ISSN: 2710-0588

Comprehensive Evaluation of Fire Alarm Systems

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Abstract

In this paper, through the methods of Topsis evaluation method, rank and ratio comprehensive evaluation method, and entropy weight method, a relevant model is established to quantitatively evaluate each type of fire detector components, alarm signal authenticity, and the comprehensive management level of fire brigade, and to propose an improvement plan.

Keywords

Fire Detector; Topsis Method; RSR Comprehensive Evaluation Method; Entropy Weight Method.

1. Introduction

1.1. Background of the Problem

With the rapid development of China's fire detection and alarm industry, various products from home and abroad are beginning to enter the market and be used in buildings. Fire detectors can convert or process the received characteristic signals and make judgments by fire alarm controllers to determine whether a fire has occurred. The sensitivity and reliability of detectors are important indicators to evaluate their merits. Therefore, when selecting a detector, it is necessary to consider the key parameters of both. If the key parameters are selected well, the fire detector can be selected to best meet the conditions of use, which has an important impact on the optimization of the fire protection system.

1.2. Problem Restatement

Question 1: Based on the alarm data, determine the real number of fires in the city. And combine the fault data and fire information schematic to establish a suitable model to quantify the evaluation index of each type of component using reliability and failure rate, so as to select the reliable type.

Problem 2: Combining with the conclusion of Problem 1, a suitable intelligent research model for the type of regional alarm components is established to determine whether there are false alarms and to determine the probability that the alarm signal in Annex III is real.

Problem Three: Based on the results of Problem One and Problem Two, and the brigade's jurisdictional data table, build a model to quantify the technical indicators of the three jurisdictions with the lowest level of comprehensive management and optimize them.

Problem Four: Based on the model, make reasonable recommendations for maintaining the components of the fire alarm system.

2. Problem Hypothesis

(1) Assume that the alarm time is negligible

(2) Assume that a normally working detector will definitely alarm when it detects a fire

(3) Assume that the jurisdictional areas of the fire brigades do not overlap

(4) Assume that the signal reception accuracy of each component is not affected by distance

ISSN: 2710-0588

3. Symbol Description

Table 1. Description of symbols used in the article

Serial number	**Symbols**	Meaning
1	a_i	Reliability of the component
2	b_i	Failure rate of the component
3	x_i	Positivization indicators
4	Z_{ij}	Standardized Metrics
5	G	Un-normalized score
6	S_i	Normalized score of term

4. Mathematical Model of Problem One

4.1. Brief Background

We first aggregated the number of real fires in the city from June 1 to June 18, and filtered the data in Annex 2 according to the 15 components mentioned in Annex 1, thus eliminating irrelevant data and narrowing the data range. Then, the quantitative criteria of reliability and failure rate were determined and the data of Annex 1 and Annex 2 were processed in a uniform manner. Then, reliability and failure rate are scored as variable indicators for each component type by applying TOPSIS model [1] to provide reference for the government to select more reliable types of fire detectors.

Table 2. Selection basis

Serial number	Part Type
1	Point smoke detector
2	Point type smoke
3	Point temperature detector
4	Point temperature detector
5	Point smoke detector
6	Point type temperature smoke
7	Multiple-sensor
8	Flame detector
9	Gas detection
10	Manual call point
11	Linear beam smoke detector
12	Hydrant
13	The signal valve
14	Pressure switch
15	Intelligent photoelectric probe

4.2. Model Solving

4.2.1. Data Areprocessing

First, we filtered the required data according to the part names in Annex 1, deleted the data with the same machine number, circuit, and address using Excel tools to derive the true number of fires, and then quantified the reliability and failure rate by the following formula.

Reliability calculations:

$$a_i = \frac{X_{iF}}{X_{iA}}$$

ISSN: 2710-0588

X_{iF} is the number of times the i component has no false alarms and is the total number of fire alarms of the i component.

Failure rate calculation:

$$b_i = \sum_{i=0}^{n} b_{ij}$$

b_{ij} is the percentage of failures of the i component in the case of different machine numbers and circuits.

The final data is organized as follows.

Table 3. Detector reliability and failure rate

Serial number	Part Type	Reliability	Failure rate
1	Point smoke detector	0	5.63E-07
2	Point type smoke	0.005231798	0.064900831
3	Point temperature detector	0.001245892	0.00015423
4	Point temperature detector	0	2.53297E-06
5	Point smoke detector	0	0.000442988
6	Point type temperature smoke	0.05	0
7	Multiple-sensor	0	2.81441E-07
8	Flame detector	0	0.00137512
9	Gas detection	0.008985684	0.05883381
10	Manual call point	0.001556824	0.000628739
11	Linear beam smoke detector	0	0.052065438
12	Hydrant	0	0.001437319
13	The signal valve	0	0.00212319
14	Pressure switch	0	0
15	Intelligent photoelectric probe	0	0
16	Point smoke detector	0.009621381	0.00107426

4.2.2. TOPSIS Model Building

Table 4. Normalized matrix data

0.00000	0.06490
0.00523	0.00000
0.00125	0.06475
0.00000	0.06490
0.00000	0.06446
0.05000	0.06490
0.00000	0.06490
0.00000	0.06353
0.00899	0.00607
0.00156	0.06427
0.00000	0.01284
0.00000	0.06346
0.00000	0.06278
0.00000	0.06490
0.00000	0.06490
0.00962	0.06383

ISSN: 2710-0588

According to the data in the above table, we can analyze that the reliability is the extreme value indicator and the failure rate is the minimal value indicator, we need to convert the minimal value indicator into the extreme value indicator and normalize both indicators. The formula for converting the minimal value indicator into the maximal value indicator is as follows.

$$x_i = max - x_i$$

PS: M is the farthest distance from the interval:$\max(a - \min(x_i), \max(x_i) - b)$

When x is in the interval, the value after forwarding is 1

When x is less than the lower limit a of the interval,$x_i = 1 - \frac{a - x_i}{M}$

When x is greater than the upper limit of the interval,$x_i = 1 - \frac{x_i - b}{M}$

The final normalized data are as in Table 4.

Our resulting positive talk indicators were converted into a normalization matrix and normalized by the following formula:

$$Z_{ij} = \frac{x_{ij}}{\sqrt{\sum_1^n x_{ij}^2}}$$

The final normalized data obtained are as follows.

Table 5. Standardized Data

0.00000	0.27921
0.10060	0.00000
0.02396	0.27855
0.00000	0.27920
0.00000	0.27731
0.96142	0.27921
0.00000	0.27921
0.00000	0.27330
0.17278	0.02610
0.02994	0.27651
0.00000	0.05522
0.00000	0.27303
0.00000	0.27008
0.00000	0.27921
0.00000	0.27921
0.18500	0.27459

We calculate the scores of the 16 components according to the two main indicators, and the calculation principle is that the optimal solution is the maximum value, and the worst solution is the minimum value.

a. **Construction of scoring formula:**$\boldsymbol{S = \frac{x - min}{max - min}}$

b. **Deformation of scoring formula:**$\boldsymbol{S = \frac{x - min}{(max - x) + (x - min)}}$

c. **Calculate D+ and D-:**

Define the maximum value: the Z+ vector is used to hold the maximum value of each column in the normalized matrix

ISSN: 2710-0588

Define the minimum: Z- vector to hold the minimum value of each column in the normalized matrix

Define the i distance of the evaluation object from the maximum value: equal to 0.5 times the sum of the squares of the differences between each element of the first row and the maximum value of the column in which it is located. (i=1,2,...,16)

Define the distance of the i evaluation object from the maximum value: equal to 0.5 times the sum of the squares of the differences between each element of the first row and the minimum value in its column. (i=1,2,...,16)

d. Calculate the un-normalized scores noted as G

$$G = \frac{D_-}{D_+ + D_-}$$

e. Normalize the score

4.3. Calculation Results

After removing duplicate values and invalid values, the final true number of fires was obtained as 451.

Table 6. Estimation results

Serial number	Part Type	Rate
1	Point smoke detector	0.05493
2	Point type smoke	0.02442
3	Point temperature detector	0.05607
4	Point temperature detector	0.05493
5	Point smoke detector	0.05464
6	Point type temperature smoke	0.24409
7	Multiple-sensor	0.05493
8	Flame detector	0.05403
9	Gas detection	0.04253
10	Manual call point	0.05612
11	Linear beam smoke detector	0.01293
12	Hydrant	0.05399
13	The signal valve	0.05353
14	Pressure switch	0.05493
15	Intelligent photoelectric probe	0.05493
16	Point smoke detector	0.07297

4.4. Analysis of Results

From the above calculation results, it can be seen that the top six component types in the final quantitative score are beam smoke, intelligent photoelectric probe, point smoke detector, linear beam smoke detector, intelligent temperature sensor and intelligent photoelectric detector. This indicates that these six detectors are more reliable and have a lower failure rate, which can provide a higher rate of correct fire alarm information and help reduce the false alarm rate. The government can give priority to these six component types when selecting detectors.

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5. Mathematical Model of Problem Two

5.1. Brief Background

Combining problem one and the requirements of the topic requires us to select parameters to build an intelligent research and judgment model to improve the accuracy of the alarm, first to judge different affiliated firefighting agencies, and then to evaluate the fire authenticity and derive the probability by combining the different components obtained from problem one. Since 15 affiliated fire agencies and 2 indicators are involved, we directly use the rank and ratio comprehensive evaluation method [2] to make a comprehensive evaluation of the affiliated fire agencies while classifying the rank for authenticity judgment and probability calculation.

5.2. Model Solving

5.2.1. Data Areprocessing

As in question one, the relevant indicators for the affiliated firefighting agencies are calculated as follows.

Table 7. The two main indicators of affiliation with the fire agency

Name	Reliability	Failure rate
A	0.009365245	0.006050979
B	0.001863841	0.023315407
C	0.010356455	0.068017226
D	0.011226252	0.012443065
E	0.007428041	0.003828159
F	0.005518764	0.030568139
G	0.001124633	0.099884778
H	0.005091218	0.057196387
I	8.18684E-05	0.002059866
J	0.004964646	0.146007874
L	0.006683081	0.026369604
M	0.004707416	0.134836078
N	0.00631136	0.065789903
P	0.011872639	0.014102159
Q	0.018211034	0.034475101

5.2.2. Modeling of Rank and Ratio Integrated Evaluation Method

First we apply the entropy weighting method after the initial processing of the data, and we obtain the indicator weights as follows.

Table 8. Indicator weights obtained by entropy weighting method

item	Information entropy value e	Information utility value d	Weights
Reliability	0.916	0.084	0.334
Failure rate	0.914	0.086	0.341
Jurisdictional Area	0.918	0.082	0.325

According to the three evaluation indexes, reliability, failure rate, and jurisdictional area, the rank value is calculated using the non-integer rank method to obtain the rank, and the rank is used to replace the original evaluation index value, and the rank data matrix of each index is established according to the compiled rank result. The rank here can be understood as an order

ISSN: 2710-0588

or sorting, which is solved according to the sorting position of the original data [3]. The table of rank values is obtained as follows.

Table 9. Three evaluation indicators rank value

Name	x_1 Reliability	R_1 Reliability	x_2 Jurisdictional Area	R_2 Jurisdictional Area	x_3 Failure rate	R_3 Failure rate	RSR	RSR_Rank
A	0.51194	8.16712	0.20639	3.88952	0.99844	14.97813	0.59462	10
B	0.10268	2.43747	0.68594	10.60320	0.99090	14.87262	0.61735	8
C	0.56602	8.92421	0.49412	7.91772	0.99576	14.94061	0.70228	3
D	0.61347	9.58857	0.24448	4.42266	0.87487	13.24823	0.60097	9
E	0.40625	6.68746	0.81758	12.44617	0.99844	14.97813	0.75624	2
F	0.30208	5.22914	0.29478	5.12694	0.00156	1.02187	0.25522	15
G	0.06235	1.87285	0.95393	14.35496	0.99844	14.97813	0.69237	5
H	0.27876	4.90257	0.76117	11.65632	0.99576	14.94061	0.69769	4
I	0.00546	1.07638	0.96615	14.52609	0.99576	14.94061	0.67770	6
J	0.27185	4.80590	0.98401	14.77621	0.99576	14.94061	0.76649	1
L	0.36560	6.11845	0.27739	4.88340	0.99576	14.94061	0.57076	12
M	0.25782	4.60942	0.07240	2.01363	0.99576	14.94061	0.47188	13
N	0.34532	5.83453	0.89563	13.53879	0.00156	1.02187	0.46000	14
P	0.64873	10.08229	1.00000	15.00000	0.00156	1.02187	0.58788	11
Q	0.99454	14.92362	0.00000	1.00000	0.87487	13.24823	0.64201	7

It is determined that the isotropic trending process is performed in the ranking process, i.e., negative indicators (cost-based indicators) are converted into positive indicators (benefit-based indicators), and all indicators are uniformly ranked from smallest to largest. First, the RSR values are arranged in the order from smallest to largest, and the frequencies of each group are listed. Then, the cumulative frequencies of each group are calculated and the rank R and average rank R — of each RSR group are determined.

Table 10. Regression results

RSR	Frequency f	Cumulative frequency Σf	Evaluation rank	Evaluation rank/n*100%	Probit
0.25522	1	1	1	6.66667	3.49891
0.46000	1	2	2	13.33333	3.88923
0.47188	1	3	3	20.00000	4.15838
0.57076	1	4	4	26.66667	4.37707
0.58788	1	5	5	33.33333	4.56927
0.59462	1	6	6	40.00000	4.74665
0.60097	1	7	7	46.66667	4.91635
0.61735	1	8	8	53.33333	5.08365
0.64201	1	9	9	60.00000	5.25335
0.67770	1	10	10	66.66667	5.43073
0.69237	1	11	11	73.33333	5.62293
0.69769	1	12	12	80.00000	5.84162
0.70228	1	13	13	86.66667	6.11077
0.75624	1	14	14	93.33333	6.50109
0.76649	1	15	15	98.33333	7.12805

ISSN: 2710-0588

Calculate downward accumulation frequency $\frac{R-}{n\times100\%}$,the last item is corrected with a correction. Then, according to the cumulative frequency, look up the "Comparison table of percentages and probability units" and find the corresponding probability unit Probit value.

Finally, using the RSR distribution values in the table as independent variables and Probit values as dependent variables, a linear regression was performed with the following results.

We calculated linear regression equations to fit the corresponding RSR estimates using the Probit value (the probability unit corresponding to the cumulative frequency) as the independent variable and the RSR value as the dependent variable.

Table 11. Results of linear regression analysis

n=15									
	Non-standardized coefficient		Standardization factor	t	p	VIF	R2	Adjusted R2	F
	B	Standard error	Beta						
Constant	-0.015	0.079	-	-0.19	0.853	-	0.831	0.819	F=64.144 P=0.000***
Probit	0.121	0.015	0.912	8.009	0.000***	1			

From the analysis of the results of the F-test, we can get that the significance P-value is 0.000*** and the level presents significance, which rejects the original hypothesis that the regression coefficient is 0. Meanwhile, the goodness-of-fit R^2 of the model is 0.831, and the model performance is relatively excellent, so the model basically meets the requirements. For the performance of variable co-collinearity, VIF is all less than 10, so the model has no multiple co-collinearity problem and the model is well constructed. For the variable covariance performance, VIF is all less than 10, so the model has no multiple covariance problem and the model is well constructed. The equations of the model are as follows.

$$y = 0.015 + 0.121 \text{ Probit}$$

5.3. Calculation Result

Table 12. Calculation Result

Name	RSR_Rank	Probit	RSR Regression	Level
A	3	6.11077	0.72328	3
B	2	6.50109	0.77044	3
C	1	7.12805	0.84618	3
D	10	4.74665	0.55848	2
E	8	5.08365	0.59920	2
F	9	4.91635	0.57899	2
G	5	5.62293	0.66435	2
H	4	5.84162	0.69077	2
I	6	5.43073	0.64113	2
J	12	4.37707	0.51384	2
L	13	4.15838	0.48742	2
M	11	4.56927	0.53706	2
N	7	5.25335	0.61970	2
P	15	3.49891	0.40775	1
Q	14	3.88923	0.45490	1

ISSN: 2710-0588

5.4. Analysis of Result

From the above modeling results, it can be concluded that by substituting the test data into the model, the fire information belonging to C, E, and J is judged to be a fire, the fire information belonging to F and N is judged to be a false alarm as no fire has occurred, and the rest of the fire information belonging to them is judged to be likely to occur.

6. Summary

6.1. Conclusion

From the relevant literature as well as the results, it is clear that the standardized and reasonable use of fire alarm systems can avoid many non-fire situations caused by false alarms and component failures, and can greatly avoid the abuse of firefighting resources by huge and complicated alarm information; at the same time, because different fire departments have different comprehensive management capabilities in front of fires, their maintenance of fire alarm systems also differs. Thus, for those jurisdictions that do not have strong management ability or have great responsibility, it is more important to take the initiative to do a good job in maintaining the fire alarm system to achieve the reasonable use of firefighting resources and to protect the lives of residents.

6.2. Suggestions

6.2.1. Detector Maintenance

(1) give priority to alarm devices with low failure rates and high reliability to reduce component failures and false alarms.

(2) Improving the stability and accuracy of fire research and judgment models to reduce system component failures and false alarms.

(3) for fire warning, according to the correlation with the occurrence of fire, hierarchical processing of various types of alarm information.

6.2.2. Alarm Maintenance

In the city automatic fire alarm system, the alarm belongs to the brain, which can receive, analyze and process external information, and direct the operation of equipment and control the operation of established procedures. With the use, the failure is episodic and intermittent, initially causing some impact on the troubleshooting. Dust will be adsorbed on the alarm circuit board, affecting its heat dissipation, and if the environment is humid, it will also lead to a short circuit alarm, so it must be regularly cleaned and inspected to master the working status of the alarm. Each alarm is configured with a backup battery, if the main power failure, the backup battery can replace its work, the detection phase requires timely battery charging, discharging maintenance, replacement of the failed battery to ensure the stability of the alarm power supply.

6.2.3. Computer Maintenance

Computer belongs to the core components of the automatic fire alarm system in the city, with the help of the computer can promote the visualization of the automatic fire alarm system in the city, linkage of each fire station automatic fire alarm system, so as to achieve full coverage of all-round protection. In the entire automatic fire alarm system, computer management and maintenance are very important.

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ISSN: 2710-0588

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