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Research on Risk Assessment Model of Epidemic Diseases in a Certain Region Based on Markov Chain and AHP

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ABSTRACT Epidemic risk has great uncertainty and harmfulness, which poses a potential threat to public health in a certain region. Establishing a special risk assessment system to assess and predict the potential epidemic risk of a region can effectively avoid or reduce the impact of epidemic risk. Therefore, this paper combs the related factors that affect the epidemic risk, and proposes an epidemic risk assessment model based on 12 indicators by combining Markov chain and AHP. The model can assess the epidemic situation in a certain region from four aspects: the probability of risk occurrence, the probability of loss, the possibility of risk disappearance and risk duration, so as to provide detailed data for the risk management and control of epidemic in the region, and help the epidemic prevention work to be carried out in a targeted way. Finally, the case analysis and method comparison are carried out,and the results show that the model proposed in this paper is reasonable and feasible.

INDEX TERMS AHP, disease assessment, epidemic diseases, epidemic risk, Markov chain, risk assessment.

I. INTRODUCTION

In January 2020, the acute respiratory infectious disease covid-19 (Coronavirus disease 19) swept the world [1]–[3], which had a great impact on the social operation of countries around the world and brought challenges to the diseases prevention and control in various regions. So, even in the medical technology highly-developed today there are still uncertain epidemic risk, which pose a potential threat to public health and safety. Throughout the whole process of human development, it is not uncommon to find such outbreaks. Since 1990, new epidemics such as avian influenza [4], West Nile virus [5], Streptococcus suis [6], global influenza A*H1N1 [7], dengue fever [8], Middle East respiratory syndrome coronavirus [9] have been emerging all over the world. These epidemics have great occurrence uncertainty and loss uncertainty. In the absence of effective assessment and monitoring, the management and control of emergency risk by relevant departments will become particularly difficult. Once the risk outbreak, it will have a great impact on the public safety of a certain region and even the whole society. Therefore, the scientific assessment and prediction of epidemic risk has important practical significance for regional social security [10].

In order to cope with the epidemic and ensure the health and safety of the public, there have been many relevant studies, such as the research on the clinical phenomena of diseases [11], [12], the research on pathogens [13], the research on the medical treatment of epidemics [14]. These studies provide effective methods for the treatment of specific diseases. However, in addition to the treatment of diseases, in order to effectively avoid or reduce the losses caused by epidemic risk, we should also strengthen the research on epidemic prevention and control [15]. For epidemic prevention and control, Jian *et al.* [16] pointed out that effective data monitoring and risk assessment are the key to epidemic control, and elaborated the importance of risk management on epidemic control. Mikler *et al.* [17] pointed out that in the process of disease control, quantitative data is very important for decision making. In order to obtain the quantitative data, Mikler pointed out that a special evaluation framework should be established according to the characteristics of epidemic

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risk. Moss *et al.* [18] concluded that when there is uncertainty in epidemic control a special assessment system of epidemic risk should be established, so as to help relevant departments to carry out risk control according to the assessment results. These studies have discussed the importance of risk assessment for epidemic control. In order to carry out epidemic risk assessment, the key problem to be solved is establishing a perfect risk assessment system and on this basis to explore an effective epidemic risk measurement. As we all know, risk assessment usually includes three important stages: risk identification, risk analysis and risk assessment. The common risk assessment methods include Delphi method [19], [20], AHP(analytic hierarchy process) [21], [22], risk matrix method [23], [24], etc. These methods provide solutions for risk quantitative analysis, and they are also suitable for epidemic risk assessment. However, due to the persistence and periodicity of epidemic risk, the actual risk situation cannot be reflected by static assessment results. Through the study of relevant epidemic assessment methods at home and abroad, Han [25] pointed out that the current model-based static assessment has great limitations, and the assessment results can only reflect the epidemic risk status at a certain time. In order to provide more objective assessment results for epidemic prevention and control, X Han pointed out that dynamic assessment of epidemic risk should be carried out.

In summary, scientific assessment is very important for the prevention and control of epidemics. To carry out scientific risk assessment, the first problem to be solved is to establish a perfect risk assessment system. Ma and Liu [26] pointed out that epidemic risk is closely related to medical conditions, management policies, population quality, public health, transportation and other factors in an area. In order to establish a risk assessment system for epidemics, it is necessary to analyze these factors and sort out their complex relationships. Secondly, it needs to explore an effective risk measurement method based on the established assessment system. This method should not only be objective and comprehensive, but also be able to do dynamic analysis. Finally, the assessment should be able to help decision-makers to manage and control risk. Therefore, in order to realize the assessment and prediction of the epidemic risk in a region, this paper proposes to establish an epidemic risk assessment model based on AHP and Markov chain. According to the viewpoint of system science, a region can be regarded as a complex system with multiple uncertain risk factors and random states. On the one hand, AHP method is used to measure the uncertainty of epidemic risk from different levels and dimensions; on the other hand, Markov chain is used to assess and predict the random risk state of the region.

II. RELEVANT RESEARCH

The study of epidemic risk can be divided into two main aspects: risk identification and control. The identification of risk mainly focuses on the study of the disease itself and its related influencing factors, while the control of risk mainly focuses on the prevention and treatment of disease. In order to fully understand the epidemic risk and establish a reasonable assessment model, this paper analyzes the related research at home and abroad from the following two aspects.

A. THE INFLUENCING FACTORS OF EPIDEMIC RISK

Quinn [27] pointed out that the factors affecting the epidemic risk include biological factors from the pathogen itself, natural factors related to climate, and social factors. Zhang *et al.* [28] pointed out people's awareness of epidemic risk will directly affect the control of disease risk. Mcconnon [29], Moghadas *et al.* [30], and Alahmadi *et al.* [31] pointed out that public health and related policies are important factors in infectious disease control. Hu *et al.* [32] introduced the concept of population density into the epidemic transmission model, studied the epidemic transmission mechanism of different population density, and pointed out that population density is the key factor affecting the spread of infectious diseases. Liu *et al.* [33] pointed out that there is an important correlation between population health literacy and epidemic infection. Zhaoying *et al.* [34] pointed out that the factors influencing the epidemic risk include geographical factors, climate factors and customs. Smith [35] and Little [36] pointed out that geographical location is an important factor affecting the spread of epidemics.

B. THE ASSESSMENT OF EPIDEMIC RISK

Common epidemic risk assessment methods include expert investigation [37], [38], Delphi method [39], [40], etc. These methods have certain subjectivity in the assessment process, and are prone to produce conflict information, which leads to the assessment results inconsistent with the actual situation. The risk matrix method is also a common risk assessment method. Zhong-Shan *et al.* [41] and Yang *et al.* [42] applied the risk matrix method to the assessment of epidemic risk, evaluated the regional epidemic risk and determined its risk level. However, this assessment method can only get a fixed result, which cannot truly reflect the change of epidemic risk in a region.

In addition to the above methods, as a disaster, the assessment method of epidemic risk can also make reference to some common risk assessment methods, such as risk probability-based modeling and assessment [43], risk modeling and assessment based on index system [44], [45], risk modeling and assessment based on GIS(Geographic Information System) [46], [47], etc. However, these methods all need to establish a special risk assessment model. When establishing the model there are many factors to be considered. Therefore, how to effectively sort out these risk factors has become the key. In addition, the cost and consumption of establishing the assessment model is also a key point to be considered. Combined with the above classical methods, some scholars put forward some special epidemic risk assessment models according to the characteristics of epidemic risk. Sainz-Elipe *et al.* [48] evaluated the risk of malaria recurrence in the Ebro Delta by combining the modified climate map, gradient model risk (GMR) index and

spatial characteristics. Huang *et al.* [49] proposed a quantitative evaluation model for the control effect of covid-19. Tao *et al.* [50] defined the epidemic risk as a combination of possibility, severity and sensitivity, and assessed the risk of school opening during the epidemic. Seuc *et al.* [51] proposed a framework called CDA (Comparative disease assessment) to assess the impact of some diseases' incidence rate on health outcomes. These studies explored the characteristics of epidemics from different perspectives and put forward special assessment models according to epidemic risk characteristics. However, these models usually only assess the risk state at a certain moment, and do not carry out the prediction and analysis of the change of the epidemic risk state, resulting in the assessment results cannot effectively support the decision-making of risk control.

Through the above analysis, to carry out the assessment and prediction of epidemic risk, there are still some problems to be solved, such as: how to establish a comprehensive index system of epidemic risk, how to ensure the objectivity of the assessment method, how to predict and analyze the change of epidemic risk and how to assist the decision-making for risk control. In view of these problems, in order to get more accurate and comprehensive assessment results, this paper will sort out the relevant risk factors of epidemic, establish a special assessment model to assess the epidemic risk in a region, and finally put forward a feasible epidemic risk assessment model.

III. QUANTITATIVE DESCRIPTION AND STATE DEFINITION OF EPIDEMIC RISK

In order to provide support for the follow-up assessment, this paper carried out the following research.

A. QUANTITATIVE DESCRIPTION OF EPIDEMIC RISK

It is known that risk refers to the combination of the possibility and harmfulness of a certain hazardous event [52]. As the object of this study, epidemic risk also belongs to the category of risk. In order to describe the risk more comprehensively and provide the basis for risk management and control, the concept of risk controllability is introduced in this paper, and the epidemic risk is defined as a set of risk occurrence possibility, harmfulness and controllability, as shown in the following equation

$$R = \{P, H, C\} \tag{1}$$

In Equation (1), R is the epidemic risk, P is the possibility of the risk, $0 < P < 1$; H is the degree of harm that will be caused after the risk has occurred, the greater its value, the more serious the harmfulness, $0 < H < 1$; C is the controllable degree of the risk, the higher its value is, the easier the risk can be controlled, $0 < C < 1$;

B. EPIDEMIC RISK STATE DESCRIPTION BASED ON MARKOV CHAIN

Markov chain is a widely used statistical model in mathematical statistics, which is suitable for evaluating and predicting things with random state. On the one hand, it can use matrix to describe the random state of things at a certain time, and give things a mathematical definition. On the other hand, according to Markov chain theory, by establishing the transition matrix between each state, the probability of each random state in things' long-term development process can be calculated, so as to realize the prediction of the random state of things. It is known that the development of epidemic diseases is also a random process, which contains multiple random states. These states can reach each other in the process of epidemic development, and forming a random state space. Therefore, according to the characteristics of the epidemic, this paper proposes to integrate Markov chain into the risk assessment of epidemic diseases, and the research process is as follows.

According to the Markov chain, the epidemic risk is regarded as a process. Combined with the description of risk in Equation (1), the development process of epidemic risk can be divided into three random state, which are the possible state S_1, the damage state S_2, and the disappearance state S_3. As shown in Figure 1:

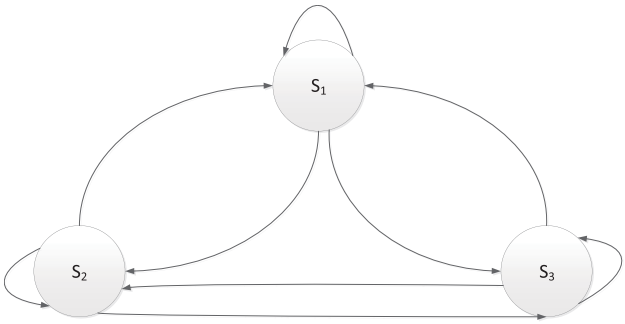

FIGURE 1. The random state of epidemic risk.

The development of the epidemic will be constantly changing among the three states.

Suppose that the probability of S_i in a region is $P(S_i)$, Then the epidemic risk state of the region is shown as follows:

$$P(S_i) = \{P(S_1), P(S_2), P(S_3)\} \tag{2}$$

And its state transition matrix is as follows:

$$\mathrm{STM} = \begin{bmatrix} \mathrm{P}(\mathrm{S}_{11}) & \mathrm{P}(\mathrm{S}_{12}) & \mathrm{P}(\mathrm{S}_{13}) \\ \mathrm{P}(\mathrm{S}_{21}) & \mathrm{P}(\mathrm{S}_{22}) & \mathrm{P}(\mathrm{S}_{23}) \\ \mathrm{P}(\mathrm{S}_{31}) & \mathrm{P}(\mathrm{S}_{32}) & \mathrm{P}(\mathrm{S}_{33}) \end{bmatrix} \tag{3}$$

In Equation (3), STM is the state transition matrix. The diagonal element $P(S_{ii})$ represents the probability that the state remains unchanged. The non-diagonal element $P(S_{ii})$ represents the probability from state S_i to state S_i. The sum of the elements in each row is equal to 1, $\sum_{i=1}^{3} P(S_{ij}) = 1$.

Therefore, according to the definition of Markov state transition matrix, the state description of epidemic risk as shown in the Table 1.

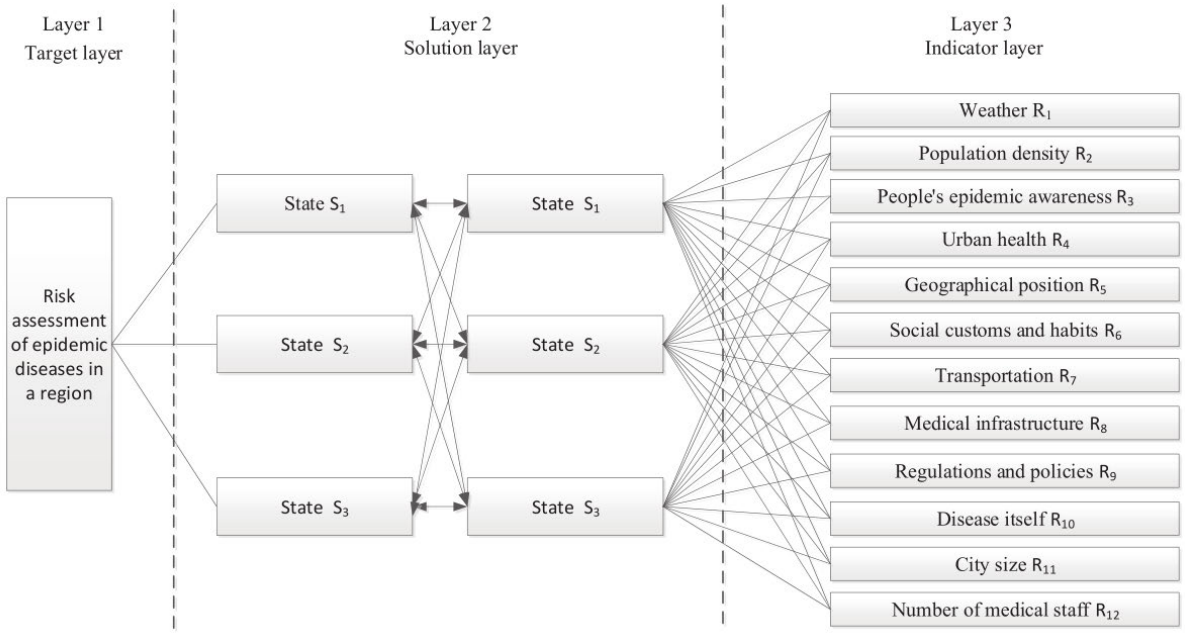

FIGURE 2. The risk state assessment system of epidemic diseases.

TABLE 1. The state description of epidemic risk.

State	$\mathbf{S_1}$	$\mathbf{S_2}$	$\mathbf{S_3}$
$\mathbf{S_1}$	$\mathbf{P(S_{11})}$ The probability that the state of risk occurrence remains unchanged	$\mathbf{P(S_{12})}$ The probability from risk occurrence state to risk damage state	$\mathbf{P(S_{13})}$ The probability from risk occurrence state to risk disappearance state
$\mathbf{S_2}$	$\mathbf{P(S_{21})}$ The probability from risk damage state to new risk occurrence state	$\mathbf{P(S_{22})}$ The probability that the state of risk damage remains unchanged	$\mathbf{P(S_{23})}$ The probability from risk damage state to risk disappearance state
$\mathbf{S_3}$	$\mathbf{P(S_{31})}$ The probability from risk disappearance state to new risk occurrence state	$\mathbf{P(S_{32})}$ The probability from risk disappearance state to re-damage state	$\mathbf{P(S_{33})}$ The probability that the state of risk disappearance remains unchanged

IV. EPIDEMIC RISK ASSESSMENT MODE BASED ON MARKOV CHAIN AND AHP

A. EPIDEMIC RISK ASSESSMENT SYSTEM

The epidemic risk assessment system proposed in this paper includes two contents: risk attribute model and indicator weight assignment method.

1) EPIDEMIC RISK ATTRIBUTE MODEL

Before the assessment, the first problem to be solved is to establish an assessment system of epidemic risk and ensure the objectivity of the assessment. It is known that AHP (Analytic Hierarchy Process) [53] is a decision-making research method combining qualitative and quantitative analysis, which is suitable for multi-objective, multi factor and multi-level problems. In the process of assessment, AHP usually establishes the hierarchy of assessment, establishes the comparison matrix of each indicator, and verifies the objectivity of assessment results through special consistency test method. This method is mature, reliable and widely used [54]–[57]. It can effectively reduce the impact of human subjective factors in the assessment process and ensure the objectivity of the assessment results. Therefore, in order to achieve quantitative and objective assessment, this paper will use AHP method.

According to the method of AHP, the system usually consists of three layers, namely target layer, solution layer and indicator layer. Among them, the target layer refers to the goal of decision-making and the problems to be solved, it is the core of the whole AHP framework. The solution layer refers to the solution to be implemented to achieve the goal. The indicator layer consists of relevant factors that affect decision-making.

In this paper, based on the characteristics of the epidemic, through investigation and literature review, taking the urban epidemic risk as the assessment object, a total of 12 assessment indicators are proposed. These indicators are interrelated and influence each other, which together constitute the assessment system of epidemic risk.

The establishment of the assessment system is an important basis for the study of the assessment method in this paper. Its assessment results can be used as the input data for the subsequent assessment based on Markov chain, these results include the risk state $P(S_i)$ of epidemic diseases and the STM(state transfer matrix) of epidemic diseases. In order to get these results, this paper proposes the corresponding risk assessment system of epidemic diseases based on AHP, as shown in Figure 2.

TABLE 2. The influence of each indicator on epidemic risk.

	The influence of each indicator on the probability of risk state				The influence of each indicator on risk state transition			
$\mathbf{R_i}$	description	$\mathbf{P}(\mathbf{S_1})$	$\mathbf{P}(\mathbf{S_2})$	$\mathbf{P}(\mathbf{S_3})$	State	$\mathbf{S_1}$	$\mathbf{S_2}$	$\mathbf{S_3}$
R_1	The weather is worse	higher	higher	lower	$\mathbf{S_1}$	higher	modest	lower
					$\mathbf{S_2}$	higher	modest	lower
					$\mathbf{S_3}$	higher	modest	lower
R_2	The population density is greater	higher	higher	lower	$\mathbf{S_1}$	higher	modest	lower
					$\mathbf{S_2}$	modest	higher	lower
					$\mathbf{S_3}$	higher	modest	lower
R_3	The awareness of epidemic is higher	lower	lower	higher	$\mathbf{S_1}$	modest	lower	higher
					$\mathbf{S_2}$	modest	lower	higher
					$\mathbf{S_3}$	lower	modest	higher
R_4	The urban health is better	lower	lower	higher	$\mathbf{S_1}$	modest	lower	higher
					$\mathbf{S_2}$	modest	lower	higher
					$\mathbf{S_3}$	lower	modest	higher
R_5	The geographical location is more central	higher	higher	lower	$\mathbf{S_1}$	higher	modest	lower
					$\mathbf{S_2}$	higher	modest	lower
					$\mathbf{S_3}$	modest	higher	lower
R_6	More customs and habits	higher	higher	lower	$\mathbf{S_1}$	higher	modest	lower
					$\mathbf{S_2}$	modest	higher	lower
					$\mathbf{S_3}$	higher	modest	lower
R_7	The transportation is more complex	higher	higher	lower	$\mathbf{S_1}$	higher	modest	lower
					$\mathbf{S_2}$	modest	higher	lower
					$\mathbf{S_3}$	modest	higher	lower
R_8	The medical infrastructure is better	lower	lower	higher	$\mathbf{S_1}$	modest	lower	higher
					$\mathbf{S_2}$	modest	lower	higher
					$\mathbf{S_3}$	lower	modest	higher
R_9	The epidemic prevention policies are more perfect	lower	lower	higher	$\mathbf{S_1}$	modest	lower	higher
					$\mathbf{S_2}$	modest	lower	higher
					$\mathbf{S_3}$	lower	modest	higher
R_{10}	The disease is more difficult to cure	higher	higher	lower	$\mathbf{S_1}$	modest	higher	lower
					$\mathbf{S_2}$	modest	higher	lower
					$\mathbf{S_3}$	higher	modest	lower
R_{11}	The city size is larger	higher	higher	lower	$\mathbf{S_1}$	modest	higher	lower
					$\mathbf{S_2}$	modest	higher	lower
					$\mathbf{S_3}$	higher	modest	lower
R_{12}	More medical staff	lower	lower	higher	$\mathbf{S_1}$	modest	lower	higher
					$\mathbf{S_2}$	modest	lower	higher
					$\mathbf{S_3}$	lower	modest	higher

In this system:

1) The first layer is the target layer, which is the evaluation target of the assessment, that is, the risk assessment of epidemic diseases in a certain region.
2) The second layer is the solution layer, which is the assessment solution to achieve the goal. As shown, in order to realize the risk assessment of epidemic diseases in a certain region, this paper will analyze the risk state $S_i = \{S_1, S_2, S_3\}$. There is the possibility of mutual transfer among the three risk states.
3) The third layer is the indicator layer, which contains 12 risk assessment indicators $R_i, i = 1, 2, \ldots, 12$ of epidemic diseases.

2) INDICATOR WEIGHT ASSIGNMENT METHOD

For the assessment system proposed in Figure 2, this paper proposes the corresponding indicator weight evaluation method, as shown in Table 2.

According to the definitions in Table 2, this paper uses the method of pairwise comparison to divide the weight of each indicator into five levels, as shown in Table 3.

As described in the Table 3, in the whole assessment process in this paper, all indicator weights are not directly allocated, but obtained by pairwise comparison of AHP. Compared with the direct assignment method, the pairwise comparison method can effectively reduce the impact of human subjective factors on the scoring results.

TABLE 3. Weight comparison method.

Weight ratio	Value	Definition and Description
$W(R_i)/W(R_j)$	1	R_i and R_j have the same weight on the impact of epidemic risk
$W(R_i)/W(R_j)$	3	Relative to R_j, R_i has more influence on the epidemic risk
$W(R_i)/W(R_j)$	5	Relative to R_j, R_i has absolute influence on the epidemic risk
$W(R_i)/W(R_j)$	2,4	A scale representing a compromise between the above criteria

In addition, there are inevitably conflict information in the process of assessment. In order to solve this problem, this research will transform the scoring result into a comparison matrix and verify it with the consistency test method of AHP [54]. If the experts'scoring results fail to pass the consistency test, all experts will discuss the specific conflict problems together, then set the corresponding confidence interval through investigation and analysis [58], and

re-scoring according to the confidence interval until the assessment results meet the consistency requirements.

As mentioned above, through the above processing, on the one hand to ensure the objectivity of the evaluation, on the other hand to solve the problem of conflict information in the assessment process,so as to provide accurate data for subsequent assessment.

B. CALCULATION OF EPIDEMIC RISK STATE AND ITS TRANSFER MATRIX

According to the definition in Table 3, we need to build the judgment matrix of the indicator layer through expert assignment. Its meaning is the weight matrix of each indicator relative to the risk of epidemic diseases in the whole region. The matrix is as follows:

$$A = \begin{vmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ A_{m1} & A_{m2} & \cdots & A_{mm} \end{vmatrix} \tag{4}$$

Matrix A is the result of expert scoring, and m is the total number of indicators. For example, A_{12} represents the weight ratio of indicator R_1 to indicator R_2 relative to the risk of epidemic diseases in the region. Then, the judgment matrix of the indicator layer can be obtained by normalizing the column vectors of matrix A, as follows:

$$\begin{aligned} W &= \begin{vmatrix} A_{11}/\sum_{i=1}^{m} A_{i1} & \cdots & A_{1m}/\sum_{i=1}^{m} A_{im} \\ A_{21}/\sum_{i=1}^{m} A_{i1} & \cdots & A_{2m}/\sum_{i=1}^{m} A_{im} \\ \cdots & \cdots & \cdots \\ A_{m1}/\sum_{i=1}^{m} A_{i1} & \cdots & A_{mm}/\sum_{i=1}^{m} A_{im} \end{vmatrix} \\ &= \begin{vmatrix} w_{11} & w_{12} & \cdots & w_{1m} \\ w_{21} & w_{22} & \cdots & w_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ w_{m1} & w_{m2} & \cdots & w_{mm} \end{vmatrix} \end{aligned} \tag{5}$$

After the matrix W is obtained, the maximum eigenvector W_i and the maximum eigenvalue $\lambda_{\max}$ of the matrix can be calculated by method of ANC(Asymptotic Normalization Coefficient) [59].

$$\begin{aligned} w_i &= |w_1, w_2, \ldots, w_m|^T \\ &= \left| \frac{\sum_{j=1}^{m} w_{1j}}{m}, \frac{\sum_{j=1}^{m} w_{2j}}{m}, \ldots, \frac{\sum_{j=1}^{m} w_{mj}}{m} \right|^T \end{aligned} \tag{6}$$

W_i is the weight of indicator R_i relative to the risk of epidemic diseases, $\sum_{i=1}^{m} w_i = 1$. The larger its value is, the greater the weight of the index on the risk of epidemic diseases is. The objectivity of the results can be tested by the consistency test method of AHP.

1) CALCULATION OF EPIDEMIC RISK STATE

Based on the assessment system in Figure 2, to evaluate the risk status of epidemic diseases, it is necessary to further construct the judgment matrix of the solution layer, as shown in the following matrix:

$$A\left(S_j\right) = \begin{vmatrix} A_{11}\left(S_j\right) & A_{12}\left(S_j\right) & \cdots & A_{1m}\left(S_j\right) \\ A_{21}\left(S_j\right) & A_{22}\left(S_j\right) & \cdots & A_{2m}\left(S_j\right) \\ \cdots & \cdots & \cdots & \cdots \\ A_{m1}\left(S_j\right) & A_{m2}\left(S_j\right) & \cdots & A_{mm}\left(S_j\right) \end{vmatrix}$$

In the matrix, $S_j = \{S_1, S_2, S_3\}$ are the three random states of epidemic risk. For example, $A_{12}(S_j)$ represents the weight ratio of indicator R_1 to indicator R_2 relative to the risk state S_j. Similarly, according to Equation (5) and (6), the weight of each indicator relative to different risk states of the solution layer can be obtained, The formula is as follows:

$$w_i\left(s_j\right) = \left|w_1\left(s_j\right), w_2\left(s_j\right), \ldots, w_m\left(s_j\right)\right|^T$$

$w_i(S_j)$ is the weight of indicator R_i relative to risk state S_j, $\sum_{i=1}^{m} w_i(s_j) = 1$. The larger its value is, the greater the influence weight of index i on risk state S_j is. Then, the weight of each risk state of epidemic diseases in a certain region at a certain time can be calculated by the following equation:

$$\begin{aligned} \mathrm{w}\left(s_j\right) &= \{\mathrm{w}\left(s_1\right), \mathrm{w}\left(s_2\right), \mathrm{w}\left(s_3\right)\} \\ &= \{\sum_{i=1}^{m} w_i \cdot w_i\left(s_1\right), \sum_{i=1}^{m} w_i \cdot w_i\left(s_2\right), \sum_{i=1}^{m} w_i \cdot w_i\left(s_3\right)\} \end{aligned} \tag{7}$$

In Equation (7), $w(s_1) + w(s_2) + w(s_3) = 1$. According to the weight definition of AHP, the higher the value of $w\left(s_j\right)$, the greater the probability of S_j state in this region. Therefore, the value of $w\left(s_j\right)$ can be used to represent the probability $P\left(S_j\right)$ in this region.

The traditional risk assessment research usually ends at this step. However, $P\left(S_j\right) = P\left(S_1\right), P\left(S_2\right), P\left(S_3\right)$ can only represent the epidemic risk state at a certain time. Taking the result as a reference for decision-making cannot help the relevant departments to effectively control the risk. Therefore, after getting the epidemic risk state at a certain time, this paper proposes to make dynamic assessment of the epidemic risk though Markov Chain.

2) CALCULATION OF EPIDEMIC RISK STATE TRANSITION MATRIX

Based on the evaluation system in Figure 2, the weight matrix of each indicator relative to the transfer possibility between risk states are constructed. It is as follows:

$$A\left(S_{1\,j}\right) = \begin{vmatrix} A_{11}\left(S_{1j}\right) & A_{12}\left(S_{1j}\right) & \cdots & A_{1m}\left(S_{1j}\right) \\ A_{21}\left(S_{1j}\right) & A_{22}\left(S_{1j}\right) & \cdots & A_{2m}\left(S_{1j}\right) \\ \cdots & \cdots & \cdots & \cdots \\ A_{m1}\left(S_{1j}\right) & A_{m2}\left(S_{1j}\right) & \cdots & A_{mm}\left(S_{1j}\right) \end{vmatrix}$$

$$A\left(S_{2\,j}\right) = \begin{vmatrix} A_{11}\left(S_{2j}\right) & A_{12}\left(S_{2j}\right) & \cdots & A_{1m}\left(S_{2j}\right) \\ A_{21}\left(S_{2j}\right) & A_{22}\left(S_{2j}\right) & \cdots & A_{2m}\left(S_{2j}\right) \\ \cdots & \cdots & \cdots & \cdots \\ A_{m1}\left(S_{2j}\right) & A_{m2}\left(S_{2j}\right) & \cdots & A_{mm}\left(S_{2j}\right) \end{vmatrix}$$

$$A\left(S_{3\,j}\right) = \begin{vmatrix} A_{11}\left(S_{3j}\right) & A_{12}\left(S_{3j}\right) & \cdots & A_{1m}\left(S_{3j}\right) \\ A_{21}\left(S_{3j}\right) & A_{22}\left(S_{3j}\right) & \cdots & A_{2m}\left(S_{3j}\right) \\ \cdots & \cdots & \cdots & \cdots \\ A_{m1}\left(S_{3j}\right) & A_{m2}\left(S_{3j}\right) & \cdots & A_{mm}\left(S_{3j}\right) \end{vmatrix}$$

For example, In the formula, $A_{12}(S_{1j})$ represents the weight ratio of indicator R_1 to indicator R_2 relative to the impact on risk state from S_1 to S_j. Similarly, according to (5) and (6), The weight of each indicator relative to the risk state transition can be calculated, and the results are as follows:

$$\begin{aligned} w_i\left(S_{1\,j}\right) &= \left|w_1\left(S_{1\,j}\right), w_2\left(S_{1\,j}\right), \ldots, w_m\left(S_{1\,j}\right)\right|^T \\ w_i\left(S_{2\,j}\right) &= \left|w_1\left(S_{2\,j}\right), w_2\left(S_{2\,j}\right), \ldots, w_m\left(S_{2\,j}\right)\right|^T \\ w_i\left(S_{3\,j}\right) &= \left|w_1\left(S_{3\,j}\right), w_2\left(S_{3\,j}\right), \ldots, w_m\left(S_{3\,j}\right)\right|^T \end{aligned}$$

$w_i(S_{1j})$ represents the impact weight of indicator R_i relative to risk status from S_1 to S_j, $\sum_{i=1}^{m} w_i(S_{1j}) = 1$. $w_i(S_{2j})$ represents the impact weight of index i relative to risk status from S_2 to S_j, $\sum_{i=1}^{m} w_i(S_{2j}) = 1.w_i(S_{3j})$ represents the impact weight of index i relative to risk status from S_3 to S_j, $\sum_{i=1}^{m} w_i(S_{3j}) = 1$.

The transfer weight of epidemic risk state in a certain region can be calculated by the following equation:

$$\begin{aligned} \mathrm{w}(S_{1\,j}) &= \{\mathrm{w}(S_{11}), \mathrm{w}(S_{12}), \mathrm{w}(S_{13})\} \\ &= \{\sum_{i=1}^{m} w_i \cdot w_i(S_{11}), \sum_{i=1}^{m} w_i \cdot w_i(S_{12}), \sum_{i=1}^{m} w_i \cdot w_i(S_{13})\} \end{aligned} \tag{8}$$

$$\begin{aligned} \mathrm{w}(S_{2\,j}) &= \{\mathrm{w}(S_{21}), \mathrm{w}(S_{22}), \mathrm{w}(S_{23})\} \\ &= \{\sum_{i=1}^{m} w_i \cdot w_i(S_{21}), \sum_{i=1}^{m} w_i \cdot w_i(S_{22}), \sum_{i=1}^{m} w_i \cdot w_i(S_{23})\} \end{aligned} \tag{9}$$

$$\begin{aligned} \mathrm{w}(S_{3\,j}) &= \{\mathrm{w}(S_{31}), \mathrm{w}(S_{32}), \mathrm{w}(S_{33})\} \\ &= \{\sum_{i=1}^{m} w_i \cdot w_i(S_{31}), \sum_{i=1}^{m} w_i \cdot w_i(S_{32}), \sum_{i=1}^{m} w_i \cdot w_i(S_{33})\} \end{aligned} \tag{10}$$

$w\left(S_{1j}\right) = \{w\left(S_{11}\right), w\left(S_{12}\right), w(S_{13})\}$ is the transfer weight from risk state S_1 to risk state S_j; $w\left(S_{2j}\right) = \{w\left(S_{21}\right), w\left(S_{22}\right), w(S_{23})\}$ is the transfer weight from risk state S_2 to risk state S_j; $w\left(S_{3j}\right) = \{w\left(S_{31}\right), w\left(S_{32}\right), w(S_{33})\}$ is the transfer weight from risk state S_3 to risk state S_j. According to the weight definition of AHP, the higher the value of $w\left(S_{1j}\right)$, the greater the probability from S_1 to S_j in this region. Therefore, the *STM* (state transition matrix) of this region can be represented as follows:

$$\begin{aligned} STM &= \begin{vmatrix} P\left(S_{11}\right) & P\left(S_{12}\right) & P\left(S_{13}\right) \\ P\left(S_{21}\right) & P\left(S_{22}\right) & P\left(S_{23}\right) \\ P\left(S_{31}\right) & P\left(S_{32}\right) & P\left(S_{33}\right) \end{vmatrix} \\ &= \begin{vmatrix} w\left(S_{1j}\right) \\ w\left(S_{2j}\right) \\ w\left(S_{3j}\right) \end{vmatrix} = \begin{vmatrix} w\left(S_{11}\right) & w\left(S_{12}\right) & w\left(S_{13}\right) \\ w\left(S_{21}\right) & w\left(S_{22}\right) & w\left(S_{23}\right) \\ w\left(S_{31}\right) & w\left(S_{32}\right) & w\left(S_{33}\right) \end{vmatrix} \end{aligned}$$

C. STABLE-STATE PREDICTION OF EPIDEMIC RISK

Assume that the epidemic risk state at T moment in region A is $P\left(S_i^T, A\right) = \{P\left(S_1^T, A\right), P\left(S_2^T, A\right), P\left(S_3^T, A\right)\}$, $\sum_{i=1}^{3} P\left(S_i^T, A\right) = 1$. The risk state transition matrix of the region is $STM(A)$. Then according to Markov's theory, the state of $T+1$ moment depends on the state of T moment, as shown in

$$\begin{aligned} \mathrm{P}\left(S_i^{T+1}, \mathrm{A}\right) &= \mathrm{P}\left(S_i^T, \mathrm{A}\right) * \mathrm{STM(A)} \\ &= \left\{\mathrm{P}\left(S_1^t, \mathrm{A}\right), \mathrm{P}\left(S_2^t, \mathrm{A}\right), \mathrm{P}\left(S_3^t, \mathrm{A}\right)\right\} \\ &\quad \begin{vmatrix} \mathrm{P}\left(\mathrm{S}_{11}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{12}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{13}, \mathrm{A}\right) \\ \mathrm{P}\left(\mathrm{S}_{21}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{22}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{23}, \mathrm{A}\right) \\ \mathrm{P}\left(\mathrm{S}_{31}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{32}, \mathrm{A}\right) & \mathrm{P}\left(\mathrm{S}_{33}, \mathrm{A}\right) \end{vmatrix} \end{aligned} \tag{11}$$

It is possible to further infer the risk state at the $T+K$ moment in region A, as shown in

$$\mathrm{P}\left(S_i^{T+K}, \mathrm{A}\right) = \mathrm{P}\left(S_i^T, \mathrm{A}\right) * \mathrm{STM(A)}^K \tag{12}$$

In Equation (12), $P\left(S_i^{T+K}, A\right)$ represents epidemic risk state at $T+K$ moment in region A, and K is the number of state transitions.

According to the principle of Markov chain, with the increase of K value, the change of epidemic risk state will gradually become smaller, and finally remain in a stable state, that is, $\hat{P}(S_i, A) = \hat{P}(S_1, A), \hat{P}(S_2, A), \hat{P}(S_3, A)$. This state describes the epidemic risk in a region from three perspectives, including occurrence possibility of the risk $\hat{P}(S_1, A)$, harmfulness $\hat{P}(S_2, A)$, and controllability $\hat{P}(S_3, A)$. Therefore, from the description of the above Formula, it can be obtained the meaning shown in Table 4 below.

TABLE 4. The meaning of each parameter in epidemic risk state.

	Meaning
$\hat{P}(S_1, A)$	The higher the value, the more likely the epidemic risk is to occur in region A without control.
$\hat{P}(S_2, A)$	The larger the value, the more damaging it will be in an uncontrolled situation and after the epidemic risk occurs in region A.
$\hat{P}(S_3, A)$	The higher the value, the higher the probability that the risk will disappear in an uncontrolled situation and after the epidemic risk occurs in region A.
K	The higher the value, the longer the epidemic risk persists in region A without control.

D. ASSESSMENT STEPS FOR THE MODEL

As mentioned above, this paper proposes an epidemic risk assessment model based on Markov chain, the model's detailed calculation steps are as follows:

Step 1: Establish the risk assessment system of epidemic diseases based on AHP.

Step 2: According to the description in Table 2 and Table 3, get the matrix $A, A(S_j), A(S_{1j}), A(S_{2j}), A(S_{3j})$ by expert scoring.

Step 3: According to Equation (6), calculate the weight $w(R_i)$ of each indicator.

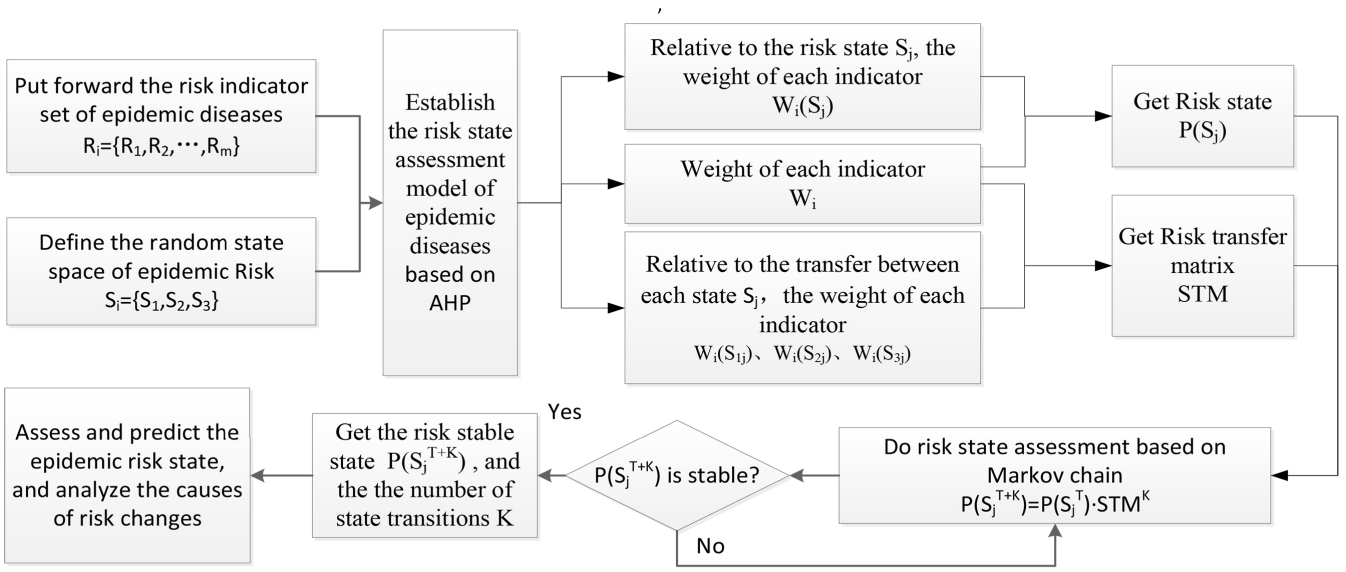

FIGURE 3. The whole assessment process of the proposed model.

Step 4: According to Equation (7), calculate the weight $w(S_j)$ of each state, set $w(S_j)$ *as* $P\left(S_j^T, A\right)$. $P\left(S_j^T, A\right)$ is the risk state of epidemic diseases at time T in region A.

Step 5: According to Equation (8),(9),(10), calculate $\{w(S_{1j}), w(S_{2j}), w(S_{3j})\}$, set it as $\{P(S_{1j}), P(S_{2j}), P(S_{3j})\}$, so that get the $STM(A)$.

Step 6: Set $P\left(S_j^T, A\right)$ as the risk state of epidemic diseases at T moment in region A, according to Equation (12), calculate the risk state $P\left(S_i^{T+K}, A\right)$ at $T+K$ moment.

Step 7: Continue executing Equation (7) until the result $P\left(S^{T+K}\right)$ is stable. Finally, according to the method of Markov chain, when $P\left(S^{T+K}\right)$ is no longer changes we can get the risk stability state $\hat{P}(S_i) = P\left(S^{T+K}\right)$ and number of state transitions K.

As mentioned above, the whole assessment process of the proposed model is shown in Figure 3, and the whole algorithm is as Algorithm 1.

V. MODEL CASE ANALYSIS AND METHOD COMPARISON

A. CASE ANALYSIS

In order to verify the feasibility of the proposed model, this paper gathered 15 experts in related fields, and selected three representative cities in China. According to the investigation and analysis, the characteristics of the three cities are summarized as shown in Table 5.

As shown in Table 5, around the risk indicators in Figure 2, the characteristics of the three cities in different aspects are listed. According to the data in Table 5, experts will use pairwise comparison method to assess the epidemic risk of the three cities.

First, according to algorithm 1, the risk indicator weight W_i, the risk state $P(S_i)$, the STM of three different cities are calculated in turn, and the results are as follows:

$$\mathrm{STM}(A) = \begin{vmatrix} 0.000 & 0.750 & 0.250 \\ 0.412 & 0.333 & 0.255 \\ 0.212 & 0.394 & 0.394 \end{vmatrix}$$

$$\mathrm{STM}(B) = \begin{vmatrix} 0.000 & 0.683 & 0.317 \\ 0.505 & 0.145 & 0.345 \\ 0.289 & 0.422 & 0.289 \end{vmatrix}$$

$$\mathrm{STM}(C) = \begin{vmatrix} 0.000 & 0.725 & 0.275 \\ 0.475 & 0.136 & 0.390 \\ 0.265 & 0.469 & 0.265 \end{vmatrix}$$

Assuming that the risk state at T moment is $P\left(S_i^T\right)$, the algorithm steps are executed in turn, and finally the comparison results of epidemic risk assessment of three different cities are obtained, as shown in Figure 4:

1) *Probability Comparison of Risk Occurrence:* Comparisons show that $\hat{P}(S_1, A) < \hat{P}(S_1, C) < \hat{P}(S_1, B)$. The possibility of epidemic risk in city-A is the lowest, indicating that the city size is not an important indicator to affect the occurrence of epidemics, while the awareness of epidemics plays an important role in the occurrence of risk, and the probability of risk occurrence is small if the population awareness of disease is high. $\hat{P}(S_1, C) < \hat{P}(S_1, B)$,indicates that the probability of recurrence is lower than the first occurrence.

Algorithm 1 The Algorithm of the Model

Input: expert scoring results, include the matrix A, $A(S_j)$, $A(S_{1j})$, $A(S_{2j})$ and $A(S_{3j})$.

Output: $\hat{P}(S_i)$ and number of state transitions K.

for all $N \in [1, 12]$ **do**
  for all $M \in [1, 12]$ **do**
    //column vector normalization
    $w_{NM} = A_{NM} / \sum_{i=1}^{12} A_{iM}$
    for all $K \in [1, 3]$ **do**
      $w_{NM}(S_K) = A_{NM}(S_K) / \sum_{i=1}^{12} A_{iM}(S_K)$
      $w_{NM}(S_{1\,K}) = A_{NM}(S_{1\,K}) / \sum_{i=1}^{12} A_{iM}(S_{1\,K})$
      $w_{NM}(S_{2\,K}) = A_{NM}(S_{2\,K}) / \sum_{i=1}^{12} A_{iM}(S_{2\,K})$
      $w_{NM}(S_{3\,K}) = A_{NM}(S_{3\,K}) / \sum_{i=1}^{12} A_{iM}(S_{3\,K})$
    end for
  end for
end for
for all $N \in [1, 12]$ **do**
  $w_N = \frac{1}{12} \sum_{j=1}^{12} w_{Nj}$
  for all $K \in [1, 3]$ **do**
    $w_N(S_K) = \frac{1}{12} \sum_{j=1}^{12} w_{Nj}(S_K)$
    $w_N(S_{1\,K}) = \frac{1}{12} \sum_{j=1}^{12} w_{Nj}(S_{1\,K})$
    $w_N(S_{2\,K}) = \frac{1}{12} \sum_{j=1}^{12} w_{Nj}(S_{2\,K})$
    $w_N(S_{3\,K}) = \frac{1}{12} \sum_{j=1}^{12} w_{Nj}(S_{3\,K})$
  end for
end for
$P(S_j) = w(S_j) = \sum_{j=1}^{12} w_N \cdot w_N(S_j)$
$P(S_{1\,K}) = w(S_{1\,K}) = \sum_{j=1}^{12} w_N \cdot w_N(S_{1\,K})$
$P(S_{2\,K}) = w(S_{2\,K}) = \sum_{j=1}^{12} w_N \cdot w_N(S_{2\,K})$
$P(S_{3\,K}) = w(S_{3\,K}) = \sum_{j=1}^{12} w_N \cdot w_N(S_{3\,K})$
$STM = |P(S_{1\,K}), P(S_{2\,K}), P(S_{3\,K})|^T$
$T = 1, K = 1$
while $P(S^{T+K}) \neq P(S^{T+K-1})$ **do**
  $P(S_j^{T+K}) = P(S_j^T) * STM^K$
  $K++$
end while
$\hat{P}(S_i) = P(S_j^{T+K})$
Print $K, \hat{P}(S_1), \hat{P}(S_2), \hat{P}(S_3)$

2) *Probability Comparison of Risk Loss:* Comparisons show that $\hat{P}(S_2, A) > \hat{P}(S_2, C) > \hat{P}(S_2, B)$. This shows that once the risk of city-A occurs, the risk damage caused is the largest. $\hat{P}(S_2, C) > \hat{P}(S_2, B)$ suggests that the city with disease has greater risk damage in the same two cities.

3) *Probability Comparison of Risk Disappearance:* Comparisons show that $\hat{P}(S_3, A) < \hat{P}(S_3, C) < \hat{P}(S_3, B)$. This shows that once the risk of city-A occurs, the probability of risk disappearing is the lowest. $\hat{P}(S_3, C) \approx \hat{P}(S_3, B)$ indicates whether the disease itself exists or not, the probability of the disease disappearing will not change without control.

4) *Comparison of Risk Duration:* Comparisons show that $K(A) > K(C) > K(B)$. This indicates that once the risk occurs, city A has the longest duration of the epidemic.

TABLE 5. The characteristics of three different cities.

	City A	City B	City C
Weather	Air quality ranking is located at 70%-80% in China	Air quality ranking is located at 5%-10% in China	Air quality ranking is located at 5%-10% in China
Population density	9000 persons/km^2	300-500 persons/km^2	300-500 persons/km^2
People's epidemic awareness	people have stronger epidemic awareness	people have weak epidemic awareness	people have weak epidemic awareness
Urban health	Harmless treatment rate of domestic waste $\geq$ 80% Green coverage rate$\geq$ 30%	Harmless treatment rate of domestic waste $\geq$ 90% Green coverage rate$\geq$ 50%	Harmless treatment rate of domestic waste $\geq$ 90% Green coverage rate$\geq$ 50%
Geographical position	Located in an important hub of international exchanges	Located in remote areas	Located in remote areas
Are there Social customs and habits	no social customs	have folk custom	have folk custom
Total number of vehicles	more than 5 million vehicles	100-300 thousand vehicles	100-300 thousand vehicles
Medical infrastructure	100+ beds per 10000 people	40-50 beds per 10000 people	40-50 beds per 10000 people
Regulations and policies	there are specific policies for the disease	there is no specific policy for the disease	here is no specific policy for the disease
Is there an epidemic	no epidemic disease	no epidemic disease	there are already infectious diseases
City size	10,000-20,000km^2	500-1000km^2	500-1000km^2
Number of medical staff	200,000+	5000-10,000	5000-10,000

TABLE 6. The indicator weight and risk state of three cities.

		City A	City B	City C
W_i	W_1	0.108	0.035	0.033
	W_2	0.138	0.123	0.115
	W_3	0.031	0.140	0.131
	W_4	0.077	0.088	0.082
	W_5	0.092	0.088	0.082
	W_6	0.015	0.140	0.131
	W_7	0.123	0.035	0.033
	W_8	0.077	0.070	0.066
	W_9	0.046	0.088	0.082
	W_{10}	0.092	0.105	0.164
	W_{11}	0.123	0.018	0.016
	W_{12}	0.077	0.070	0.066
$P(S_i)$	$P(S_1)$	0.545	0.250	0.375
	$P(S_2)$	0.364	0.333	0.5
	$P(S_3)$	0.091	0.417	0.125

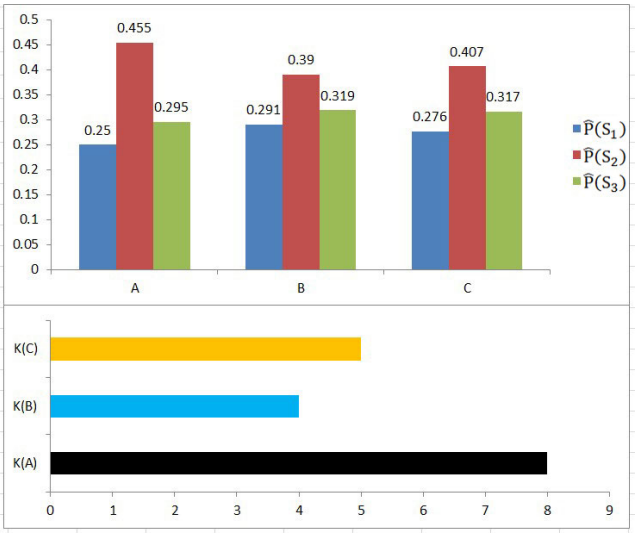

FIGURE 4. Comparison of epidemic risk assessment and prediction results in three different cities.

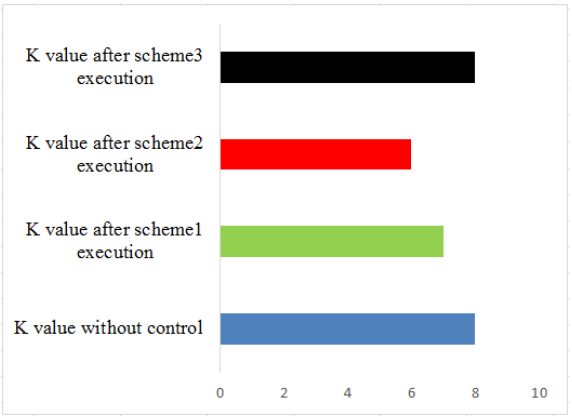

FIGURE 5. Prediction results of K value under three different schemes.

B. RISK CONTROL ANALYSIS

According to the above analysis, $K(A) = 8$, which indicates that the duration of the epidemic in city-A is the longest. In order to prevent the spread of the epidemic in the city, the duration value K of the epidemic in the city must be reduced.

In this regard, this paper has made relevant adjustments, specific adjustment programs are as follows:

Scheme1: Increase the disease awareness and health environment of the urban population (Increase the weights of indicator R_3 and R_4).

Scheme2: Improve the city's transportation and increase the number of medical facilities and medical staff in the city (Increase the weights of indicator R_7, R_8 and R_{12}).

Scheme3: Strengthens the treatment of the disease itself (Increase the weights of indicator R_{10}). With adjustment of three schemes, the change of K value of epidemic duration in city-A is shown in Figure 5.

Known indicators $\{R_3, R_4, R_7, R_8, R_{10}, R_{12}\}$ are all controllable indicators of epidemic risk. Increasing their weight can increase the controllability of risk. It can be seen from Figure 5 that under three different adjustment schemes, the effect of scheme 2 is the most obvious, which indicates that the most effective means to prevent the spread of disease is to improve the city traffic, increase the number of medical facilities and medical personnel in the city. Scheme 3 has almost no effect, indicating that only controlling the disease itself cannot effectively control the spread of the epidemic.

C. METHOD COMPARISON

In order to verify the feasibility and effectiveness of the proposed method in this paper, we still take city-A as the assessment object and carry out the following assessment.

1) *FAHP (Fuzzy Analytic Hierarchy Process):*
Combined with the 12 risk indicators proposed, this paper establishes an epidemic risk assessment system based on FAHP. In this system, the indicator layer consists of the proposed 12 indicators $R_i = \{R_1, R_2, \ldots, R_{12}\}$, the solution layer consists of the three different epidemic risk states $S_i = \{S_1, S_2, S_3\}$. In order to compare the assessment results with the method proposed in this paper, this paper also takes city-A as the assessment object, and adjusts the weight of indicators R_7, R_8 and R_{12} step by step according to scheme 2. Finally, the risk state assessment results of city-A at $T + K, K \geq 1$ moment are obtained after multiple assessment.

2) *Information Entropy Method:*
According to the theory of information entropy, a region can be regarded as a complex system with multiple uncertain risk factors. According to this theory, combined with the results of the questionnaire survey, this paper quantitatively assesses the proposed indicators from three aspects: the possibility of risk occurrence, the severity of loss and the possibility of disappearance, and obtains the weight values $w(R_i, S_1)$, $w(R_i, S_2)$, $w(R_i, S_3)$ of each indicator R_i in different dimensions. In order to compare the assessment results, this paper also takes city-A as the assessment object, and calculates the epidemic risk entropy value of city-A in three dimensions according to the information entropy formula. The larger the value of $H(S_j)$ is, the greater the uncertainty of risk state S_j is. Finally, the entropy values of the three dimensions are normalized to get the weight values of three epidemic risk states in city-A at T time. In order to get the risk assessment results of city-A at different times, this paper also adjusted the weight of indicators R_7, R_8 and R_{12} according to scheme 2, and obtained the risk state assessment results of city-A at $T + K, K \geq 1$ moment though multiple assessment.

3) *Risk Matrix Method:*
This paper sets up a special risk classification criterion from three aspects: the possibility of risk occurrence, the severity of loss and the possibility of

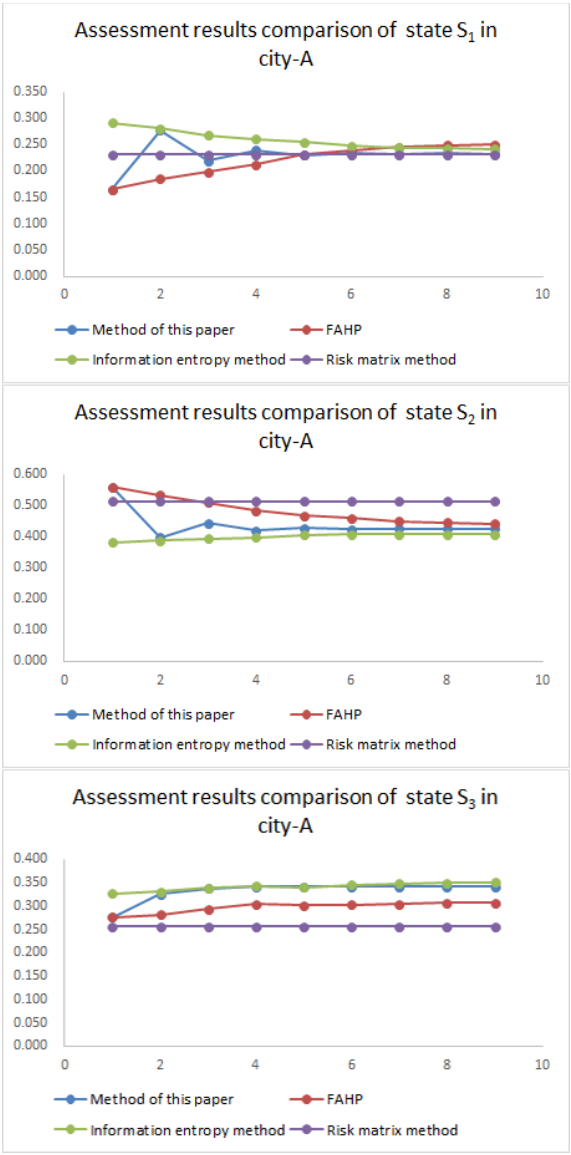

FIGURE 6. Comparison of epidemic risk assessment results in city-A.

TABLE 7. Comparison of epidemic risk assessment results in city-A.

Assessment method	$P(S_1^T, A)$	$P(S_1^{T+1}, A)$	$P(S_1^{T+2}, A)$
Method of this paper	0.165	0.277	0.219
FAHP	0.165	0.185	0.198
Information Entropy	0.292	0.281	0.268
Risk Matrix Method	0.231	0.231	0.231
	$P(S_1^{T+3}, A)$	$P(S_1^{T+4}, A)$	$P(S_1^{T+5}, A)$
Method of this paper	0.240	0.231	0.234
FAHP	0.213	0.231	0.239
Information Entropy	0.261	0.255	0.248
Risk Matrix Method	0.231	0.231	0.231
	$P(S_1^{T+6}, A)$	$P(S_1^{T+7}, A)$	$P(S_1^{T+8}, A)$
Method of this paper	0.233	0.234	0.233
FAHP	0.246	0.249	0.251
Information Entropy	0.245	0.243	0.242
Risk Matrix Method	0.231	0.231	0.231

Assessment method	$P(S_2^T, A)$	$P(S_2^{T+1}, A)$	$P(S_2^{T+2}, A)$
Method of this paper	0.559	0.398	0.444
FAHP	0.559	0.534	0.509
Information Entropy	0.382	0.388	0.394
Risk Matrix Method	0.513	0.513	0.513
	$P(S_2^{T+3}, A)$	$P(S_2^{T+4}, A)$	$P(S_2^{T+5}, A)$
Method of this paper	0.419	0.428	0.424
FAHP	0.483	0.468	0.459
Information Entropy	0.397	0.405	0.407
Risk Matrix Method	0.513	0.513	0.513
	$P(S_2^{T+6}, A)$	$P(S_2^{T+7}, A)$	$P(S_2^{T+8}, A)$
Method of this paper	0.425	0.425	0.425
FAHP	0.450	0.445	0.442
Information Entropy	0.407	0.408	0.408
Risk Matrix Method	0.513	0.513	0.513

Assessment method	$P(S_3^T, A)$	$P(S_3^{T+1}, A)$	$P(S_3^{T+2}, A)$
Method of this paper	0.276	0.325	0.337
FAHP	0.276	0.281	0.293
Information Entropy	0.326	0.331	0.338
Risk Matrix Method	0.256	0.256	0.256
	$P(S_3^{T+3}, A)$	$P(S_3^{T+4}, A)$	$P(S_3^{T+5}, A)$
Method of this paper	0.341	0.341	0.342
FAHP	0.304	0.301	0.302
Information Entropy	0.342	0.340	0.345
Risk Matrix Method	0.256	0.256	0.256
	$P(S_3^{T+6}, A)$	$P(S_3^{T+7}, A)$	$P(S_3^{T+8}, A)$
Method of this paper	0.342	0.342	0.342
FAHP	0.304	0.306	0.307
Information Entropy	0.348	0.349	0.350
Risk Matrix Method	0.256	0.256	0.256

disappearance. According to this criterion, this paper uses the three-dimensional risk matrix method to assess the epidemic risk state in city-A. According to the risk matrix method, the risk level of each dimension is $R(S_j)$, $R(S_j) = \sum_{i=1}^{m} v_i w\left(R_i, S_j\right)$. In this formula, v_i is the risk level of indicator R_i in this dimension, $w\left(R_i, S_j\right)$ is the weight value of indicator R_i in this dimension, and m is the number of risk indicators contained in this dimension. Combined with this method, this paper evaluates the epidemic risk of city-A. However, due to the limitations of this method, only a static evaluation result can be obtained.

The above three methods are relatively mature and common risk assessment methods, which are suitable for risk assessment and analysis with uncertainty. In order to verify the feasibility and effectiveness of the proposed method in this paper, the results obtained from the above-mentioned assessment are compared with the results obtained in this paper, as shown in Figure 6 and Table 7.

By comparison, the following results can be obtained:

1) The assessment results obtained by these methods are in good agreement with each other in numerical value, and they all get the results $\hat{P}(S_2) > \hat{P}(S_3) > \hat{P}(S_1)$.
2) After adjustment according to scheme 2, the assessment results of these methods all indicate that the epidemic risk in city-A will eventually tend to a stable state. This is consistent with the actual trend of epidemic risk development, which shows that the results of the proposed method are reasonable.
3) Using the three-dimensional risk matrix method, the assessment results of the epidemic risk in city-A

can be obtained, but the results can only reflect the epidemic risk status at a certain time. In comparison, the method proposed in this paper combined with Markov chain to predict and evaluate the epidemic risk status in this area, and the results are more consistent with the actual epidemic risk situation.

4) In order to assess the change of epidemic risk state after adjustment with scheme 2, FAHP and information entropy methods need to make assessment many times, while the method proposed in this paper only needs to make one assessment.

Combined with the above results, in order to intuitively illustrate the characteristics of the method proposed in this paper, the pairwise comparison of the above methods are carried out. According to the weight comparison method in Table 8, the comparison of each method is carried out from the following aspects: usability, objectivity, decision support, cost and functionality. The final comparison results are shown in Table 9.

TABLE 8. Weight comparison method.

Weight	Definition and Description
1	A and B have the same advantages over each other
3	Method A has advantages over method B in some respects
5	Relatively, method A has absolute advantages over method B.
2,4	A scale representing a compromise between the above criteria.

TABLE 9. Comparison with other method.

Method	Usability	Objectivity	Decision support	Cost	Functionality
Method of this paper	High	Modest	High	Low	High
FAHP	Modest	Modest	Modest	High	Modest
Information Entropy	High	Modest	Modest	High	Modest
Risk Matrix Method	High	Low	Low	Low	Modest

In Table 9, Usability represents the ease of use of the method; Objectivity indicates the objectivity of the method assessment; Decision support indicates the support degree of the method to decision-making; Functionality indicates the applicability of the method. Cost represents the cost of using the method.

VI. CONCLUSION

AHP method has special weight assignment method and consistency test method for assessment results, which can effectively solve the conflict problem in the assessment process and ensure the objectivity of assessment results. Though the analysis of epidemic risk characteristics, this paper establishes an epidemic risk assessment system based on AHP. On this basis, combined with Markov chain method, the state matrix and its state transition matrix of epidemic risk are proposed in this paper,so that to realize the dynamic assessment and prediction of regional epidemic risk. As mentioned above, the assessment method proposed in this paper is based on AHP and Markov chain theory, and its establishment process is scientific and reasonable.

Finally, through case analysis and method comparison, it shows that the epidemic risk assessment model proposed in this paper is simple and practical, the assessment results are objective and can provide detailed data for risk control and adjustment. The method proposed in this paper is suitable for the epidemic risk assessment in cities with stable population structure, but to assess the cities with large population flow it needs to be improved. In the following work, we will consider the impact of population mobility on the epidemic risk, continue to improve the proposed risk assessment system, and carry out further research combined with information entropy and evidence theory.

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