Research on the Effectiveness Evaluation and Risk Optimization of Crime Prevention System Based on Fuzzy Theory and AHP Model

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***Abstract*—with the rapid development of industrialization, security situation becomes more and more serious in China. Many cities have established crime prevention systems in order to maintain social stability. With the number of crime prevention system increasing, we need to assess their effectiveness in a scientific and objective manner and establishes a risk optimization model on crime prevention system. In this paper, we first apply the Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation methods in the model analysis. We not only solve the problem of interference on subject factors in traditional qualitative method for crime prevention system, but also improve the assessment objectively. In the next stage, we conduct the simulation experiment according to the specific examples of crime prevention system. The case study shows that the assessment results are consistent with the reality and this method can be reasonably used for the effectiveness evaluation of crime prevention system. Finally, combinatorial optimization technology is used to calculate the risk optimization model and a concrete example is given out to verify the model reasonably. We believe this work contributes to the theoretical framework guiding the design, development, and deployment of the crime prevention system.**

***Index Terms*—Effectiveness Evaluation, Risk Optimization, Fuzzy Theory, AHP, Crime Prevention System**

I. Introduction

With the security industry developing rapidly and the number of crime prevention systems increasing continuously in the recent years, professional effectiveness evaluation of crime prevention system has become indispensable in China. The need to choose and apply reasonable assessment method for scientific result is urgent. Another major task is for the scholars in the field of security protection to decide whether other evaluation methods can be used along with existing assessment methods.

The basic theory of effectiveness evaluation for crime prevention system is still lacking in China. Scientists mainly rely on a number of assessment heuristics borrowed from management science and simulation experiment to determine the effectiveness and identify weaker links of the crime prevention system [1][2][3]. Hence, we have not formed a relatively comprehensive theory and methodology for effectiveness evaluation, and we lack assessment models to scientifically measure the effectiveness of crime prevention system. At present, risk optimization in the area of crime prevention system still lacks studies at home and abroad. Optimization studies mainly focus on logistics capability optimization in economics [4][5][6], IT project risk optimization [7][8], fire ability optimization in cities and emergency resources the layout and optimization[9][10]. It establishes the optimization model accordingly. Whereas, very little discussion in on the optimization technology.

In this paper, we first adopt the methodology from the field of information science with the introduction of entropy risk initially documented by Shannon [11]. We establish risk entropy model to evaluate the effectiveness of crime prevention system. And then combine Analytic Hierarchy Process with Fuzzy Comprehensive Evaluation method to measure parameters Pi in the risk entropy model comprehensively in order to solve the problem of interference on subject factors in method for crime prevention system. This method not only fulfills the task of effectiveness evaluation of crime prevention system, but also enables protection capability on crime prevention system fully exertion to become technical support on public safety system. Finally, combinatorial optimization technology is used to calculate this model. The reminder of this paper is organized as follows: In section 2, we present the related work on effectiveness evaluation and risk optimization of crime prevention system. In section 3, we discuss the methods of Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation. In section 4, we give a specific example to assess the effectiveness of crime prevention system based on expert survey data. In section 5, we clarify combinatorial optimization technology application in the risk optimization model. In section 6, we denote a concrete example to verify the model reasonably. In the end of the paper we draw our conclusion and future work in section 7.

II. Related Work

At present, many foreign countries regard security protection as a very broad field of public safety [12][13][14]. It provides integrated security services to public safety from time to time. The contents of security protection include not only anti-theft, anti-robbery, anti-invasion, anti-destruction but also personal safety, fire safety, traffic safety, information security and communications security. Some of the developed countries with earlier application of the security system,

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such as the United States, Australia, the United Kingdom, have made some of the research results in this area.

In 1970's, U.S. Department of Energy's Sandia National Laboratories [15] has first introduce the basic concepts of physical protection system. At that time, it makes the idea that this system can be applied to the field of nuclear facilities protection. Subsequently, the U.S. Department of Energy put forward a model of adversary sequence diagram (ASD) [16].This model can identify deficiencies with physical protection system by analyzing various obstacles that imaginary opponent in order to achieve the purpose of the going through. The model is a qualitative analysis method, and there is no quantitative to give the weakest path of physical protection system that opponent has largest probability of attacking system. In 1980's, the U.S. Department of Energy bring forward a single path analysis model [16]. This model calculates the probability of adversary activities suspension based on qualitative analysis. The first step of this method chooses a attack path, and then calculate the probability of detection and the time of going through the barriers and reaction. Finally, it calculates the probability of suspension adversary by using the counter- power of this path. Subsequently, the U.S. Department of Energy put forward comprehensive path analysis model due to single-path analysis model has significant limitations of not analysis and selection the number of adversary attack path [17]. Although model is a combination of qualitative and quantitative analytical methods, it assesses the system through the probability of attack using a small sample of events to mock attacks entity protection system in the simulation lab. The assessment data lack a certain scientifically and objectively owing to not list and analyze completely to the attack events.

In 1981, Doyon [18] presents a probabilistic network model for a system consisting of guards, sensors, and barriers. He determines analytic representations for determining probabilities of intruder apprehension in different zones between site entry and a target object. In 1998, Hicks et al.[19]present a cost and performance analysis for physical protection systems at the design stage. Their system-level performance measure is risk which they define as follows: Risk = $P(A) \times [1 - P(E)] \times C$ where, $P(A)$ is Probability of Attack, $P(E)$ is Probability of System Effectiveness, = $P(I) \times P(N)$, $P(I)$ is Probability of Interruption, $P(N)$ is Probability of Neutralization, C is Consequence. Their discussion of the cost-performance tradeoff is limited and heavily weighted toward cost as a driver in the decision. Kobza and Jacobson [20] have presented probability models for access security systems with particular applications to aviation security. They are particularly concerned with false clear and false alarm signals. They formulate an optimization problem to determine the minimum false alarm rate for a system with a pre-specified false clear standard. Fischer and Green [21] present a very subjective risk analysis approach to ranking threats using a probability/criticality/vulnerability matrix. Cost effectiveness is discussed as a possible measure of system evaluation. Garcia [22] gives an integrated approach to designing physical security systems. Of particular note are the chapters on evaluation and analysis of protective systems as well as risk assessment. A cost-effectiveness approach is presented, and the measure of effectiveness employed for a physical protection system is the probability of interruption which is defined as "the cumulative probability of detection from the start of an adversary path to the point determined by the time available for response."

In our country, security protection is a part of social public safe, security protection industry is a branch of public safety industry. Security protection consists of personnel protection, physical protection and electronic protection on means of prevention. Personnel protection and physical protection are the traditional means of prevention, which are the basis of security protection. With the continuous progress of science and technology, these traditional means of prevention have been integrated into the content of the new technology. Electronic protection is a new concept to modern science and technology (the first electronic alarm technology) for the field of security and the gradual formation of an independent means to prevent. Electronic protection concept has become increasingly popular, more and more law enforcement agencies for the police and the public recognized and accepted with the continuous development and wider application of modern science and technology.

Chen [23] in Chinese People's Public Security University has proposed performance evaluation index and evaluation methods of security system for the assessment of the effectiveness of security system. This method is a qualitative assessment to the effectiveness of the security system based on management science. Zhao and Li [24][25] in China Institute of Atomic Energy design the analysis and evaluation software of physical protection system focusing on the problem of effectiveness evaluation. This method compute systems have been the greatest probability of successful attacks through simulation of the risk of external events attacking on the system in accordance with the different path based on the idea of probability and statistics in determining the most vulnerable paths. Subsequently, it can calculate the effectiveness of system.

III. THE ANALYTIC HIERARCHY PROCESS AND FUZZY COMPREHENSIVE EVALUATION METHODS

A. The Establishment of Index System for Effectiveness Evaluation of Crime Prevention System

Building the evaluation index system is a basic step for assessing effectiveness of crime prevention systems. That's why we should analyze the relationship among component elements which are composed of protection capability on crime prevention system and select a representative evaluation index in order to characterize the overall effectiveness of crime prevention system comprehensively [26]. The structure of hierarchical evaluation index system is constructed

The top level of hierarchical structure is the total protection capability on crime prevention system. It is analyzed from the following three aspects. So, the second level of hierarchical structure is defined as personnel protection capability, physical protection capability, and electronic protection capability. The third and forth levels are all the basic elements that three protection capabilities need to be considered.

B. Determination the Weight of Evaluation Index By AHP Method

Analytic Hierarchy Process method is a way of thinking essentially [27]. It can make the complex problem break down the component factors which form the hierarchical structure according to the relations of domination among them. The weight of evaluation indexes is determined through pairwise comparison between indexes. This method not only expresses the subjectivity of people quantitatively but also combines qualitative with quantitative research [28][29]. We can divide this method into the following four steps: 1). Analyzing the relations among evaluation indexes to construct the hierarchical structure of crime prevention system. 2). Comparing the relative importance of all the elements in the same level pairwise according to a criterion on the upper level to establish the judgment matrix. 3). Calculation the relative weights of evaluation indexes according to criteria through judgment matrices .4). Calculation the weights of evaluation indexes according to the objective criteria in each levels. We present the second and third steps process concretely as follows:

(1). the construction of judgment matrix

In this step, decision maker need to answer the question which is more important and the degree of relative importance between elements of u_i and u_j according to the criterion C. The judgment matrices with composed of n comparison elements are recorded as follows:

$$A=(a_{ij})_{n\times n}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

In this formula, a_{ij} is the degree of relative importance between elements of u_i and u_j according to the criterion C. The value a_{ij} is natural number between 1 and 9 according to the relative importance.

(2). the calculation of relative weight in the single criterion

In this step, we find relative weight of n elements $w_1, w_2, \ldots. w_n$ according to the judgment matrix A in the single criterion C. The relative weights can be written in vector form which is $w=(w_1, w_2, \ldots. w_n)^T$. There are two problems for us to solve. One is the weight calculation method. The other is consistency test in judgment matrix.

- The weight calculation method

We use square-root method to calculate the relative weight of each element according to the judgment matrix. We first obtain eigenvectors M

$$M=(m_1, m_2, \ldots, m_n) \quad (2)$$

$m_i=\sqrt[n]{a_{i1}a_{i2}\ldots a_{in}}$, we then normalize the M and get the relative weight vector of elements.

$$W=(W_1, W_2, \ldots, W_n) \quad (3)$$

$$W_i=\frac{m_i}{\sum_{i=1}^{n} m_i} \quad (4)$$

- The consistency test

Step1: calculation the consistency index (C.I)

$$C.I=\frac{\lambda_{max}-n}{n-1} \quad (5)$$

In this formula, n is the ladder of judgment matrix, λ_{max} is the latent root of judgment matrix which is recorded as follows:

$$\lambda_{max}=\sum_{i=1}^{n}\frac{(AW)_i}{nW_i} \quad (6)$$

Step2: finding a corresponding random consistency index (R.I). The value of R.I can be obtained through the table.

Step3: calculation the consistency ratio (C.R)

$$C.R=\frac{C.I}{R.I} \quad (7)$$

When $C.R<0.1$, the consistency of judgment matrix can be accepted. The logical error of each weight is none. When $C.R \ge 0.1$, we should revise the judgment matrix.

C. Measurement the Parameter of Risk Entropy Model By Fuzzy Comprehensive Evaluation Method

We introduce the parameter pi to denote the probability which one kind of protection capability is in the protection level of ai in the risk entropy model above. Because the partition of protection level is a fuzzy concept, we can use fuzzy comprehensive evaluation method to determine pi.

Fuzzy comprehensive evaluation method firstly blurs the single factor according to the judgment criterion [30][31]. At the same time, it determines the degree of importance on each single factor relative to reference factor according to the theory of fuzzy comprehensive evaluation. Finally, we obtain the comprehensive evaluation result through fuzzy operation. It can be divided into single factor comprehensive evaluation and multilevel comprehensive evaluation. In this paper, we use multilevel comprehensive evaluation method to calculate the p_i.

(1). Single factor fuzzy comprehensive evaluation

It is supposed that the set of one sub-object single factor is $U=\{U_1, U_2, \ldots U_m\}$, the set of remark is $V=\{V_1, V_2, \ldots, V_n\}$. The set of remark is described the word of very poor, poor, common, good, very good. The set of index weight is $C=\{a_1, a_2, \ldots, a_m\}$. The weight

$a_i (i = 1, 2, ..., m)$ represents the degree of importance which index $U_i (i = 1, 2, ..., m)$ is in the set of index. The set of index weight is obtained through AHP method. Generally, the weight $a_i (i = 1, 2, ..., m)$ should meet two qualifications: one is normalization, the other is non negative. $\sum_{i=1}^{m} a_i = 1,\ a_i \geq 0$. The subjection vector R which index U_i is relative to the set of remark V is $R_i = (r_{i1}, r_{i2}, ...r_{im})$. $i = 1, 2, ..., n$. The fuzzy matrix can be recorded as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{8}$$

r_{ij} is the set of weight which U_i is remarked on V_j . r_{ij} is determined by the ruler playing fuzzy score in the set of remark. The comprehensive evaluation on sub-object is recorded as follows:

$$B = C \bullet R$$
$$= (a_1, a_2, ..., a_m) \bullet \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$
$$= (b_1, b_2, ..., b_n) \tag{9}$$

In this formula, $\bullet$ represents fuzzy operation. In this paper, we use model $M(\wedge, \vee)$. The $\wedge, \vee$ represent respectively the operation on taking small and big.

IV. SPECIFIC EXAMPLE CALCULATION

According to the hierarchy model of crime prevention system shown in Fig.1, we first construct the judgment matrix which the second level is related to the first level. The judgment matrix A_B which the second level criteria personal protection, physical protection, and electronic protection are as the first level is as follows:

$$A\_B = \begin{bmatrix} 1 & 2 & \frac{1}{3} \\ \frac{1}{2} & 1 & \frac{1}{7} \\ 3 & 7 & 1 \end{bmatrix}$$

Then we can calculate the relative weight of the second level. Firstly, finding the eigenvector M= (0.874, 0.415, 2.759). Normalization the M, we can get W= (0.216, 0.103, 0.681). We calculate the matrix characteristic root $\lambda_{max} = 3.002$ according to the formula (16). Lastly, calculating the matrix consistency ratio C.R=0.0017<0.1. It shows that the matrix is consistency.

After that, we construct the judgment matrix which the third level is relative to the second level. The judgment matrix B1_C which the third level criteria configuration ratio, distribution, skill, and drilling frequency are as the second level personnel protection is as follows:

$$B_1\_C = \begin{bmatrix} 1 & 2 & \frac{1}{3} & 3 \\ \frac{1}{2} & 1 & \frac{1}{7} & 2 \\ 3 & 7 & 1 & 8 \\ \frac{1}{3} & \frac{1}{2} & \frac{1}{8} & 1 \end{bmatrix}$$

Then we can calculate the relative weight of the third level. Finding the eigenvector M= (1.189, 0.615, 3.600, 0.380). Normalization the M, we can get W= (0.206, 0.106, 0.622, 0.066). We calculate the matrix characteristic root $\lambda_{max} = 4.03$ according to the formula (16). Calculating the matrix consistency ratio C.R=0.011<0.1. It shows that the matrix is consistency.

Similarly, the judgment matrix B2_C which the third level criteria mechanical strength, configuration amount, and aging are as the second level physical protection is as follows:

$$B_2\_C = \begin{bmatrix} 1 & 2 & 3 \\ \frac{1}{2} & 1 & 2 \\ \frac{1}{3} & \frac{1}{2} & 1 \end{bmatrix}$$

Then we can calculate the relative weight of the third level. Finding the eigenvector M= (1.817, 1, 0.55). Normalization the M, we can get W= (0.54, 0.297, 0.163). We calculate the matrix characteristic root $\lambda_{max} = 3.008$ according to the formula (16). Calculating the matrix consistency ratio C.R=0.060<0.1. It shows that the matrix is consistency. According to the method of thought, the index relative weight of electronic protection is W= (0.306, 0.25, 0.194, 0.139, 0.083, 0.028).

Lastly, we construct the judgment matrix which the fourth level is related to the third level. The judgment matrix C7_D which the fourth level criteria image quality, camera number, and regional coverage are as the third level video surveillance is as follows:

$$C_7\_D = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & \frac{1}{2} \\ 5 & 2 & 1 \end{bmatrix}$$

Then we can calculate the relative weight of the fourth level. Finding the eigenvector M= (0.405, 1.144, 2.154). Normalization the M, we can get W= (0.109, 0.309, 0.582). We calculate the matrix characteristic root $\lambda_{max} = 3.003$ according to the formula (16). Calculating the matrix consistency ratio C.R=0.026<0.1. It shows that the matrix is consistency. According to the method of thought, the index relative weight of intrusion detection is W= (0.333, 0.111, 0.556). The index relative weight of explosion inspection is W= (0.625, 0.375). The index relative weight of access control is W= (0.375, 0.208, 0.292, 0.125). The index relative weight of electronic inspection is W= (0.667, 0.333). The index relative weight of parking management is W= (0.556, 0.444). The index relative weight of skill is W= (0.231, 0.115, 0.346, 0.308).

It is supposed that fuzzy comprehensive evaluation is applied to the first level index total protection capability. According to the criteria of total protection capability, the set of factor is $U=\{U_1,U_2,...U_m\}$. U_1 is personnel protection, U_2 is physical protection, U_3 is electronic protection. The set of remark is $V=\{V_1,V_2,V_3,V_4,V_5\}$. V_1 is very low, V_2 is low, V_3 is normal, V_4 is high, V_5 is very high. The experts evaluate impact on the set of factor U. the fuzzy matrix is as follows:

$$R=\begin{bmatrix}0.1 & 0.1 & 0.3 & 0.2 & 0.3\\ 0.2 & 0.4 & 0.1 & 0.2 & 0.1\\ 0.1 & 0.15 & 0.35 & 0.2 & 0.2\end{bmatrix}$$

According to the formula (19), we can obtain the fuzzy comprehensive evaluation result on crime prevention system B as follows:

$$B=W\bullet R$$

$$=(0.216,0.103,0.681)\bullet\begin{bmatrix}0.1 & 0.1 & 0.3 & 0.2 & 0.3\\ 0.2 & 0.4 & 0.1 & 0.2 & 0.1\\ 0.1 & 0.15 & 0.35 & 0.2 & 0.2\end{bmatrix}$$

= (0.216, 0.1, 0.35, 0.2, 0.216)

We get the V through normalization the B. The set of V is V= (0.20, 0.09, 0.35, 0.18, 0.20). We can determine the total protection capability on crime prevention system is normal according to the above results.

V. Combinatorial Optimization Technology Application On Risk Optimazation Model

In combinatorial optimization theory, the minimum cost flow model is the most basic model in all the network flow problems. This problem can be expressed as follows: we have to find a minimum cost of transportation program that a certain goods can be send from a supply to the demand vertex and make it meet the demand of these vertices. There are also similar to a risk optimization model on crime prevention system. The problem that can be solved by the risk optimization model is presented as follows: we need to find the attack path which has the largest protection capability on crime prevention system through resources scheduling between nodes. At the same time, it makes the average risk value decrease to a minimum on the entire crime prevention system. The establishment of risk optimization model is divided into the following three steps:

A. The Establishment Of Abstract Diagram on Crime Prevention System

The crime prevention system is abstracted into a security network diagram in order to simplify the problem. We make some assumptions as follows: firstly, any attacker starting from the outside regards the protection object as a target of attack. It exist at least one path from the attack starting point to protection object. Secondly, all nodes in the path have protection capability values that are calculated by the risk entropy model in advance. Finally, each edge has some protection weight, which is given in prior. It behalves of price which attacker pay to attack protection object through this path. The attacker needs to pay a price through the security network edges and nodes under any circumstances.

B. The Establishment Of Risk Optimization Model On Crime Prevention System

The abstract security network is regarded as network diagram, which is recorded as D=(V,A). V denotes the set of all nodes on crime prevention system. A indicates the set of all edges on crime prevention system. It is assumed that the protection capability values of each node are expressed as $x_1,x_2,.....x_n$. For each edge $(v_i,v_j)\in A$, the edge weight is recorded as $c(v_i,v_j)\ge 0$ (abbreviated as c_{ij}). The risk optimization model on crime prevention system is expressed as follows:

$$f=\max\sum_{\substack{(v_i,v_j)\in A\\ n\in V}} c_{ij}x_n \qquad (10)$$

$$\text{s.t}\quad\begin{cases}x_1+x_2+...+x_n=S\\ 0\le x_1\le m_1\\ 0\le x_2\le m_2\\ ....\\ 0\le x_n\le m_n\\ 0\le c_{ij}\le 1\end{cases}$$

In this formula, S is known in prior, which denotes the sum of protection capability values on the entire nodes. $m_1,m_2,.....m_n$ are also known in prior, which indicates the threshold of protection capability on each nodes.

C. Getting set of all the attack paths M

We get set of all the attack paths M from the attack point to the protection object through enumeration method according to the abstract diagram of security network. It recorded as M={ph_1,ph_2,…….ph_n}. ph_1, ph_2,……ph_n express attack paths.

D. Risk Optimization on Crime Prevention System

According to the set of M getting above, we use the risk optimization model to adjust the protection capability values on all the nodes so that the risk of crime prevention system is optimized. Then we obtain the maximum protection capability values on crime prevention system in different attack paths. At the same time, the risk of crime prevention system reaches minimum. The risk optimization model is a typical linear programming model corresponding to each attack path. So the calculation of optimization model uses simplex method.

E. Comparison The Protection Capability Values On All The Attack Paths Of Crime Prevention System

We get the maximum protection capability value through comparison the protection capability values on all the attack paths of crime prevention system. At the same time, the path is recorded as the largest attack path, along which the attacker needs to pay the greatest price to attack against protection object.

F. The Average Risk Of Crime Prevention System Decrease To Minimum

Taking into account the weight of each path are equal, the objective functions which different paths correspond to are weighted average in order to transform the multi-objective optimization problem into a single-objective optimization problem. Next, we get the global optimal solution through the optimization of objective function. It represents the optimal value of protection capability on crime prevention system. The average risk of crime prevention system decreases to minimum under these conditions.

VI. THE CONCRETE EXAMPLE FOR RISK OPTIMIZATION MODEL APPLICATION

In this section, we give a concrete example for risk optimization model application in order to verify the model reasonably. The risk optimization method on crime prevention system consists of the following four step4:

A. The Production of Abstract Diagram On Crime prevention system

As seen in Fig.3, we assume that the abstract diagram on crime prevention system is composed of five nodes. These are recorded as V={A,B,C,D,E}. The corresponding protection capability values are obtained through the risk entropy formula. x_1=3.1、x_2=2.7、x_3=4.2、x_4=1.2、x_5=1.8. The weight value of each edge has been given in the chart.

B. The Establishment Of Risk Optimization Model With Five Nodes On Cime Prevention System

The establishment of risk optimization model with five nodes on crime prevention system is as follows:

$$f=\max \sum_{\substack{(v_i,v_j)\in A \\ n\in V}} c_{ij}x_n \qquad (11)$$

$$\text{s.t} \begin{cases} x_1+x_2+\ldots+x_5=13 \\ 0\le x_1\le 3.5 \\ 0\le x_2\le 2.9 \\ 0\le x_3\le 3.2 \\ 0\le x_4\le 2.3 \\ 0\le x_5\le 2.7 \\ 0\le c_{ij}\le 1 \end{cases}$$

C. The The Calculation Of Risk Optimization Model On Crime Prevention System

(1). getting set of all the attack paths M

Firstly, we get set of all the attack paths M from the attack point to the protection object through enumeration method according to the abstract diagram of security network. It recorded as M={ph_1,ph_2,…….ph_5}. ph_1 denotes the path of S-A-C-E-T. ph_2 denotes the path of S-B-D-E-T. ph_3 denotes the path of S-A-D-E-T. ph_4 denotes the path of S-A-D-C-E-T. ph_5 denotes the path of S-B-D-C-E-T.

(2). the calculation of risk optimization model in different paths

Secondly, According to the set of M getting above, we use the risk optimization model to adjust the protection capability values on all the nodes so that the risk of crime prevention system is optimized. Then we obtain the maximum protection capability values on crime prevention system in different attack paths. The calculation of risk optimization model in different paths is as follows:

- The risk optimization model corresponding to the ph_1

$$f_1 = Max(0.7x_1+0.4x_3+0.3x_5) \qquad (12)$$

$$\text{s.t} \begin{cases} x_1+x_2+\ldots+x_5=13 \\ 0\le x_1\le 3.5 \\ 0\le x_2\le 2.9 \\ 0\le x_3\le 3.2 \\ 0\le x_4\le 2.3 \\ 0\le x_5\le 2.7 \\ 0\le c_{ij}\le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{1\max}=4.54$, x_1=3.5, x_2=1.3, x_3=3.2, x_4=2.3, x_5=2.7.

- The risk optimization model corresponding to the ph_2

$$f_2 = Max(0.5x_2+0.4x_4+0.6x_5) \qquad (13)$$

$$\text{s.t} \begin{cases} x_1+x_2+\ldots+x_5=13 \\ 0\le x_1\le 3.5 \\ 0\le x_2\le 2.9 \\ 0\le x_3\le 3.2 \\ 0\le x_4\le 2.3 \\ 0\le x_5\le 2.7 \\ 0\le c_{ij}\le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{2\max}=3.99$, x_1=3.5, x_2=2.9, x_3=1.6, x_4=2.3, x_5=2.7.

- The risk optimization model corresponding to the ph_3

$$f_3 = Max(0.7x_1 + 0.5x_4 + 0.6x_5) \qquad (14)$$

$$\text{s.t} \begin{cases} x_1 + x_2 + ... + x_5 = 13 \\ 0 \le x_1 \le 3.5 \\ 0 \le x_2 \le 2.9 \\ 0 \le x_3 \le 3.2 \\ 0 \le x_4 \le 2.3 \\ 0 \le x_5 \le 2.7 \\ 0 \le c_{ij} \le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{3\max} = 5.22$, x_1=3.5, x_2=2.9, x_3=1.6, x_4=2.3, x_5=2.7.

- The risk optimization model corresponding to the ph_4

$$f_4 = Max(0.7x_1 + 0.5x_4 + 0.2x_3 + 0.3x_5) \qquad (15)$$

$$\text{s.t} \begin{cases} x_1 + x_2 + ... + x_5 = 13 \\ 0 \le x_1 \le 3.5 \\ 0 \le x_2 \le 2.9 \\ 0 \le x_3 \le 3.2 \\ 0 \le x_4 \le 2.3 \\ 0 \le x_5 \le 2.7 \\ 0 \le c_{ij} \le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{4\max} = 5.05$, x_1=3.5, x_2=1.3, x_3=3.2, x_4=2.3, x_5=2.7.

- The risk optimization model corresponding to the ph_5

$$f_5 = Max(0.5x_2 + 0.4x_4 + 0.2x_3 + 0.3x_5) \qquad (16)$$

$$\text{s.t} \begin{cases} x_1 + x_2 + ... + x_5 = 13 \\ 0 \le x_1 \le 3.5 \\ 0 \le x_2 \le 2.9 \\ 0 \le x_3 \le 3.2 \\ 0 \le x_4 \le 2.3 \\ 0 \le x_5 \le 2.7 \\ 0 \le c_{ij} \le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{5\max} = 3.82$, x_1=1.9, x_2=2.9, x_3=3.2, x_4=2.3, x_5=2.7.

- Comparison the protection capability values on above-mentioned five paths

We get the maximum protection capability value through comparison the protection capability values on five paths of crime prevention system. It recorded as $f_{\max} = Max\{f_{1\max}, f_{2\max}, f_{3\max}, f_{4\max}, f_{5\max}\}$ .We get the $f_{\max} = 5.22$ based on the above calculation and analysis. The largest attack path is corresponding to ph_3.

- The average risk of crime prevention system

Taking into account the weight of each path are equal, the objective functions which five paths correspond to are weighted average in order to transform the multi-objective optimization problem into a single-objective optimization problem. A single-objective optimization model is as follows:

$$f_{\text{avg}} = Max(0.42x_1 + 0.2x_2 + 0.16x_3 + 0.32x_4 + 0.42x_5) \quad (17)$$

$$\text{s.t} \begin{cases} x_1 + x_2 + ... + x_5 = 13 \\ 0 \le x_1 \le 3.5 \\ 0 \le x_2 \le 2.9 \\ 0 \le x_3 \le 3.2 \\ 0 \le x_4 \le 2.3 \\ 0 \le x_5 \le 2.7 \\ 0 \le c_{ij} \le 1 \end{cases}$$

The above-mentioned optimization model is a typical linear programming model. We get the optimal solution of this model using simplex method as follows: $f_{avg} = 4.176$, x_1=3.5, x_2=2.9, x_3=1.6, x_4=2.3, x_5=2.7. At the same time, the optimal value of protection capability on crime prevention system is 4.176, and the average risk of crime prevention system decreases to minimum.

VII. Conclusion And Future Work

In this paper, we not only present an approach for effectiveness evaluation of crime prevention system based on fuzzy theory and risk entropy, but also discuss the change trend between risk entropy and protection capability through model simulation. Our modeling approach provides several advantages for crime prevention system effectiveness evaluation. The model first solves the problem of interference on subject factors in traditional qualitative methods for crime prevention system. The model also improves the assessment objectively through quantitative effectiveness evaluation of crime prevention system. It provides the decision-making basic theory for the design, development, and implementing of crime prevention systems in the future. Finally, we bring forward a risk optimization model on crime prevention system based on an abstract security network diagram. Furthermore, combinatorial optimization technology is used to calculate and analyze the model. Future work includes how to divide the level of capability protection and determine the index of capability protection of crime prevention system reasonably. This may require further discussions and a large amount of historical data.

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