ISSN 2522-3488 Vol. 7, Issue 2: 28-34, DOI: 10.25236/IJNDES.2023.070206

Research on Fire Alarm System Based on Entropy Power Method and Topsis Superiority and Inferiority Solution Distance Method

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Abstract: *According to the statistics of China Fire and Rescue Bureau, in 2021, 748,000 fires were reported to the national fire and rescue teams, with 1,987 deaths, 2,225 injuries and direct property losses of 6.75 billion yuan. The loss of these innocent lives and the loss of a large amount of property make us think while deploring: is there a more effective, scientific and accurate way to prevent the great harm caused by the occurrence of fire. The fire alarm system studied in this paper can be used to reduce the hazards. Firstly, the number of real fires is given 430 times by using three indicators of fire occurrence: address, machine number and loop. After selecting the high-frequency parts in the loop, machine number and component type respectively and finding their corresponding false alarm rate and failure rate, the evaluation weights are obtained using the entropy weight method. A comprehensive evaluation model based on the entropy weight method is established to score each major component. Two most reliable components of the fire alarm system are obtained: the intelligent photoelectric probe and the manual alarm button. Next, the normalized management level of each fire brigade needs to be analyzed. First, the five important parameters of normalized average coverage rate, normalized component reliability, normalized component failure rate, normalized jurisdictional fire frequency (times/hour), and normalized false alarm rate are derived for each fire brigade. The comprehensive score index of each brigade was derived and ranked by the Topsis superiority and inferiority solution distance method, and it was concluded that M brigade, L brigade, and F brigade were the three jurisdictions with the lowest comprehensive management level.*

Keywords: *Entropy Power Method, Topsis Superiority and Inferiority Solution Distance Method, Fire Alarm System*

1. Introduction

The With the development of machine learning and hardware technologies and the massive popularity of fire alarm systems in recent years, the situation that fires are not easily detected and thus cause greater loss of life and property can be effectively improved. Under the assumption of proper detector installation and compliance with standards, the following issues are modeled and studied in this paper with respect to the probability of fire occurrence and the reliability of fire detectors[1].

We first analyze the real number of fires in a city in 18 days; then combine the real number of fires and the number of failures of fire detector components, score the reliability and failure rate of each component separately by building an entropy weighting method model, and select the detectors with higher scores to provide to the government[2].Next, the fire data was sorted according to each jurisdiction and combined with the areas under the responsibility of the fire brigade, the comprehensive management level of each brigade in terms of fire was quantified and analyzed using the evaluation model to identify the three jurisdictions with low management levels and to give suggestions for improvement based on the indicators of low scores[3].

To select the most reliable fire alarm, this paper selects machine number, circuit, part name and affiliated fire agency as evaluation factors to analyze the reliability rate and failure rate of each part respectively, and finally use the entropy weight method scoring model to score the reliability rate and failure rate together to give the reliable fire detector type[4].

The management level of different jurisdictions is analyzed, and the number of fire alarms and the number of real occurrences are now classified according to different fire brigade jurisdictions. In order to better evaluate the strengths and weaknesses of each district, five indicators are selected in this paper: jurisdictional fire frequency, average fire alarm coverage, component failure rate, component reliability rate, and jurisdictional fire false alarm rate. The TOPSIS solution distance method model, which can be used to effectively determine the merit, was also selected to determine the overall score of each jurisdiction and to identify the three jurisdictions with the lowest scores[5].

2. The Materials and Methods

2.1 Entropy method model

Evaluation problems are often encountered in engineering, and objective decision making on the evaluated object is achieved through different evaluation methods, in which weights are used to measure the degree of importance occupied by a certain indicator in the system of indicator terms[6]. The entropy weighting method determines the weight by the magnitude of the differentiation of indicators. The smaller the entropy value of the evaluation indicator, the greater the variation difference of the indicator[7].

In this paper, we were asked to evaluate different automatic fire alarm devices, and we selected four main objects n for evaluation: models, circuits, component names, and affiliation to fire brigades. Firstly, the models are classified into 10 different models mainly (other models are not considered as main types because the total number in Annex 1 is less than 100): 1, 5, 4, 3, 2, 94, 10, 0, 6 and 9. Then, the reliability and failure rate of each model were found separately according to what was described in 5.1.3 and normalized to these two types of data for the 10 different models with the following processing formula[8].

$$x_i^* = \frac{x_i - x_{min}}{x_i - x_{max}} \tag{1}$$

The results of the standardized processing of machine models are shown in the table 1.

Table 1: Model normalization results

Model	Reliability normalization	Failure rate normalization
1	1	0.12887
5	0.007065	0.723454
4	0.01464	0
3	0.030252	0.01882
2	0.047254	0.044135
94	0.000822	1
10	0.001691	0.381322
0	0.21571	0.400617
6	0.006139	0.119018
9	0	0.004822

Next, the three remaining evaluation objects: loops, component names (both loops and component names ignore the lesser number of categories and retain the greater number as the main category) and the affiliated fire brigade are normalized for reliability and failure rate, respectively, and the results are processed as Table 2 and Table 3 and Table 4.

Table 2: Loop normalisation results

Loop	False alarm rate normalization	Failure rate normalization
8	0.368718	0.19619
2	1	0
6	0.061753	0.578962
7	0.019021	0.843532
5	0.046585	0.584452
1	0.285423	0.092286
3	0.043635	0.613159
9 Summary	0	1
4 Summary	0.020966	0.772857

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Table 3: Part type normalisation result

Part Type	False alarm rate normalization	Failure rate normalization
Summary of point type temperature detectors	0.001510831	0.340254
Summary of point type smoke detectors	1	1
Manual alarm button summary	0	0
Smart Photoelectric Probes Summary	0.020615239	0

Table 4: False alarm rate normalisation results

Team	False alarm rate normalization	Failure rate normalization	Team	False alarm rate normalization	Failure rate normalization
I	1	0	E	0.00564	0.060877
G	0.441554	0.072362	O	0.008759	0.708173
B	0.073576	0.039615	A	0.026075	0.06706
M	0.100195	0.511965	K	0.010691	0.031746
J	0.047009	0.483746	C	0.02832	0.546642
H	0.01516	0.307592	D	0.006207	1
F	0.017831	0.73593	P	0.011258	0.21436
N	0.050523	0.391959	Q	0.01134	0.588339
L	0.018741	0.920846	R	0	0.021788

After standardizing these four main evaluation indicators, the normalized values were used to replace the corresponding positions in Annex 1 with the names of each classification.

2.2 TOPSIS superior and inferior solution distance method model

TOPSIS model when by assuming positive and negative ideal solutions, measuring the distance between each sample and positive and negative ideal solutions[9], to get its relative posting progress with the ideal solution, that is, the closer to the positive ideal solution at the same time the farther away from the negative ideal solution, to carry out the superiority and inferiority ranking of each evaluation object, and this question requires the superiority and inferiority analysis of the 18 brigades, so the TOPSIS comprehensive analysis method can be used, the specific steps are as follows[10].

(1) Index isotropization and standardization to get weights: This step is a combination with the entropy weighting method in 5.1 to get the standardization matrix, and the weights are derived based on the matrix.

(2) Obtain the weighted normalization matrix Z:

$$Z = (Z_{ij})_{n\times m} = (P_{ij} \times \omega_j) \tag{2}$$

(3) Determine the positive and negative ideal solutions: positive ideal solution means that each indicator reaches the best value in the sample, and negative ideal solution means that each indicator is the worst value in the sample.

(4) Calculate the distance of each sample from the positive and negative ideal solution: the formula is as follows

$$D_i^+ = \sqrt{\sum_{j=1}^{m}(z_{ij} - z_j^+)^2}, D_i^- = \sqrt{\sum_{j=1}^{m}(z_{ij} - z_j^-)^2}, (i = 1, \cdots, n) \tag{3}$$

(5) Calculate the closeness of each evaluation object to the optimal solution: where the range of values

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is [0,1], and the closer to 1 indicates the better sample score.

3. Model construction and solving

3.1 Entropy method model construction and solution

The entropy weight method is a method to calculate the entropy weight of each indicator based on the degree of variation of each indicator using information entropy. The general calculation process of the entropy weight method is as follows.

(1) Construction of indicator data matrix for all cleaned data.

$$A = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{pmatrix} \tag{4}$$

First, the four parameters involved in the false alarm rate for its entropy value, the data is normalized, as this question we want to seek the false alarm rate and failure rate scores respectively, so the selected are negative indicators, the formula is.

$$x_{ij} = \frac{max(x_j) - x_{ij}}{max(x_j) - min(x_j)} \tag{5}$$

(2) Calculate the weight of the ith program under the jth indicator for that indicator.

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \,(i = 1,2,\cdots,n; j = 1,2,\cdots m) \tag{6}$$

(3) Calculate the entropy value of the jth indicator.

$$e_j = -k \sum_{i=1}^{n} P_{ij} ln(P_{ij}) \tag{7}$$

Among them$\frac{1}{ln(m)} > 0,0 \le e_j \le 1$

(4) Calculate the coefficient of variation of the jth indicator.

$$d_j = 1 - e_j \tag{8}$$

(5) Calculation of weights.

$$\omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{9}$$

The entropy weighting method using SPSSPRO is solved to derive the corresponding information entropy value e, information utility value d and entropy weight for each indicatorω values show as Table 5.

Table 5: False alarm rate entropy method weights

False alarm rate			
Indicator Name	Information entropy value e	Information utility value d	Weights
Model	0.968	0.032	0.189
Brigade number	0.997	0.003	0.02
Loop	0.981	0.019	0.115
Parts	0.886	0.114	0.677

The same steps were used to solve the entropy method using SPSSPRO for the four indicators involved in the failure rate, i.e., circuit, model, part name, and affiliated fire department, and the weights of the indicators were derivedω values in the following table 6.

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Table 6: Failure rate entropy weight method

Failure rate			
Indicator Name	Information entropy value e	Information utility value d	Weights
Model	0.997	0.003	0.019
Brigade number	0.989	0.011	0.073
Loop	0.98	0.02	0.132
Parts	0.885	0.115	0.776

3.2 TOPSIS superior and inferior solution distance method model construction and solution

The normalized information entropy values e, information utility values d and weights of the five indicators were first derived using the entropy weighting method as Table 7.

Table 7: Determination of indicator weights

Entropy method			
item	Information entropy value e	Information utility value d	Weights
Normalized Component Reliability	0.858	0.142	0.222
Normalized component failure rate	0.942	0.058	0.091
Normalization of the frequency of fires in the jurisdiction	0.963	0.037	0.058
Normalized average coverage	0.62	0.38	0.594
Normalized false alarm rate	0.978	0.022	0.034

Output intermediate result display in Table 8.

Table 8: Display of Indicator Results

item	Positive ideal solution	Negative ideal solution
Normalized average coverage	0.67944308	0.00006794
Normalized Component Reliability	0.79771443	0.00007976
Normalized component failure rate	0.33450063	0.00003345
Normalization of the frequency of fires in the jurisdiction	0.31105619	0.0000311
False alarm rate normalization	0.25422625	0.00002542

The results of TOPSIS superior and inferior solution distance method are calculated in the following table 9.

Table 9: TOPSIS calculation results

Brigade	Positive ideal distance(D+)	Negative ideal distance(D-)	Overall Score Index	Sort by
M	0.61278115	0.078070132	0.113005698	18
L	0.620436451	0.093257613	0.130668893	17
F	0.622632851	0.0958918	0.13345652	16
C	0.591963229	0.110152596	0.156886645	15
O	0.603636025	0.113718473	0.158524793	14
H	0.623636124	0.103618371	0.131524563	13
D	0.628960212	0.153718452	0.157554721	12
B	0.603636452	0.143718413	0.158484713	11
I	0.613636075	0.133718415	0.148323798	10
A	0.653636125	0.123718423	0.138224754	9
E	0.64078163	0.113718473	0.128124743	8
N	0.546689664	0.131718177	0.194157805	7
K	0.602239891	0.148325772	0.197618648	6
Q	0.577549596	0.160574435	0.217543974	5
G	0.432047929	0.323654498	0.428282994	4
R	0.332089892	0.440852175	0.570356038	3
J	0.342589498	0.531682334	0.608143045	2
P	0.269366613	0.452799619	0.627001927	1

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4. Results and Analysis

4.1 Entropy method model analysis

After the entropy value of the indicators related to false alarm rate and failure rate is found in the entropy weight method, the data in each Annex 1.2 can be scored, and the scoring is calculated by multiplying the normalized values of different models, loops, component names and affiliated fire brigades in 5.1.4 (a) by the corresponding entropy weight sum. Because the optimal part name is eventually given, the four main parts: point type temperature detector, point type smoke detector, manual alarm button and intelligent photoelectric probe all data are classified and summed, that is, all point type temperature detector will be summed up for its failure rate score and its false alarm rate score; after summing up, the average of the false alarm rate and failure rate scores of the parts are calculated in turn as indicators and filled in the table below. After finding out the average value of false alarm rate and failure rate of each typical component, we assume that both of them have equal weights to find out the final total score, and the table is as follows in Table 10.

Table 10: Overall rating

Part Name	False alarm rate score mean	Failure rate score mean	Overall Rating
Point type temperature sensor	0.053467	0.179061	0.116264
Point type smoke detector	0.560763	0.620781	0.590772
Manual Alarms	0.07774	0.065266	0.071503
Intelligent photoelectric probe	0.073679	0.060989	0.067334

Since we selected the scoring items for false alarm rate and failure rate, the smaller these two figures represent the superior performance of the components as fire alarms, so we recommend government departments to install more intelligent photoelectric probes and manual alarms as reliable types of fire detectors.

4.2 TOPSIS superior and inferior solution distance method model analysis

Based on the results derived from TOPSIS, it can be concluded that Brigade M, Brigade L, and Brigade F are the three jurisdictions with the lowest level of comprehensive management. From the comparison of the normalized values of fire frequency, average fire alarm coverage, component failure rate, component reliability rate, and false alarm rate for each jurisdiction in 5.3.1, we can conclude that M Brigade has a higher frequency of fires in its jurisdiction compared to other teams, and the fire department in this jurisdiction can increase the education of fire prevention awareness to the residents in the area to reduce the frequency of fires at the source; meanwhile, the detector reliability of M Brigade is The average coverage rate of fire detectors in the jurisdiction of L brigade is low, and the regional government should increase the coverage density of detectors to ensure safety; in addition, the probability of failure of the detector components installed in L and F brigades is also high, so they can also choose to replace them with detectors with higher ratings. The above measures will not only improve the rating of the region, but also achieve more scientific and accurate detection of fire to protect people's lives and property.

5. Conclusion and Discussion

5.1 Model Benefits

Entropy weighting method: The first question in this paper is used in finding the weights, which is more accurate and objective compared to those subjective assignment methods, and can better explain the results obtained. It can be used for any process that requires the determination of weights, such as reliability and failure rate in this question. The ability to determine the indicator weights based on the degree of variation in the indicator values of each indicator is an objective assignment method that avoids the bias caused by human factors and thus provides a more objective evaluation of each type of component.

TOPSIS evaluation: Question three needs to evaluate the merits of the comprehensive management

ISSN 2522-3488 Vol. 7, Issue 2: 28-34, DOI: 10.25236/IJNDES.2023.070206

capability of the 18 fire brigades, which is equivalent to determining the level to which each evaluation object belongs. TOPSIS can carry out the comparison of the merits of the quality between objects among different evaluation objects, and the principle is simple. TOPSIS can evaluate multiple objects at the same time, with fast calculation, high resolution, good reasonableness and applicability, and high practical value.

5.2 Model shortcomings and improvements

Entropy weight method: Ignoring the importance of the indicators themselves, sometimes the determined indicator weights can be far from the expected results, while the entropy method cannot reduce the number of dimensions of the evaluation indicators.

TOPSIS evaluation: It can only reflect the relative proximity within the evaluation object, and does not reflect the relative proximity to the ideal optimal solution

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