey on experts, there may be a subjectivity bias involved in the process. Although the fuzzy set theory is used to solve the problem, there may still be some other errors that might not possibly be eliminated. Lastly, the research conclusions of this paper need to be verified and supplemented in medical practice. These problems need to be addressed carefully by constantly improving the thinking process and research methods of smart healthcare in the framework of big data.

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