

Optimization Model for the Selection of the Community Risk Registration Indicator and Its Application in Fire Risk*

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Abstract—According to the reality and requirement of our country’s community risk registration, this paper puts forward four principles for the selection of community risk registration indicator and then designs the evaluation “goodness” for evaluating the community risk registration indicator. On this basis, this paper constructs a multi-objective programming to select a comprehensive evaluation indicator system. Finally, this paper takes the community fire risk register as an example and couples with experts grading method to construct a scientific and feasible community fire risk registration form.

Keywords—fire risk; risk registration; evaluation “goodness”

I. INTRODUCTION

With the increasing of complexity and frequency of occurrence of the social harmfulness, risk management has been an important part of the comprehensive social management work. As a significant prerequisite and segment of risk management, risk registration plays a role of connecting between the preceding and the following in the whole process of risk management. Constructing risk registration system scientifically can help to guide the risk management more effectively.

Foreign Study on risk registration has been relatively mature, for example, London establishes a city risk management system based on the comprehensive risk registration, compiles and releases risk register every year, which enhances the emergency management capability [1-3]. The study of risk registration in our country is accelerating these years, for example, You Zhibin analyzes the main work of the federal government in promoting the construction of risk management[4]; Zhou Yonggen,etc. proposes the construction principle and the implementation advice of the standard system of risk management in cities[5].

This paper put forward four principles for the selection of community risk registration indicator and then designs the evaluation “goodness” for evaluating the community risk registration indicator. On this basis, this paper constructs a multi-objective programming to select a comprehensive evaluation indicator system. Finally, this paper takes the community fire risk register as an example and coupled with experts grading method to construct a scientific and feasible community fire risk registration form.

II. PRINCIPLES FOR THE SELECTION OF COMMUNITY RISK REGISTRATION INDICATOR

A. Scientificity

Scientificity means the indicator system can reflect the major aspects of the regional risks comprehensively, as well as the specific content of a particular aspect correctly.

B. Feasibility

Feasibility means the selected indicator is sure to be acquired and be obtained relevant data, even if the selected indicator is difficult to acquire, it should be able to be reflected from other aspects and eventually be quantified.

C. Stability

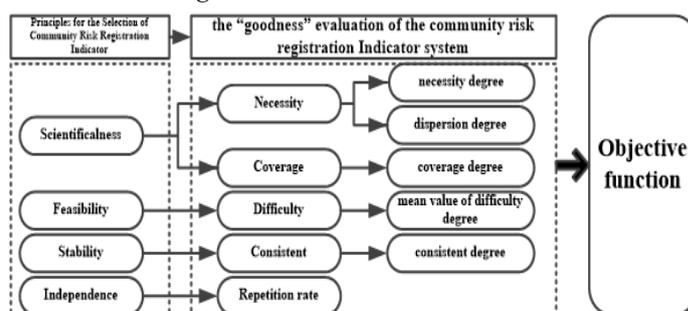
Stability means the selected indicator is not determined by accident factors, the selected indicator should be regulated by laws and regulations or be mentioned in relevant documents, it must be robustness.

D. Independence

Independence means the selected indicator should be one-to-one mapping with the evaluation factor theoretically, there is no one-to-many or many-to-one relationship between the selected indicator and the evaluation factor.

III. A MULTI-OBJECTIVE PROGRAMMING FOR THE SELECTION OF COMMUNITY RISK REGISTRATION INDICATOR BASED ON EVALUATION “GOODNESS”

A. Evaluation “goodness” indicator and calculation method



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1) *Necessity of indicator system.*

Necessity is measured by necessity degree and dispersion degree.

Necessity degree is evaluated by experts, the specific indicator should be evaluated by each expert and then calculate the mean value of evaluation of all experts. The higher the necessity degree is, the higher the necessity of indicator is.

If there are m indicator in an indicator system and q experts, and the necessity degree of indicator is divided into 5 levels, that is $j = (1, 2, 3, 4, 5)$ means the necessity degree of indicator is "extremely high", "very high", "high", "moderate", "low", thus, the formula of the necessity degree can be described as follows:

$$F_i = \frac{1}{q} \sum_{j=1}^5 E_j n_{ij} \quad (1)$$

$$F = \frac{1}{m} \sum_{i=1}^m F_i = \frac{1}{mq} \sum_{i=1}^m \sum_{j=1}^5 E_j n_{ij}$$

F_i is the mean value of the necessity degree of indicator i evaluated by q experts; E_j is the value of level j of indicator i ; n_{ij} is the number of experts who evaluate indicator i as level j ; F is the overall necessity degree of indicator system.

Dispersion degree is indicated by D and measured by standard error δ . Dispersion degree reflects the degree of experts' opinion when evaluating the necessity of the indicator system. The lower the dispersion degree is, the more consistent the expert's opinion is.

$$D_i = \delta_i = \sqrt{\frac{1}{q-1} \sum_{j=1}^5 n_{ij} (E_j - F_i)^2} \quad (2)$$

$$D = \sum_{i=1}^m D_i / m$$

D_i is the dispersion degree of indicator i evaluated by q experts, in general, $\delta_i > 0.63$ means the dispersion degree of indicator i is high and experts' opinion is inconsistent. D is the overall dispersion degree of indicator system.

2) *Coverage degree of indicator system*

The coverage degree means whether all the evaluation factors have corresponding evaluation indicators. In this paper, each evaluation factor has at least one corresponding evaluation indicator. Therefore, the coverage degree of the evaluation factors is 1.

3) *Difficulty degree of obtaining the indicator system*

The difficulty degree of obtaining the indicator is evaluated by experts and measured by the mean value of the difficulty degree. In general, the difficulty degree has 5 levels whose value are 1/2/3/4/5.

Defining $x_i (i = 1, 2, \dots, m)$ as follows:

$$x_i = \begin{cases} 1, & \text{index } i \text{ is choosen} \\ 0, & \text{index } i \text{ is not choosen} \end{cases} \quad (3)$$

Defining N_i as the difficult degree of indicator i . So the mean value of the difficulty degree of indicator is:

$$N = \sum_{i=1}^m N_i x_i / \sum_{i=1}^m x_i \quad (4)$$

If the mean value of the difficulty degree of indicator is less than 2, then we can say indicator i is easy to obtain.

4) *Consistent degree of indicator system*

Suppose there are m indicator evaluated by q experts, the score set evaluated by expert j is X_j , $X_j = \{x_{1j}, x_{2j}, \dots, x_{mj}\}$.

Taking the mean value of the score set as ideal data set:

$$t_i = \sum_{j=1}^q x_{ij} / q \quad (5)$$

Based on the formula above we can calculate the consistent degree ρ_j between each expert's score and the ideal data group:

$$\rho_j = \frac{\sum_{i=1}^m (x_{ij} - \bar{x}_i)(t_i - \bar{t})}{\sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_i)^2 \sum_{i=1}^m (t_i - \bar{t})^2}} \quad (j = 1, 2, \dots, q) \quad (6)$$

$$\bar{x}_i = \sum_{j=1}^q x_{ij} / q, \quad \bar{t} = \sum_{i=1}^m t_i / m$$

The overall consistent degree of the indicator system is ρ :

$$\rho = \sum_{j=1}^m \rho_j / q \quad (7)$$

In general, $\rho \in (0, 0.3)$ means the evaluations of experts are high consistent; $\rho \in (0.3, 0.6)$ means the evaluations of experts are moderately consistent; $\rho \in (0.6, 1)$ means the evaluations of experts are high inconsistent.

5) *Repetition rate of indicator system*

This paper suppose the selected indicator is one-to-one mapping with the evaluation factor, there is no one-to-many or many-to-one relationship between the selected indicator and the evaluation factor. Thus, the repetition rate is 0.

B. Multi-objective programming

In order to select a comprehensive indicators from many factors related to community, this paper uses the objective programming method [10-11].

1) Multi-objective programming

Because coverage degree and repetition rate have little effect on calculation result, so we choose necessity degree, dispersion degree, mean value of the difficulty degree and overall consistent degree as four objective functions, each objective is maximum necessity degree, minimum dispersion degree, minimum mean value of the difficulty degree and minimum overall consistent degree. So the mathematic model as follow:

$$\begin{aligned} & \max F; \min D; \min N; \min \rho \\ & \left\{ \begin{aligned} & \frac{1}{mq} \sum_{i=1}^m \sum_{j=1}^5 E_j n_{ij} \geq 0.5 \\ & \sqrt{\frac{1}{q-1} \sum_{j=1}^5 n_{ij} (E_j - F_i)^2} \leq 0.1 \\ & \frac{\sum_{i=1}^m N_i x_i}{\sum_{i=1}^m x_i} \leq 2 \\ & \frac{\sum_{j=1}^q \sum_{i=1}^m (x_{ij} - \bar{x}_i)(t_i - \bar{t})}{q \sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_i)^2 \sum_{i=1}^m (t_i - \bar{t})^2}} \leq 0.3 \end{aligned} \right. \quad (8) \end{aligned}$$

2) Optimizing multi-objective programming

A single objective programming model is obtained by optimizing the above multi-objective programming. In general, the priority of the above evaluation "goodness" is from high to low as follows: necessity degree, mean value of the difficulty degree and overall consistent degree, dispersion degree.

$$\begin{aligned} & \min [p_1 d_1^- + p_2 (d_2^- + d_3^-) + p_3 d_4^+] \\ & \text{s.t.} \\ & \left\{ \begin{aligned} & \frac{1}{mq} \sum_{i=1}^m \sum_{j=1}^5 E_j n_{ij} + d_1^- - d_1^+ = 0.5 \\ & \sqrt{\frac{1}{q-1} \sum_{j=1}^5 n_{ij} (E_j - F_i)^2} + d_4^- - d_4^+ = 0.1 \\ & \left(\frac{\sum_{i=1}^m N_i x_i}{\sum_{i=1}^m x_i} \right) + d_2^- - d_2^+ = 2 \\ & \frac{\sum_{j=1}^q \sum_{i=1}^m (x_{ij} - \bar{x}_i)(t_i - \bar{t})}{q \sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_i)^2 \sum_{i=1}^m (t_i - \bar{t})^2}} + d_3^- - d_3^+ = 0.3 \end{aligned} \right. \quad (9) \end{aligned}$$

IV. SELECTION OF THE COMMUNITY FIRE RISK REGISTRATION INDICATOR SYSTEM

A. Experts grading and calculation

In the analysis of community fire risk, the evaluation factors are divided into five categories which are residential area features, population density, meteorological factors, municipal fire fighting capability and mobile fire fighting capability. Each category has an evaluation indicator system including several different indicators.

Designing a questionnaire and give it to experts to evaluate each indicator, calculating the necessity degree, dispersion degree, difficulty degree and overall consistent degree. The number below in table is the average score evaluated with the above formulas by all the experts.

TABLE I. EXPERT SCORING TABLE

Evaluation Factors	Indicators Set	Necessity Degree	Difficulty Degree	Consistent Degree	Dispersion Degree
Residential Area Features	Building volume ratio	0.93	1.00	0.000	0.163
	Proportion of fire-resistant building	1.00	1.00	0.283	0.000
	Years of power supply circuit in building	0.93	1.00	0.000	0.163
	Gas network density	1.00	1.67	0.346	0.000
	Community greening rate	0.20	1.00	0.346	0.000
	Community building interval	0.20	1.00	0.200	0.000
	Building orientation	0.20	1.00	0.490	0.000
	Community road width	0.27	1.00	0.346	0.163
	Proportion of high risk building	0.87	1.33	0.283	0.163
	Community building design	0.20	4.33	0.200	0.000
	Community monitoring system	0.20	3.33	0.200	0.000
	Intact rate of community fire facility	1.00	1.67	0.000	0.000
	Community safety monitoring and alarm system	0.33	1.67	0.490	0.163
	Community education facilities	0.20	1.00	0.490	0.000
Community medical facilities	0.40	1.00	0.600	0.000	
Passing rate of fire road	1.00	1.00	0.283	0.000	
Community property management	0.20	2.00	0.346	0.000	
Community post business service	0.27	1.67	0.346	0.163	
Community peripheral business service	0.20	1.67	0.566	0.000	
Community male and female ratio	0.33	4.00	0.346	0.163	
Number of elderly people in the community	0.45	4.67	0.346	0.163	
Number of children in the community	0.47	4.67	0.346	0.163	
Community floating population	0.47	4.67	0.346	0.163	
Population From Other Places in the community	0.47	5.00	0.346	0.163	
Relative humidity	0.93	1.33	0.000	0.163	
Wind	1.00	1.33	0.200	0.000	
Number of fire fighting water resources	0.87	1.00	0.283	0.163	
Temperature	0.33	1.33	0.346	0.163	
Air pressure	0.20	1.33	0.346	0.000	
Solar radiation	0.20	2.33	0.346	0.000	
Pipeline fire fighting water supply capacity	0.93	1.67	0.000	0.163	
Intact rate of fire hydrant	0.93	1.67	0.000	0.163	
Number of drainage pipes	0.33	2.00	0.490	0.163	
Quantity of gas pipeline	0.40	1.67	0.490	0.000	
Fire station	0.80	1.33	0.000	0.000	
Fire equipment	0.87	1.00	0.000	0.163	
Fireman	1.00	1.00	0.283	0.000	
Service construction	0.8	2.00	0.283	0.000	

B. Calculating with optimized objective programming

Importing the above value into Excel to calculate the optimal solution. The final result is:

In the evaluation factor "residential area feature", we select "building volume rate", "proportion of fire-resistant building", "years of power supply circuit in building", "gas network density", "proportion of high risk building", "intact rate of community fire facility", "passing rate of fire road" these 7 indicators;

In the evaluation factor "Meteorological Factors", we select "relative humidity", "wind", "number of fire fighting water resources" these 3 indicators;

In the evaluation factor "municipal fire fighting capacity", we select "pipeline fire fighting water supply capacity", "intact rate of fire hydrant" these 2 indicators;

In the evaluation factor "mobile fire fighting capability", we select "fire station", "fire equipment", "fireman", "service construction" these 4 indicators.

C. Filling in the community fire risk registration form

By using objective programming, we select 16 indicators which are closely related to the community fire risk. Actually, the community fire risk is not always evaluated by the experts on the risk management field. Therefore, it is necessary to further simplify the above table and get the risk registration form suitable for the general public. In this paper, some technical terms will be simplified.

TABLE II. CONTENT OF THE COMMUNITY FIRE RISK REGISTRATION FORM

Fire risk indicators	Content on fire registration form	Registrant	
Building volume ratio	Building volume ratio	Community committee	neighborhood committee
Proportion of fire-resistant building	Community building structure	Community committee	neighborhood committee
Years of power supply circuit in building	Years has been built up	Community committee	neighborhood committee
Gas network density	Total length of gas pipe	Community committee	neighborhood committee
High rise building	Proportion of buildings which are more than 7 storey	Community committee	neighborhood committee
Public buildings	Quantity of nearby shopping center / post office / Kindergarten / Chess Room / hospital, etc.	Community committee	neighborhood committee
Intact rate of fire hydrant	Quantity of automatic alarm system / indoor fire hydrant / outdoor fire hydrant	Community committee	neighborhood committee
Passing rate of fire road	Fire road width and whether or not be blocked	Community committee	neighborhood committee
Population density	Population of community registered	Community committee	neighborhood committee
Relative humidity	Community monthly rainfall situation	Community committee	neighborhood committee
Wind	Community monthly wind situation	Community committee	neighborhood committee
Number of fire fighting water resources	Number of fire water resources	Fire department	
Pipeline fire fighting water supply capacity	Number of fire pipeline	Fire department	
Protection area	preparing time consuming	Fire department	
Built-up area	Fire station building area	Fire department	
Response time of adjacent group	Response time of adjacent group	Fire department	
Quantity of fire engine	Quantity of fire engine	Fire department	
Quality of fire fighting equipment	Bubble car / water-tank lorry quality	Fire department	
Number of people be protected by per fireman	Number of people be protected by per fireman	Fire department	
Working years	Firefighters' number work for more than 3 years / 5 years	Fire department	
Guarantee Rate of training time	Firemen's training time every day	Fire department	
Plan	Distribution of key divisions of fire station	Fire department	

Through the above table we can finally get the community fire risk registration form as follows:

TABLE III. COMMUNITY FIRE RISK REGISTRATION FORM

Community name:	Population of community registered:	Community built year:	year
Community area: km ²	Building volume ratio:	Total length of gas pipe:	km
Number of fire roads:	Fire road width: m	Fire road width and whether or not be blocked:	①yes ②no
1. Community building structure: ①steel reinforced concrete; ②steel structure roof; ③wooden structure roof			
2. Proportion of building more than seven storey: ①≥70%; ②70%-50%; ③50%-30%; ④30%-10%; ⑤<10%			
3. Quantity of nearby shopping center ①≥3; ②2; ③1; ④0;			
4. Quantity of nearby post office ①≥3; ②2; ③1; ④0;			
5. Quantity of nearby Kindergarten ①≥3; ②2; ③1; ④0;			
6. Quantity of nearby chess room ①≥3; ②2; ③1; ④0;			
7. Quantity of nearby hospital ①≥3; ②2; ③1; ④0;			
8. Community automatic alarm system ①intact; ②small part is damaged; ③large part is damaged; ④no automatic alarm system			
9. Community indoor fire hydrant ①intact; ②small part is damaged; ③large part is damaged; ④no indoor fire hydrant			
10. Community outdoor fire hydrant ①intact; ②small part is damaged; ③large part is damaged; ④no outdoor fire hydrant			
11. Community rainfall times monthly ①≥4 times; ②3 times; ③2 times; ④1 times; ⑤0 times;			
12. Community average wind speed monthly ①extremely high; ②high; ③moderate; ④low;			

Below is filled in by the fire department

1. Number of firefighters	①≥5000; ②4000-5000; ③3000-4000; ④≤3000;
2. Firefighters' number work for more than 3 years	Firefighters' number work for more than 5 years
3. Community fire safety level	①level I ; ②level II ; ③level III
4. Number of fire fighting water resources	①≥3; ②2; ③1; ④0;
5. Number of fire pipeline	①≥5; ②4; ③3; ④2; ⑤≤1;
6. preparing time consuming	①≥5min; ②5-4min; ③4-3min; ④3-2min; ⑤≤2min
7. Fire station building area	①4500-5200m ² ; ②2400-4500m ² ; ③1400-2400m ² ; ④0-1400m ²
8. Response time of adjacent group	①≥30min; ②30-20min; ③20-15min; ④15-10min; ⑤≤10min
9. Quantity of fire engine	①≥6; ②6-4; ③4-2; ④≤2;
10. Bubble car quality	①≥40L/s; ②30-40L/s; ③<30L/s; ④no;
11. water-tank lorry quality	①≥5000L; ②3500-5000L; ③<3500L; ④no;
12. Firemen's training time every day	①≥8h; ②6-8h; ③4-6h; ④≤4h

Note: Check directly "no" or "0" if the item is none.

V. CONCLUSION

In this paper, we firstly obtain a comprehensive indicator system by using expert grading method and objective programming, and then get a scientific and reasonable risk registration form, which can provide a standard system for the assessment of community fire risk, make the risk assessment quantified, improve the efficiency and effect of risk management, make sure to make the right decisions faced with risk and improve the response capability.

At the same time, the method in this paper provide a reference for the construction of the risk register in other fields.

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